CCI Land Surface Temperature

# Product User Guide

## WP4A – DEL-D4.3

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Organisation: Consortium CCI LST

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## Change log

| Version | Date | Changes |
|---|---|---|
| 1.0 | 3-Jun-2020 | First version |
| 1.1 | 27-Jul-2020 | RIDs addressed |
| 1.2 | 22-Oct-2020 | Change of cover page logo |

## List of Changes

| Version | Section | Changes |
|---|---|---|
| | | |

# Quick Start Guide to ESA CCI LST Products

## What products are available?

Currently available CCI products are summarised in the table below. For the remainder of this document the products will be referred to by the Product Name given in the table.

| Product Name | Version | Instrument | Satellite | Spatial resolution | Temporal resolution | Time period |
|---|---|---|---|---|---|---|
| ERS-2_ATSR__L2P | 1.00 | ATSR-2 | ERS-2 | 1 km swath | Full orbit | 1995-2003 |
| ERS-2_ATSR__L3C | 1.00 | | | 0.05° global lon-lat grid | Daily and Monthly (day and night) | |
| ENVISAT_ATSR__L2P | 1.00 | AATSR | Envisat | 1 km swath | Full orbit | 2002-2012 |
| ENVISAT_ATSR__L3C | 1.00 | | | 0.05° global lon-lat grid | Daily and Monthly (day and night) | |
| TERRA_MODIS_L2P | 1.00 | MODIS | EOS Terra | 1 km swath | 5 minute granules | 2000-2018 |
| TERRA_MODIS_L3C | 1.00 | | | 0.05° global lon-lat grid | Daily and Monthly (day and night) | |
| AQUA_MODIS_L2P | 1.00 | MODIS | EOS Aqua | 1 km swath | 5 minute granules | 2002-2018 |
| AQUA_MODIS_L3C | 1.00 | | | 0.05° global lon-lat grid | Daily and Monthly (day and night) | |
| SENTINEL3A_SLSTR_L2P | 1.00 | SLSTR | Sentinel 3A | 1 km swath | 3 minute granules | 2016-2018 |
| SENTINEL3A_SLSTR_L3C | 1.00 | | | 0.05° global lon-lat grid | Daily and Monthly (day and night) | |
| MSG_SEVIRI_L3U | 1.01 | SEVIRI | Meteosat | 0.05° global lon-lat grid | Hourly | 2008-2010 |
| SSMI_SSMIS_L2P | 1.12 | SSM/I + SSMIS | DMSP | 25 km swath | Full orbit | 1995 - 2018 |
| SSMI_SSMIS_L3C | 1.12 | SSM/I + SSMIS | DMSP | 0.25° global lon-lat grid | Daily (descending and ascending) | 1995 - 2018 |
| MULTISENSOR_IRCDR_L3S | 1.00 | ATSR-2 + AATSR | ERS-2 + Envisat | 0.05° global lon-lat grid | Daily and Monthly (day and night) | 1995-2012 |

## What tools are available for these products?

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. For example see http://www.unidata.ucar.edu/software/netcdf/software.html

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, including LST_cci datasets, will be accessible to the Toolbox. More information is available here: http://climatetoolbox.io/. Documentation for the CCI toolbox is provided online, including a Quick Start guide.

The Sentinel Application Platform (SNAP), which is a follow on from the BEAM software, can also read LST_cci data. More information on SNAP is available here: https://step.esa.int/main/toolboxes/snap/.

## How to download the data and tools

LST_cci datasets from processing cycle 1 are being maintained on a public partition of the LST_cci workspace on the JASMIN "super-data-cluster" (http://www.jasmin.ac.uk/). Access to the LST_cci data on JASMIN is available to those with a JASMIN account or via request to the LST_cci team (contact djg20@le.ac.uk). The location of the data products on the JASMIN workspace are as follows:

- ERS-2_ATSR__L2P:
  - Available upon request
- ENVISAT_ATSR__L2P
  - Available upon request
- TERRA_MODIS_L2P:
  - Available upon request
- AQUA_MODIS_L2P:
  - Available upon request
- SENTINEL3A_SLSTR_L2P:
  - Available upon request
- SSMI_SSMIS_L2P:
  - Available upon request
- MSG_SEVIRI_L3U:
  - /group_workspaces/jasmin2/esacci_lst/public/MSG_SEVIRI_L3U/1.00/{year}/{month}/{day}
- ERS-2_ATSR__L3C:
  - /group_workspaces/jasmin2/esacci_lst/public/ERS-2_ATSR__L3C/1.00/{year}/{month}/{day}
- ENVISAT_ATSR__L3C:
  - /group_workspaces/jasmin2/esacci_lst/public/ENVISAT_ATSR__L3C/1.00/{year}/{month}/{day}
- TERRA_MODIS_L3C:
  - /group_workspaces/jasmin2/esacci_lst/public/TERRA_MODIS_L3C/1.00/{year}/{month}/{day}
- AQUA_MODIS_L3C:
  - /group_workspaces/jasmin2/esacci_lst/public/AQUA_MODIS_L3C/1.00/{year}/{month}/{day}
- SENTINEL3A_SLSTR_L3C:
  - /group_workspaces/jasmin2/esacci_lst/public/SENTINEL3A_SLSTR_L3C/1.00/{year}/{month}/{day}
- SSMI_SSMIS_L3C:
  - /group_workspaces/jasmin2/esacci_lst/public/SSMI_SSMIS_L3C/1.00/{year}/{month}/{day}
- MULTISENSOR_IRCDR_L3S:
  - /group_workspaces/jasmin2/esacci_lst/public/MULTISENSOR_IRCDR_L3S/1.00/{year}/{month}/{day}

Access to the CCI toolbox is available here: [http://climatetoolbox.io/](http://climatetoolbox.io/).

## 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 both L2P and L3 (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 1: 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. One reference time is provided for each file. |
| Per pixel time difference from the reference time. | dtime | Time difference in seconds of LST retrievals from the reference time in the "time" variable. The acquisition time of each pixel can be determined from adding this to the reference time. |
| Per pixel latitude. | lat | The format of the latitudes is decimal degrees between 90 and 90° North. No scaling of the values is required. |
| Per pixel longitude. | lon | The format of the longitudes is decimal degrees between -180 and 180° East. No scaling of the values is required. |
| 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_flags is set. |
| Per pixel total uncertainty associated with the lst variable. | lst_uncertainty | |
| Per pixel quality flags for each LST retrieval. | qual_flags | For L2P and L3U IR datasets the qual_flags are:<br>• day_or_night-1_is_night<br>• summary_cloud-1_is_cloudy<br>• summary_confidence-1_is_low_confidence<br>• aerosol_mask-1_is_aerosol_detected |
| | | For MW datasets the qual_flags are:<br>• no_use<br>• no_use<br>• snow_ice-1_is_snow_ice<br>• summary_inversion_quality-1_is_less_reliable_inversion<br>• microwave_penetration_depth-1_is_ground_with_large_penetration_depth |

| Description of Key Variable | Name of Key Variable in Files | Comment |
|---|---|---|
| | | • deep_convection_occurence-1_is_possibility_of_deep_convection<br>• coast-1_is_cost<br>• 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, but to apply manually (for LST in this example):

LST = (pixel_value * scale_factor) + add_offset

## 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 info.lst-cci@acri-st.fr. We also welcome any feedback about the data to this address.

## Table of Content

# List of Figures

# List of Tables

# 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) project (LST_cci) of the European Space Agency's (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:** Tables describing the features of each of the ESA LST_cci products.
- **Section 5:** A detailed description of the ESA LST_cci data files.
- **Section 6:** Description of the data file format and tools that can be used to read them.
- **Section 7:** Worked examples of how to use the data.
- **Section 8:** Dictionary of acronyms, abbreviations and jargon that may be encountered when reading this document.
- **Section 9:** List of references.
- **Section 10:** Acknowledgements.
- **Appendix 1:** A summary of how the ESA LST_cci data are processed.
- **Appendix 2:** 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. |

## 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. and Ghent, D. (2019) Product Specification Document. V1.10. |
| AD-2 | Bulgin, C. and Ghent, D. (2019) End-To-End ECV Uncertainty Budget. V1.10 |
| AD-3 | Ghent, D., Perry, M., Veal, K., Jimenez, C., (2019) Algorithm Development Plan. V1.10 |
| AD-4 | Dodd, E., Ghent, D., Jimenez, C., and Ermida, S. (2019) Algorithm Theoretical Basis Document. V1.10. |
| AD-5 | Martin, M. and Ghent, D. (2020) Product Validation and Intercomparison Report (PVIR). V1.0. |

## 1.5. Glossary

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

| Term | Definition |
|---|---|
| ATSR | Along Track Scanning Radiometer |
| 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 |
| IPMA | Instituto Português do Mar e da Atmosfera |
| IR | InfraRed |
| LST | Land Surface Temperature |

| Term | Definition |
|---|---|
| MSG | Meteosat Second Generation |
| 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 |
| SW | Split Window Algorithm |
| TES | Temperature and Emissivity Separation Algorithm |
| TIR | Thermal InfraRed |

# 2. Introduction to the ESA LST_cci Project

## 2.1. Background

Satellite derived Land Surface Temperature (LST) is the temperature of the surface of the Earth as seen by a sensor onboard a satellite platform. This temperature may be a mix of the ground and vegetation canopy temperatures within a satellite pixel, and is different from the surface air temperature measured with thermometers typically located 1-2 metres above the ground at weather stations. 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[1], is increasingly being used in diverse applications such as drought monitoring and crop management, hydrological monitoring and water management, evapotranspiration and land-atmosphere feedbacks, land cover 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 Copernicus Sentinel-3 satellite). 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 is 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

[1] The Global Observing System for Climate: Implementation Needs (https://gcos.wmo.int/en/gcos-implementation-plan)

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) sensors which observe the Earth in the microwave part of the electromagnetic spectrum, allowing them to 'see' through the majority of clouds [RD-4]. SSM/I 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 achieves 'climate quality', so that it meets very stringent requirements on aspects 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), Meteo Romania (Romania).

## 2.2. The ESA LST_cci project

The LST_cci project aims to provide an accurate view of temperatures across land surfaces globally over the past 20 to 25 years and to 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 multi-satellite records. The project will provide a comprehensive suite of high quality IR LST ECV Products and MW LST ECV Products for 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 IR CDR from input bias corrected Level-1 GEO and LEO data at 0.05° and 3-hourly resolution, 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.

The information obtained through the surveys and interviews 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-3].

### 2.2.2. A multi-sensor matchup database

Validation of LST within CCI is undertaken in two different ways. The first approach is the validate of satellite LST data against in situ LST from station data, the second is 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, will be 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 will be documented in the LST_cci Product Validation and Intercomparison Report (PVIR).

### 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 will continue 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 CCO products.

### 2.2.4. The ESA LST_cci products

The ESA LST_cci project is prototyping two product families: LST Essential Climate Variable (ECV) products, and LST Climate Data Record (CDR) products. LST ECV products are climate records formed from single satellite sensors. Separate products will be produced from many satellite sensors including ATSR-2, ATSR-3 (AATSR), MODIS Terra, MODIS Aqua, SLSTR, SSM/I and SEVIRI. CDR products are climate records produced from combining data from different satellite sensors. Three CDRs will be produced. An IR CDR, which is a merged IR CDR product produced from AATSR, SLSTR (Sentinel 3A and 3B), MODIS (Terra and Aqua), AVHRR (Metop A to C), SEVIRI (MSG satellites 1-4), IMAGER (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 an LST MGP, which is an experimental all-sky merged IR and MW product produced from AATSR, SLSTR (Sentinel 3A and 3B), MODIS (Terra and Aqua), AVHRR (Metop A to C), SEVIRI (MSG satellites 1-4), IMAGER (GOES satellites 12-16) and JAMI (MTSAT-1 and 2 satellites), SSM/I and SSMIS (DMSP F11, F13, F17 and F18).

Only the following 14 products are described in this version of this document (V1.0 of the LST_cci PUG). The remaining products will be added in V2.0.

- ERS-2_ATSR__L2P
- ENVISAT_ATSR__L2P:
- TERRA_MODIS_L2P
- AQUA_MODIS_L2P
- SENTINEL3A_SLSTR_L2P
- SSMI_SSMIS_L2P
- MSG_SEVIRI_L3U
- ERS-2_ATSR__L3C
- ENVISAT_ATSR__L3C
- TERRA_MODIS_L3C
- AQUA_MODIS_L3C
- SENTINEL3A_SLSTR_L3C
- SSMI_SSMIS_L3C
- MULTISENSOR_IRCDR_L3S

#### 2.2.5. Data dissemination and testing

LST_cci datasets produced during processing cycle 1 are being maintained on the public partition of the LST_cci workspace on the JASMIN "super-data-cluster" (http://www.jasmin.ac.uk/) funded through the Natural Environment Research Council (NERC) and delivered by the Science and Technology Facilities Council. Access to the LST_cci data on JASMIN is available to those with a JASMIN account and via request to the LST_cci team (contact djg20@le.ac.uk).

### 2.3. The future

This PUG currently includes products to be provided in Cycle 1 of the LST_cci project. Products to be disseminated in Cycle 2, which include both improvements to existing products and new products, are:

- Updated products:
  - Version 2.0 products will include improvements to retrieval coefficients, cloud masking and uncertainties as well as other updates indicated below
  - LST ECVs:
    - ERS-2_ATSR__L2P
    - ERS-2_ATSR__L3C
    - ENVISAT_ATSR__L2P
    - ENVISAT_ATSR__L3C.
    - SENTINEL3A_SLSTR_L2P (new years: 2019-2020)
    - SENTINEL3A_SLSTR_L3C (new years: 2019-2020)
    - TERRA_MODIS_L2P (new years: 2019-2020)
    - TERRA_MODIS_L3C (new years: 2019-2020)
    - AQUA_MODIS_L2P (new years: 2019-2020)
    - AQUA_MODIS_L3C (new years: 2019-2020)
    - MSG_SEVIRI_L3U (new years: 2019-2020)
    - SSMI_SSMIS_L2P (new years: 2019-2020)
- New products:
  - LST ECVs:
    - AVHRR/3 on NOAA platforms 15 to 19.
    - AVHRR/3 on Metop platforms A-C.
    - Imager and ABI on GOES platforms 12 to 16.
    - JAMI on MTSAT platforms 2 to 3.
    - SENTINEL3B_SLSTR_L2P
    - SENTINEL3B_SLSTR_L3C
  - LST CDRs:
    - Merged IR CDR
    - ATSR-SLSTR CDR
    - Prototype all-sky Merged Product

# 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 start 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. See also Section 8, which contains explanations of acronyms, abbreviations and jargon.

## 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 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 ECV Products** are available from the following sensors and data levels:

- ATSR-2 (L2P and L3C)
- AATSR (L2P and L3C)
- MODIS Terra (L2P and L3C)
- MODIS Aqua (L2P and L3C)
- SLSTR (L2P and L3C)
- MSG SEVIRI (L3U)
- SSM/I and SSMIS (L2P and L3C)

**The following LST CDR Products** are available:

- Multisensor IR CDR (L3S)

Detailed descriptions of the products can be found in Section 4. Note, these products are distinct from their corresponding operational data streams disseminated by ESA, NASA and EUMETSAT for instance. The LST_cci products are focussed on delivering climate quality data with high accuracy and high stability, with consistency across products (such as retrieval algorithms, cloud masking, uncertainty characterisation) a key feature. Where retrieval algorithms are of the same functional form as the corresponding operational algorithms new retrieval coefficients are generated using a common Calibration Database developed to be portable for different algorithms and sensors.

### 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 product).
- L3S products are L2 data from multiple instruments combined in a space-time grid. LST CDR products will be L3S products.

The L2 data are stored on an irregular grid and require two-dimensional longitude and latitude data arrays to determine the locations of the LST data. L3 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.

### 3.1.3. Other LST datasets

LST datasets are available from the precursor project ESA DUE GlobTemperature on the GlobTemperature Data portal at: http://data.globtemperature.info/.

## 3.2. How do I get the data?

Currently, LST_cci datasets from processing cycle 1 are being maintained on a public partition of the LST_cci workspace on the JASMIN "super-data-cluster" (http://www.jasmin.ac.uk/). Access to the LST_cci data on JASMIN is available to those with a JASMIN account and via request to the LST_cci team (contact djg20@le.ac.uk).

Access to all LST_CCI products specified here will in the future be provided via the CCI Open Data Portal (http://cci.esa.int/data) as well as the GlobTemperature Data Portal (http://data.globtemperature.info/) in GlobTemperature harmonised format for L2P products only to support the existing GlobTemperature LST community. In addition, they will provide a detailed description of externally linked datasets and should provide long term stewardship of the data.

## 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-L2P-LST-ATSR_3-20100101002328-fv1.00.nc

The first key part of the filename is the processing level of the data, which could be L2P (individual orbits of data, satellite projection) or L3C (collated orbits of data, 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]]] (0 hours, 23 minutes and 28 seconds 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 2.

***Table 2: Summary of the key variables in the NetCDF 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. One reference time is provided for each file. |
| Per pixel 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. |
| Per Pixel latitude | lat | The format of the latitudes is decimal degrees between 90 and 90° North. No scaling of the values is required. |
| Per pixel longitude | lon | The format of the longitudes is decimal degrees between -180 and 180° East. No scaling of the values is required. |
| 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_flags is set (equal to 1). |
| Per pixel total uncertainty associated with the lst variable | lst_uncertainty | |
| Per pixel quality flags for each LST retrieval. | qual_flags | For L2P and L3U IR datasets the qual_flags are:<br>• day_or_night-1_is_night<br>• summary_cloud-1_is_cloudy<br>• summary_confidence-1_is_low_confidence<br>aerosol_mask-1_is_aerosol_detected<br><br>For MW datasets the qual_flags are:<br>• no_use<br>• no_use<br>• snow_ice-1_is_snow_ice<br>• summary_inversion_quality-1_is_less_reliable_inversion |

| | | |
|---|---|---|
| | | • microwave_penetration_depth-1_is_ground_with_large_penetration_depth<br>• deep_convection_occurence-1_is_possibility_of_deep_convection<br>• coast-1_is_cost<br>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, but to apply manually (for LST in this example):

LST = (pixel_value * scale_factor) + add_offset

### 3.3.2. Using the Uncertainty Estimates

All files contain estimated uncertainties broken down into components characterising 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).

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 both L2P and L3C 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. Examples of reading the data and tools that can be used on the data

### 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 http://cci.esa.int/lst.

For help related to polar orbiting TIR products specifically you can also contact emad2@le.ac.uk (Emma Dodd, LST_cci scientist). For microwave products you can also contact carlos.jimenez[at]estellus.fr (Carlos Jimenez, LST_cci scientist). For geostationary TIR products you can also contact sofia.ermida@ipma.pt (Sofia Ermida).

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 rotates. 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, part of 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 geostationary satellite only observes one region and there are high satellite zenith angles at the edge of the viewed disc which reduces LST data quality, for example at high latitudes.

Polar orbiting satellites pass around the Earth, passing over or close to each pole in turn and passing alternately from daytime to 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 wide swaths 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. Aerosol also affects IR wavelengths and will prevent accurate LST retrieval. Aerosol impacted retrievals are often flagged in products or identified using 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 LST is also based on observing at atmospheric windows in the MW spectrum, but has the advantage that clouds are mostly transparent at MW wavelengths. Frequencies in the Ka band (37 GHz) are typically used for LST estimation as this band balances a reduced 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 better cover spatially the coastline.
- The MW LST will represent the surface for a varying depth as penetration depth depends on the surface observed and the MW frequency. The penetration depth depends both on MW frequency and moisture. 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 centimeters 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.

### 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. Furthermore, day and night retrievals can be determined from the solar zenith angle if this information is not provided elsewhere. Typically, night-time values are determined as those with a solar zenith angle greater than, or equal to, 90°.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. Do I care about the land cover type (biome)?

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 SAR 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 method. There may also be uncertainties 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 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 field of view (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 difference between a measurement of something and its true value (often unknown), 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 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.

# 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 ECV products. 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). Both L2P and L3C data are provided. Further information is given in the Table below. Examples of the data are provided in plots below each table.

***Table 3: Information evaluating the ERS-2_ATSR__L2P 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 1.0 |
| **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). |
| **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 |
| **Spatial resolution** | 1 km (L2P) and or 0.05° (L3C) |
| **Temporal resolution** | Full orbit files (~100 minutes) |
| **Timeliness of new data** | Not currently being extended |
| **Dataset volume** | ERS-2_ATSR__L2P: 3.0Tb<br>ERS-2_ATSR__L3C: 146Gb |
| **Valid data fraction** | LST from clear-sky observations only |
| **Data level / grid** | 1 km swath (L2) and or 0.05° regular latitude-longitude grid (L3C) |
| **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 UOL ATSR LST Biome Classification data, Copernicus Global Land Service FCOVER dataset, and ERA-Interim. |
| **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**<br>*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]. |
| **Systematic Uncertainty**<br>*Geographical variation in the difference of satellite minus reference* | Not yet evaluated |
| **Non-systematic Uncertainty**<br>*Uncertainty associated with all effects not included in systematic uncertainty* | Not yet evaluated |
| **Stability**<br>*95% confidence interval for the relative multi-year trend between satellite LSTs and some in situ data* | Not yet evaluated |
| **Sensitivity to true LST**<br>*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** | http://cci.esa.int/lst |
| **Primary peer reviewed reference** | Not yet available |
| **Source of technical documents** | http://cci.esa.int/lst |
| **Dataset restrictions** | None, free and open access |
| **Facility for user feedback** | djg20@le.ac.uk |
| **Other Documentation** | [RD-5] |
| **Other Principles (GCOS)** | |
| | |

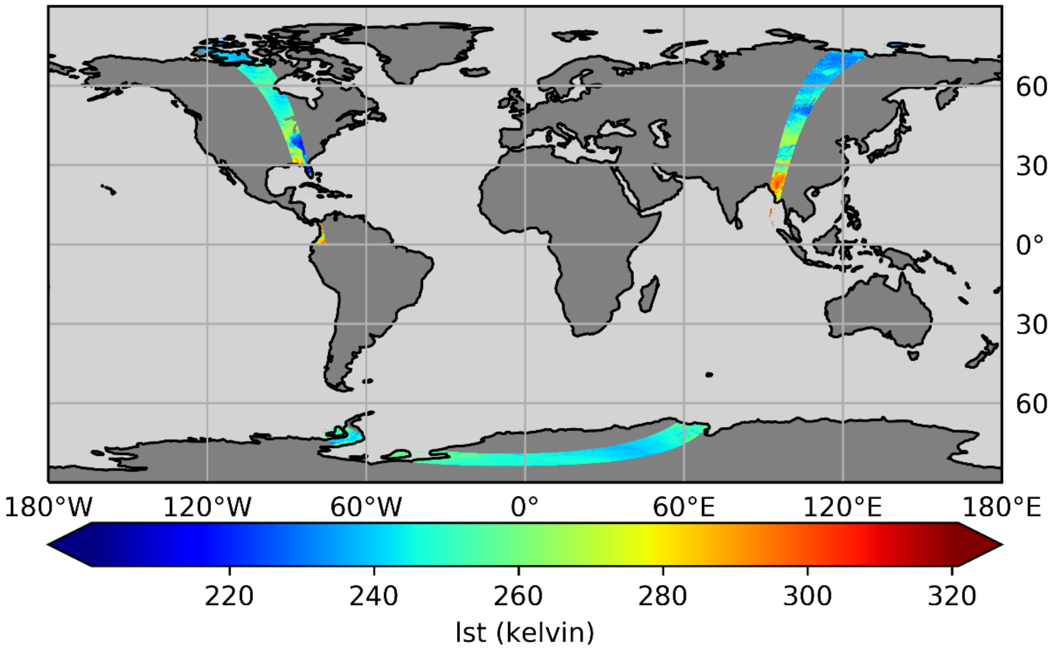


***Figure 1: Example of ERS-2_ATSR__L2P data. This data is provided as a single orbit in each file. Cloud masking has not been applied to this data.***

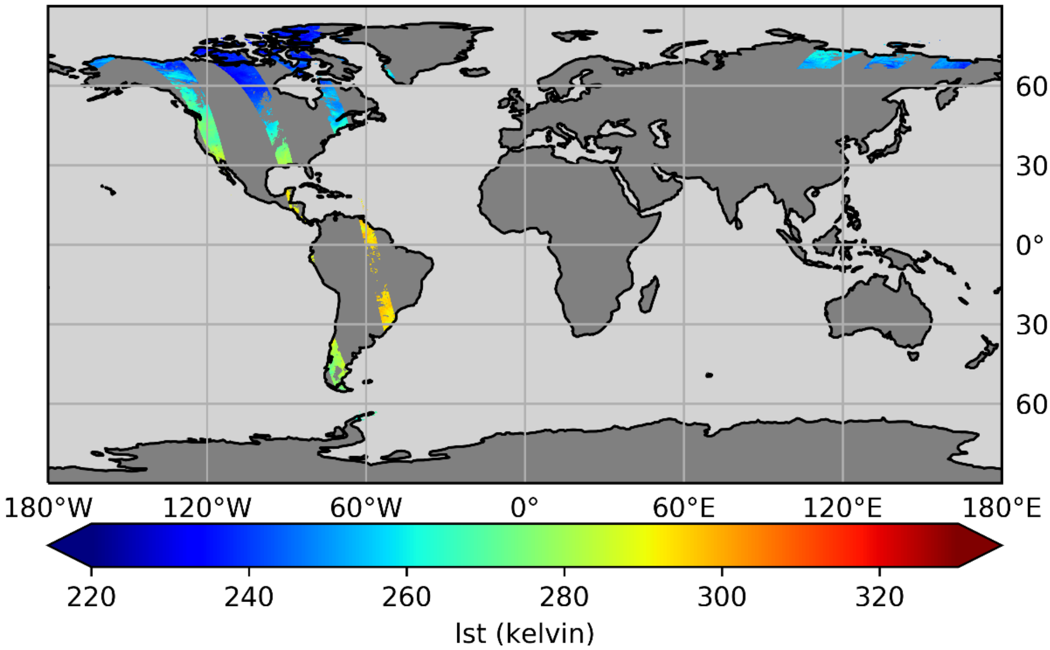


***Figure 2: Example of ERS-2_ATSR__L3C daily night-time data. This data is provided as all night-time data for a day of orbits in each file. Cloud masking has been applied to this data.***

***Table 4: 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 1.0 |
| **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). |
| **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 |
| **Spatial resolution** | 1 km (L2P) and or 0.05° (L3C) |
| **Temporal resolution** | Full orbit files (~100 minutes) |
| **Timeliness of new data** | Not currently being extended |
| **Dataset volume** | ENVISAT_ATSR__L2P: 4.4Tb<br>ENVISAT_ATSR__L3C: 212Gb |
| **Valid data fraction** | LST from clear-sky observations only |
| **Data level / grid** | 1 km swath (L2) and or 0.05° regular latitude-longitude grid (L3C) |
| **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 UOL ATSR LST Biome Classification data, Copernicus Global Land Service FCOVER dataset, and ERA-Interim. |
| **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**<br>*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]. |
| **Systematic Uncertainty**<br>*Geographical variation in the difference of satellite minus reference* | Not yet evaluated |
| **Non-systematic Uncertainty**<br>*Uncertainty associated with all effects not included in systematic uncertainty* | Not yet evaluated |
| **Stability** | Not yet evaluated |

| | |
|---|---|
| *95% confidence interval for the relative multi-year trend between satellite LSTs and some in situ data* | |
| **Sensitivity to true LST**<br>*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** | http://cci.esa.int/lst |
| **Primary peer reviewed reference** | Not yet available |
| **Source of technical documents** | http://cci.esa.int/lst |
| **Dataset restrictions** | None, free and open access |
| **Facility for user feedback** | djg20@le.ac.uk |
| **Other Documentation** | [RD-5] |
| **Other Principles (GCOS)** | |
| | |

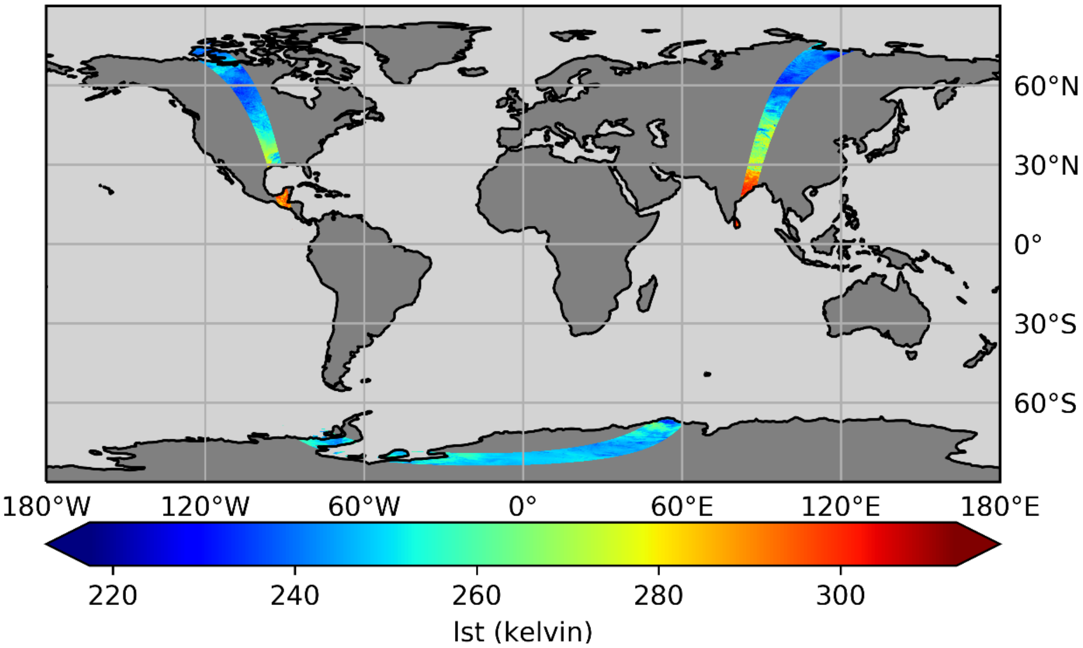


***Figure 3: Example of ENVISAT_ATSR__L2P data. This data is provided as a single orbit in each file. Cloud masking has not been applied to this data.***

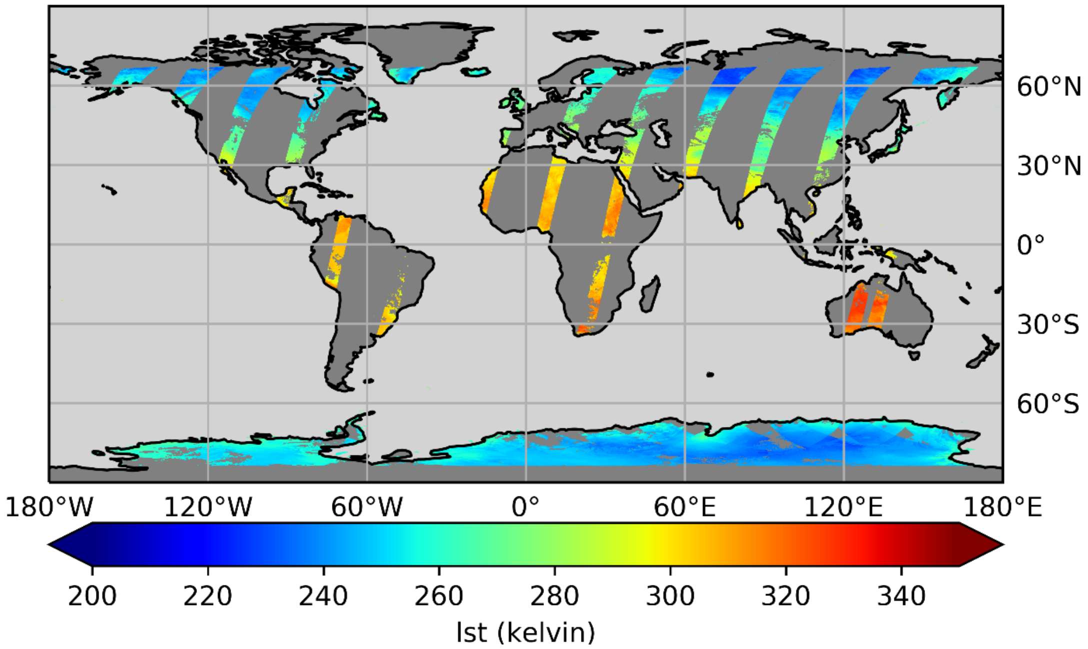


***Figure 4: Example of ENVISAT_ATSR__L3C daily daytime data. This product collates several orbits in each file. Cloud masking has been applied to this data.***

## 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). Both L2P and L3C data are provided. The products provided by LST_cci are different from the NASA MODIS products as described in section 3.1.1. Further information is given in the Table below.

***Table 5: 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 1.0 |
| **Lead Investigator and/or Agency** | Darren Ghent, University of Leicester |
| **Principal strengths of data set** | Consistently processed data 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 |
| **Spatial resolution** | 1 km (L2P) and or 0.05° (L3C) |
| **Temporal resolution** | 5 minute granules |
| **Timeliness of new data** | Will be updated with new years of data in cycle 2 of the LST_cci project. |
| **Dataset volume** | TERRA_MODIS_L2P: 29Tb<br>TERRA_MODIS_L3C: 1.1Tb |
| **Valid data fraction** | LST from clear-sky observations only |
| **Data level / grid** | 1 km swath (L2) and or 0.05° regular latitude-longitude grid (L3C) |
| **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 UW/CIMSS Baseline Fit Global Infrared Land Surface Emissivity Database |
| **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**<br>*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]. |
| **Systematic Uncertainty**<br>*Geographical variation in the difference of satellite minus reference* | Not yet evaluated |
| **Non-systematic Uncertainty**<br>*Uncertainty associated with all effects not included in systematic uncertainty* | Not yet evaluated |

| | |
|---|---|
| **Stability**<br>*95% confidence interval for the relative multi-year trend between satellite LSTs and some in situ data* | Not yet evaluated |
| **Sensitivity to true LST**<br>*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** | http://cci.esa.int/lst |
| **Primary peer reviewed reference** | Not yet available |
| **Source of technical documents** | http://cci.esa.int/lst |
| **Dataset restrictions** | None, free and open access |
| **Facility for user feedback** | djg20@le.ac.uk |
| **Other Documentation** | [RD-6] |
| **Other Principles (GCOS)** | |
| | |

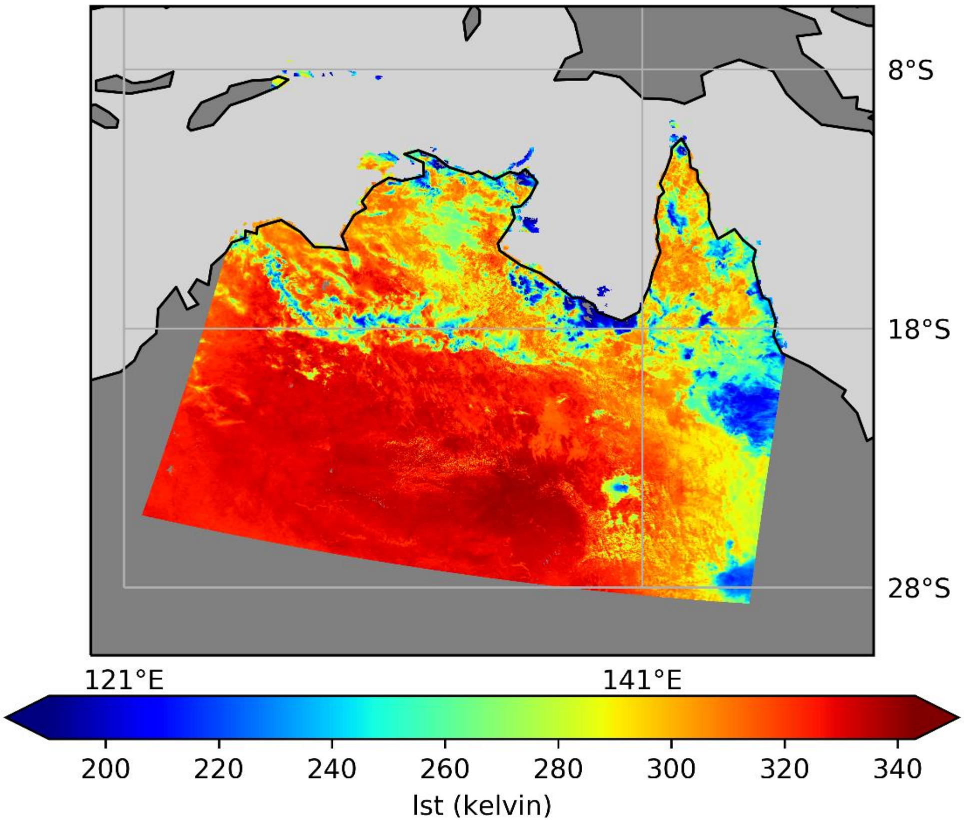


***Figure 5: Example of TERRA_MODIS_L2P data. This product is provided with a single 5 minute granule in each file. Cloud masking has not been applied to this data.***

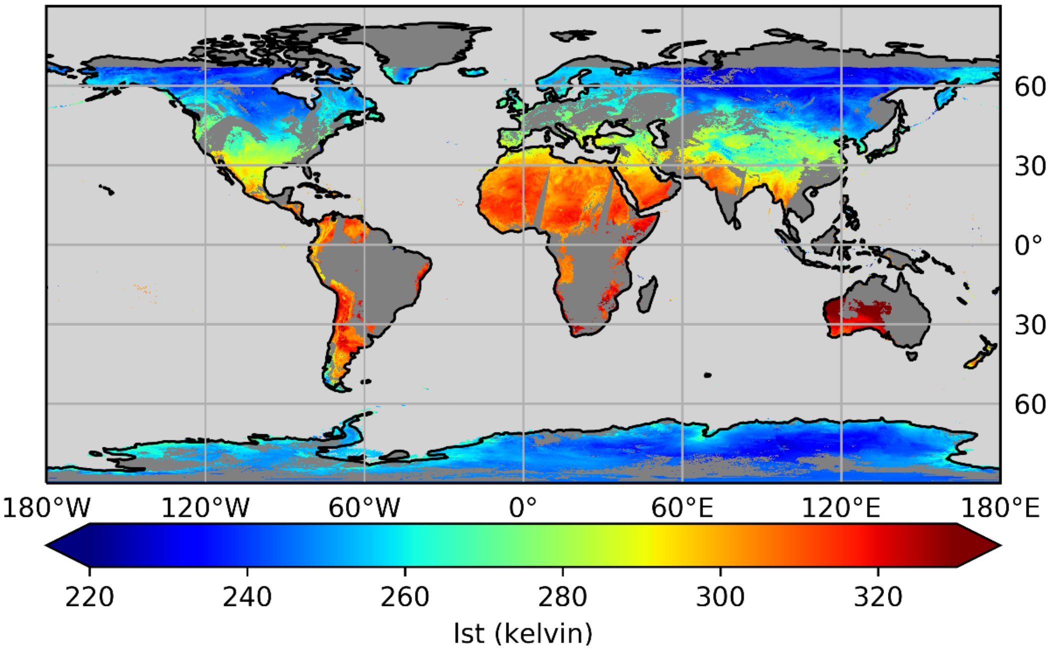


***Figure 6: Example of TERRA_MODIS_L3C daily daytime data. This product collates several orbits in each file. Cloud masking has been applied to this data.***

***Table 6: 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 1.0 |
| **Lead Investigator and/or Agency** | Darren Ghent, University of Leicester |
| **Principal strengths of data set** | Consistently processed data 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 |
| **Spatial resolution** | 1 km (L2P) and or 0.05° (L3C) |
| **Temporal resolution** | 5 minute granules |
| **Timeliness of new data** | Will be updated with new years of data in cycle 2 of the LST_cci project. |
| **Dataset volume** | AQUA_MODIS_L2P: 24Tb<br>AQUA_MODIS_L3C: 932Gb |
| **Valid data fraction** | LST from clear-sky observations only |
| **Data level / grid** | 1 km swath (L2) and or 0.05° regular latitude-longitude grid (L3C) |
| **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 UW/CIMSS Baseline Fit Global Infrared Land Surface Emissivity Database |
| **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**<br>*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]. |
| **Systematic Uncertainty**<br>*Geographical variation in the difference of satellite minus reference* | Not yet evaluated |
| **Non-systematic Uncertainty**<br>*Uncertainty associated with all effects not included in systematic uncertainty* | Not yet evaluated |
| **Stability**<br>*95% confidence interval for the relative multi-year trend between satellite LSTs and some in situ data* | Not yet evaluated |
| **Sensitivity to true LST**<br>*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** | http://cci.esa.int/lst |
| **Primary peer reviewed reference** | Not yet available |
| **Source of technical documents** | http://cci.esa.int/lst |
| **Dataset restrictions** | None, free and open access |
| **Facility for user feedback** | djg20@le.ac.uk |
| **Other Documentation** | [RD-6] |
| **Other Principles (GCOS)** | |
| | |

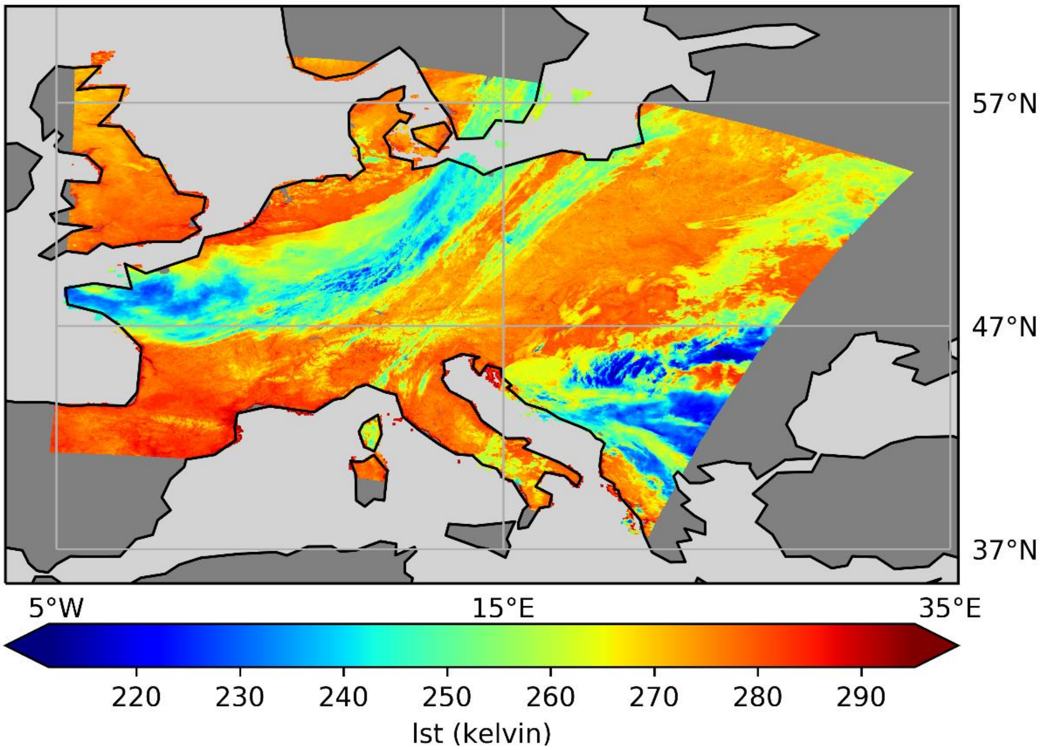


*Figure 7: Example of AQUA_MODIS_L2P data. This product is provided with a single 5 minute granule in each file. Cloud masking has not been applied to this data.*

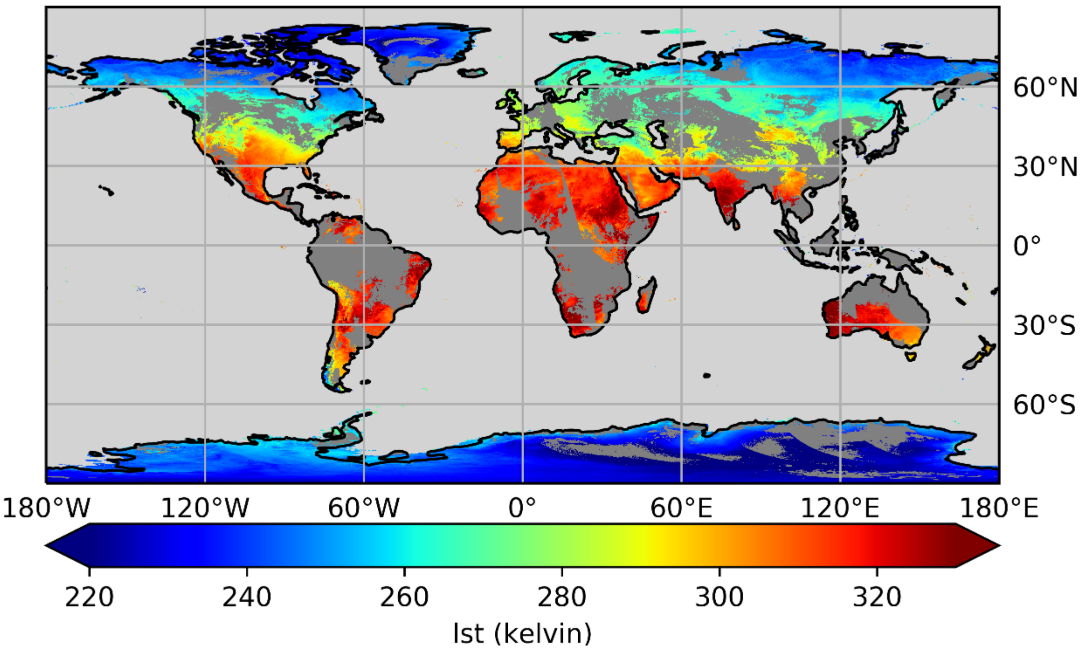


*Figure 8: Example of AQUA_MODIS_L3C daily daytime data. This product collates several orbits in each file. Cloud masking has been applied to this data.*

## 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 only (internally represented as SLSTRA). The SLSTR products provided by LST_cci are different from the standard ESA SLSTR LST products, as described in section 3.1.1 Both L2P and L3C data are provided. Further information is given in the Table below.

***Table 7: 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 |
| **Lead Investigator and/or Agency** | Darren Ghent, University of Leicester |
| **Principal strengths of data set** | Consistently processed data currently spanning one SLSTR sensor on the Sentinel 3A platform. |
| **Principal recommended applications** | Climate research; particularly applications requiring long-term, stable, low bias records of LST |
| **Key Descriptive Features** | |
| **Period covered** | May 2016 – December 2018 |
| **Geographic range** | Global |
| **Spatial resolution** | 1 km (L2P) and or 0.05° (L3C) |
| **Temporal resolution** | 3 minute granules |
| **Timeliness of new data** | Will be updated with new years of data in cycle 2 of the LST_cci project. |
| **Dataset volume** | SENTINEL3A_SLSTR_L2P: 8.4Tb<br>SENTINEL3A_SLSTR_L3C: 116Gb |
| **Valid data fraction** | LST from clear-sky observations only |
| **Data level / grid** | 1 km swath (L2) and or 0.05° regular latitude-longitude grid (L3C) |
| **Observational technology** | The Sea and Land Surface Temperature Radiometer (SLSTR) series of infrared sensors currently comprises two instruments. One is currently included in the ESA LST_cci SLSTR data products: SLSTR on Sentinel 3A (2016-2018). |
| **Dependence on other data** | None identified |
| **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**<br>*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]. |
| **Systematic Uncertainty**<br>*Geographical variation in the difference of satellite minus reference* | Not yet evaluated |

| | |
|---|---|
| **Non-systematic Uncertainty**<br>*Uncertainty associated with all effects not included in systematic uncertainty* | Not yet evaluated |
| **Stability**<br>*95% confidence interval for the relative multi-year trend between satellite LSTs and some in situ data* | Not yet evaluated |
| **Sensitivity to true LST**<br>*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** | http://cci.esa.int/lst |
| **Primary peer reviewed reference** | Not yet available |
| **Source of technical documents** | http://cci.esa.int/lst |
| **Dataset restrictions** | None, free and open access |
| **Facility for user feedback** | djg20@le.ac.uk |
| **Other Documentation** | None currently available |
| **Other Principles (GCOS)** | |
| | |

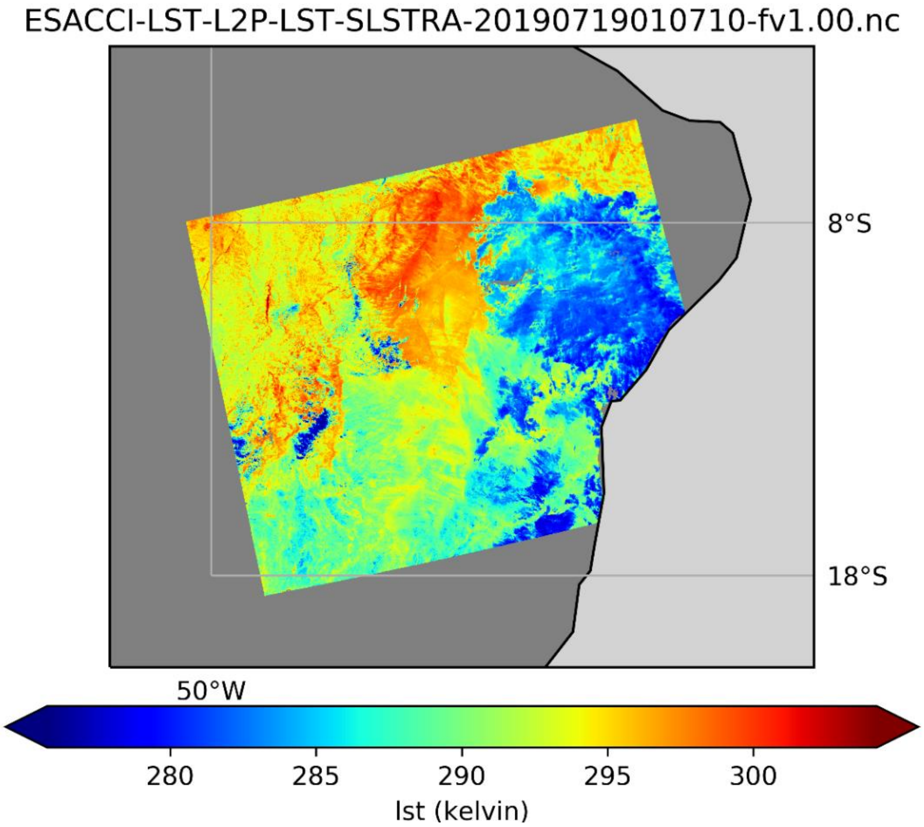


*Figure 9: Example of SENTINEL3A_SLSTR_L2P data. This product is provided with a single 5 minute granule in each file. Cloud masking has not been applied to this data.*

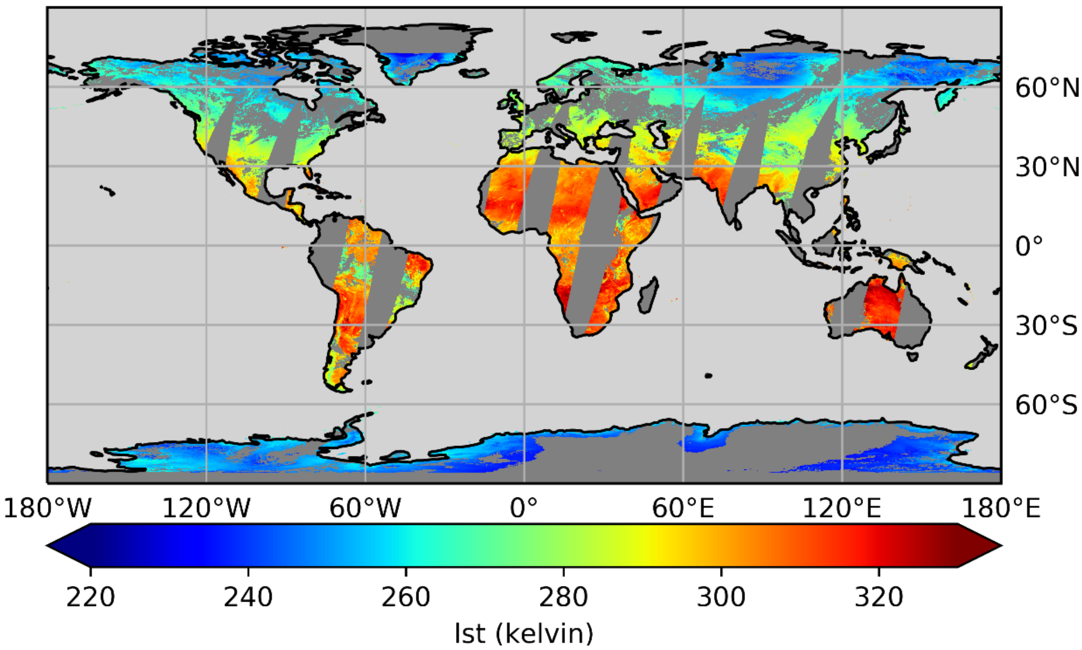


*Figure 10: Example of SENTINEL3A_SLSTR_L3C daily daytime data. This product collates several orbits in each file. Cloud masking has been applied to this data.*

## 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). The products provided by LST_cci are different from the Eumetsat LSA SAF SEVIRI LST products, as described in section 3.1.1. Both L2P, L3U and L3C data are provided. Further information is given in the Table below.

***Table 8: 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 1.0 |
| **Lead Investigator and/or Agency** | Isabel Trigo, IPMA |
| **Principal strengths of data set** | Consistently processed data spanning all MSG platforms |
| **Principal recommended applications** | Climate research; particularly applications requiring long-term, stable, low bias records of LST |
| **Key Descriptive Features** | |
| **Period covered** | January 2008 – December 2010 |
| **Geographic range** | Europe, Africa and part of South America |
| **Spatial resolution** | 0.05° (L3U) |
| **Temporal resolution** | hourly |
| **Timeliness of new data** | Will be updated with new years of data in cycle 2 of the LST_cci project. |
| **Dataset volume** | MSG_SEVIRI_L3U: 2.9 Tb |
| **Valid data fraction** | LST from clear-sky observations only |
| **Data level / grid** | 0.05° regular latitude-longitude grid (L3U) |
| **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**<br>*Global median difference of satellite minus reference across the full dataset.* | Not yet evaluated |
| **Systematic Uncertainty**<br>*Geographical variation in the difference of satellite minus reference* | Not yet evaluated |
| **Non-systematic Uncertainty**<br>*Uncertainty associated with all effects not included in systematic uncertainty* | Not yet evaluated |
| **Stability** | Not yet evaluated |

| | |
|---|---|
| *95% confidence interval for the relative multi-year trend between satellite LSTs and some in situ data* | |
| **Sensitivity to true LST**<br>*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** | http://cci.esa.int/lst |
| **Primary peer reviewed reference** | Not yet available |
| **Source of technical documents** | http://cci.esa.int/lst |
| **Dataset restrictions** | None, free and open access |
| **Facility for user feedback** | sofia.ermida@ipma.pt |
| **Other Documentation** | [RD-7] |
| **Other Principles (GCOS)** | |
| | |

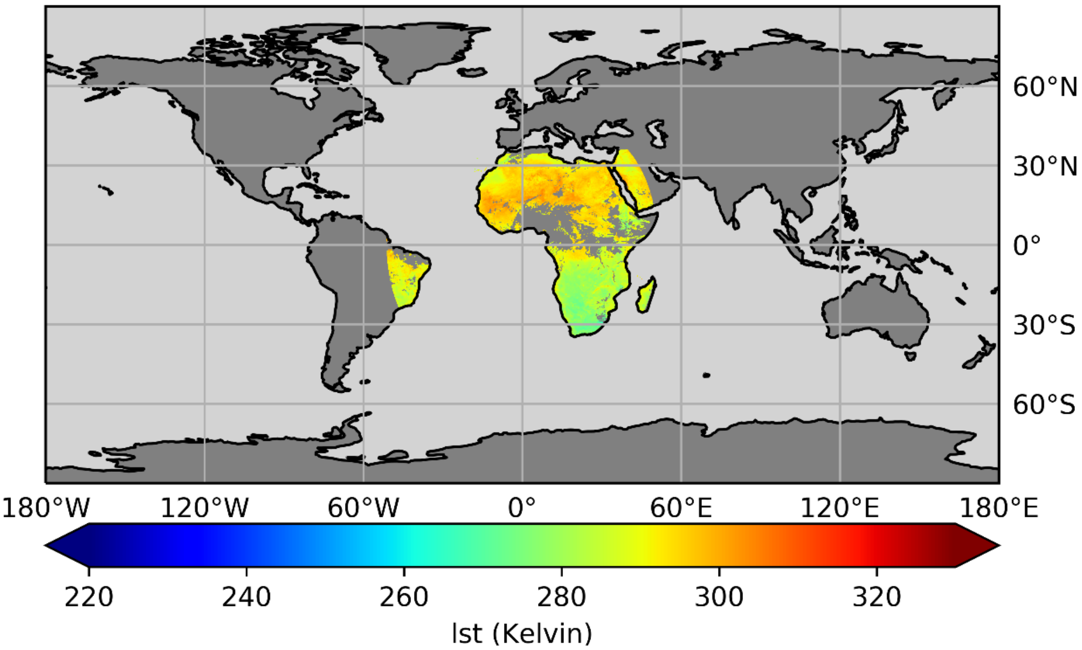


***Figure 11: Example of MSG_SEVIRI_L3U data. This product contains one orbit in each file. Cloud masking has been applied to this data.***

## 4.5. SSM/I and SSMIS LST ECV Product

SSM/I-SSMIS LST ECV products from ESA LST_cci are climate records formed from single satellite sensors, currently comprising the SSM/I instrument onboard the DMSP satellite F13 (1995-2008) (internally represented as SSMI13), and the SSMIS onboard the F17 (2008-2015) (internally represented as SSMI17) and F18 (2016-2019) (internally represented as SSMI18). Both L2P and L3C data are provided. Further information is given in the Table below.

***Table 9: Information evaluating the ESA LST_cci SSM/I-SSMIS ECV 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 ECV product version 1.0 |
| **Lead Investigator and/or Agency** | Carlos Jimenez, Estellus |
| **Principal strengths of data set** | Consistently processed data currently spanning three sensors on DMSP satellite platforms. |
| **Principal recommended applications** | Climate research; particularly applications requiring all-sky records of LST |
| **Key Descriptive Features** | |
| **Period covered** | January 1995 – December 2018 |
| **Geographic range** | Global |
| **Spatial resolution** | ~25 km (L2P) and 0.25° (L3C) |
| **Temporal resolution** | Twice per day at ~ 6 AM/PM local times |
| **Timeliness of new data** | Not currently being extended |
| **Dataset volume** | SSMI_SSMIS_L2P: 270Gb<br>SSMI_SSMIS_L3C: 46Gb |
| **Valid data fraction** | LST from clear-sky and cloudy observations |
| **Data level / grid** | ~25 km swath (L2P) and 0.25° regular latitude-longitude grid (L3C) |
| **Observational technology** | The MW instruments SSM/I and SSMIS are operated onboard the Defense Meteorological Satellite Program (DMSP) satellites. Three DMSP platforms are used to complete the full time series: F13, carrying the SSM/I instrument (1995-2008), and F17 (2008-2015) and F18 (2016-2019), 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**<br>*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]. |
| **Systematic Uncertainty** | Not yet evaluated |

| | |
|---|---|
| *Geographical variation in the difference of satellite minus reference* | |
| **Non-systematic Uncertainty**<br>*Uncertainty associated with all effects not included in systematic uncertainty* | Not yet evaluated |
| **Stability**<br>*95% confidence interval for the relative multi-year trend between satellite LSTs and some in situ data* | Not yet evaluated |
| **Sensitivity to true LST**<br>*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** | http://cci.esa.int/lst |
| **Primary peer reviewed reference** | Not yet available |
| **Source of technical documents** | http://cci.esa.int/lst |
| **Dataset restrictions** | None, free and open access |
| **Facility for user feedback** | carlos.jimenez[at]estellus.fr |
| **Other Documentation** | None currently available |
| **Other Principles (GCOS)** | |
| | |

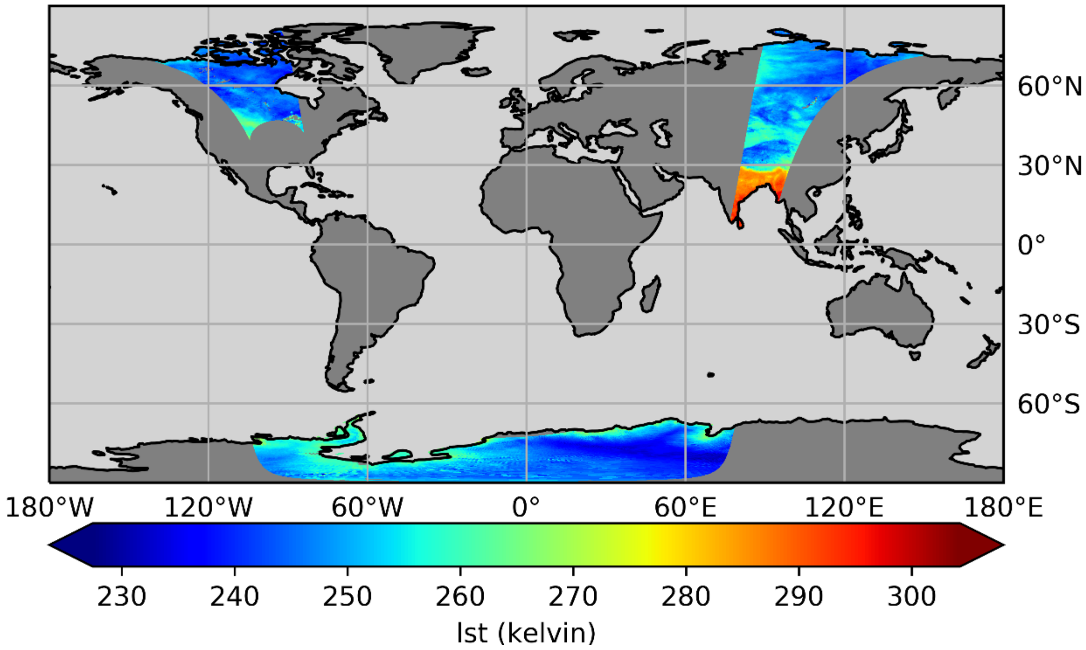


***Figure 12: Example of SSMI_SSMIS_L2P data. This product is provided with a single orbit in each file.***

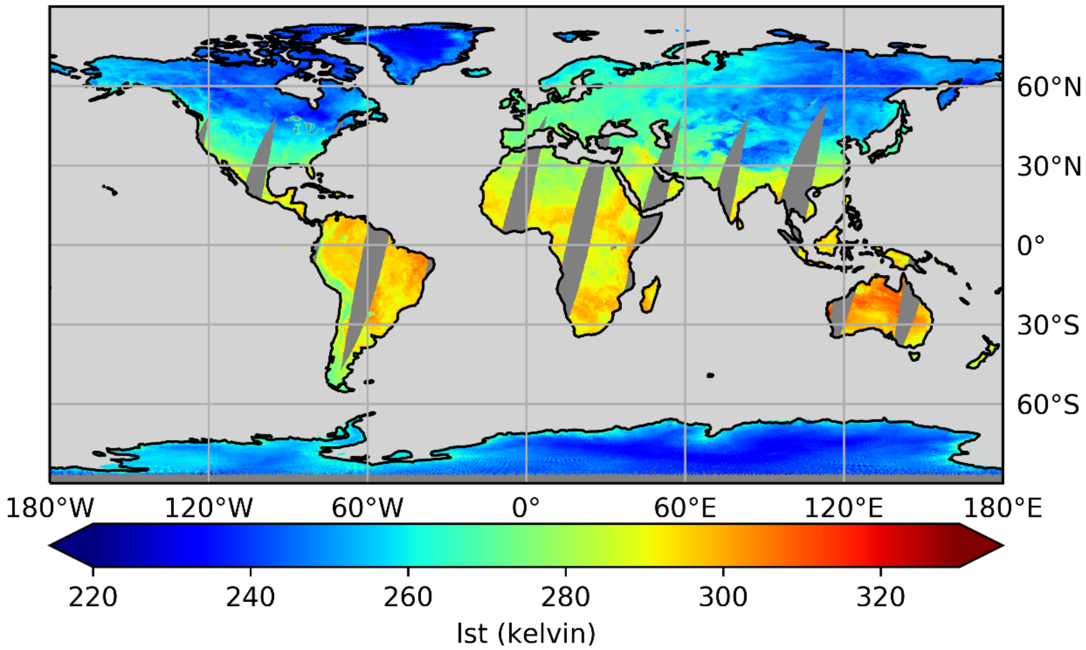


***Figure 13: Example of SSMI_SSMIS_L3C daily ascending data. This product collates several orbits in each file.***

## 4.6. ATSR LST CDR Product

Climate records produced from combining data from different satellite sensors. The ATSR LSR CDR product combines ATSR-2 and AATSR (internally represented as ATSR_2 or ATSR_3) and data is provided as L3S.

***Table 10: Information evaluating the ESA LST_cci ATSR LST CDR product as a climate record.***

| Summary | |
|---|---|
| **Status of assessment** | Assessed in the PVIR [AD-5]. |
| **Dataset name and version** | ESA LST_cci ATSR LST CDR product version 1.0 |
| **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). |
| **Principal recommended applications** | Climate research; particularly applications requiring long-term, stable, low bias records of LST |
| **Key Descriptive Features** | |
| **Period covered** | August 1995 – March 2012 |
| **Geographic range** | Global |
| **Spatial resolution** | 0.05° (L3S) |
| **Temporal resolution** | Daily (daytime and night-time) |
| **Timeliness of new data** | Not currently being extended |
| **Dataset volume** | MULTISENSOR_IRCDR_L3S: 296Gb |
| **Valid data fraction** | LST from clear-sky observations only |
| **Data level / grid** | 0.05° regular latitude-longitude grid (L3S) |
| **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 UOL ATSR LST Biome Classification data, Copernicus Global Land Service FCOVER dataset, and ERA-Interim. |
| **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**<br>*Global median difference of satellite minus reference across the full dataset.* | Not yet evaluated |
| **Systematic Uncertainty**<br>*Geographical variation in the difference of satellite minus reference* | Not yet evaluated |
| **Non-systematic Uncertainty**<br>*Uncertainty associated with all effects not included in systematic uncertainty* | Not yet evaluated |

| | |
|---|---|
| **Stability**<br>*95% confidence interval for the relative multi-year trend between satellite LSTs and some in situ data* | Not yet evaluated |
| **Sensitivity to true LST**<br>*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** | http://cci.esa.int/lst |
| **Primary peer reviewed reference** | Not yet available |
| **Source of technical documents** | http://cci.esa.int/lst |
| **Dataset restrictions** | None, free and open access |
| **Facility for user feedback** | djg20@le.ac.uk |
| **Other Documentation** | [RD-5] |
| **Other Principles (GCOS)** | |
| | |

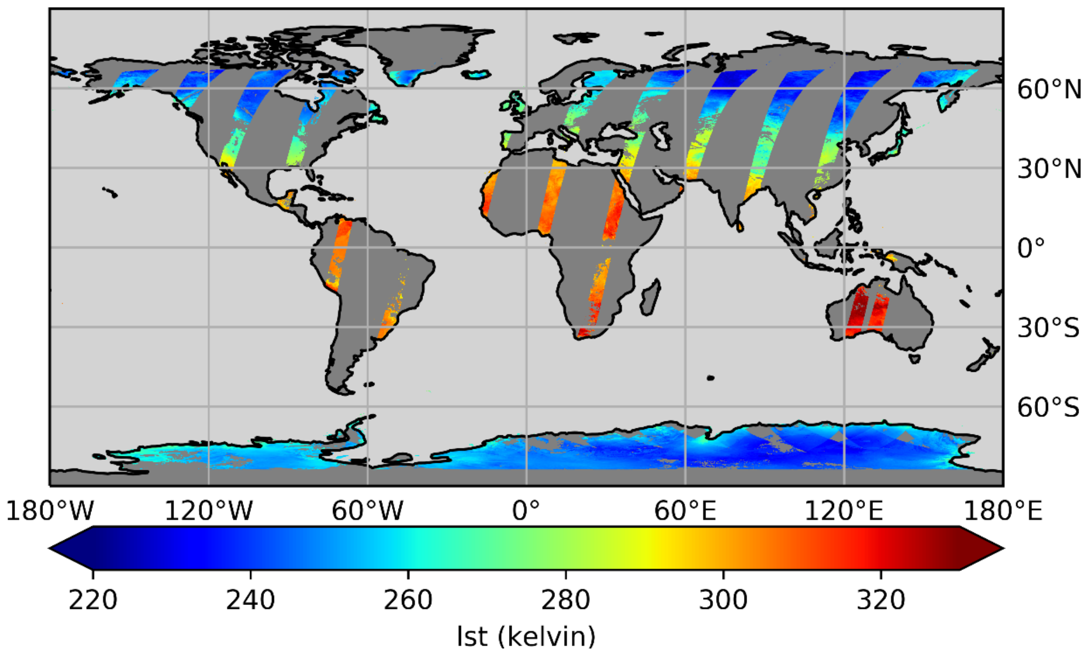


***Figure 14: Example of MULTISENSOR_IRCDR_L3S daily daytime data. This product collates several orbits in each file.***

# 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-L2P-LST-ATSR_3-20100101002328-fv1.00.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 “L2P”, “L3U” or “L3C”. For LST CDRs this is “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”, “SEVIRI”, “SSMI13”, “SSMI17”, “SSMI18”, .

### 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 data, for example in SSMI files (“0.25deg_1DAILY_ASC”) and MODIS files (“0.05deg_1DAILY_DAY”, “0.05deg_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 external cycle will increment main digit by 1. Internal cycle will increment first digit after decimal point to 5. Each minor release will increment by second digit after decimal point. For example: 1.53 would be the Year 2 internal cycle 3rd minor release (such as due to a bug fix).

### 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. Please see the information on tools given in the quick start guide at the start of this document.

### 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].

Two different file formats are used for the ESA LST_cci data products: one for L2P data and one for L3 data. To find the file format for a given dataset, refer to the directory of ESA LST_cci products in Section

4. The description of each data product includes the data level and therefore which file format description to read.

In the sections below each of the two 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 for each data level in turn (L2P format in Section 6.4.3 and L3 in Section 6.4.4). A sample listing of the structure of each type of file is given in Appendix 2.

For a complete, technical description of the file format see the ESA LST_cci Product Specification Document [AD-1], which can be downloaded from http://cci.esa.int/lst.

### 5.4.1. Global Attributes

The global attributes common to all the ESA LST_cci product files are described in Table 11. 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 12.

***Table 11: 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. |
| tracking_id | string | A UUID (Universal Unique Identifier) value produced using version 4 (random number based) for consistency with CMIP5. | ACDD | As stated in Description column. |

| Global Attribute Name | Format | Description | Source | LST_CCI definition |
|---|---|---|---|---|
| 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. |
| 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. |

| Global Attribute Name | Format | Description | Source | LST_CCI definition |
|---|---|---|---|---|
| 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<br>creator_url<br>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. |
| 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. |

| Global Attribute Name | Format | Description | Source | LST_CCI definition |
|---|---|---|---|---|
| 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. |
| 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 12: 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). |

### 5.4.2. Variable Attributes

The attributes that contain the metadata associated with particular variables are listed in Table 13. 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 13: 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.<br><br>For LST_cci this is set to -32768. |
| calendar | A string giving the calendar used for the time variable.<br><br>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.<br><br>For LST_cci this is set as “lat lon” or “ni nj” for L2P and L3C 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. L2P Data Format

Level 2 pre-processed (L2P) data files contain LSTs from a single orbit of a satellite instrument. The LSTs are stored as a data strip corresponding to the section of the Earth viewed by the satellite as it travelled through its orbit.

The dimensions of the data in the file are described in Table 14. The data are stored in variables in the NetCDF file with the names given in Table 15. Not all variables will be included in all L2P files.

***Table 14: The dimensions of the data in a L2P file.***

| Dimension Name | Description |
| --- | --- |
| ni | Data array dimension corresponding to the direction perpendicular to the track of the instrument. |
| nj | Data array dimension corresponding to the direction along the track of the instrument. |
| time | This is always 1 for L2P 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 15: Data arrays stored in L2P 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 14.***

| 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 nj x ni) | Time differences of LST retrievals from the base time in the "time" coordinate variable |
| | lat (nj x ni) | Coordinate variable; central latitude of each spatial point of the data arrays |
| | lon (nj x ni) | Coordinate variable; central latitude of each spatial point of the data arrays |
| | channel (channel) | Coordinate variable; sensor channel information |
| Geophysical variables | lst (time x nj x ni) | Best available LST retrievals; fill values to be provided where there is ocean (ice free or ice covered) or cloud. |
| | fv (time x nj x ni) | Fractional vegetation value of the pixel. |
| | ndvi (time x nj x ni) | Normalised Difference Vegetation Index of the pixel. |
| | emis (time x channel x nj x ni) | Land Surface Emissivity of the pixel. |
| | t2m (time x nj x ni) | Surface Air Temperature at the pixel (2 m height). |
| | sh2m (time x nj x ni) | Humidity at the pixel (2 m height). |
| | ws2m (time x nj x ni) | Wind speed at the pixel (2 m height). |
| | lcc (time x nj x ni) | Land cover classification of the pixel (biome). |
| | tcwv (time x nj x ni) | Total Column Water Vapour of the pixel. |
| Uncertainty information – total uncertainty | lst_uncertainty (time x nj x ni) | 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 nj x ni) | Random uncertainties, which are uncorrelated (or weakly correlated) on all spatial and temporal scales. |
| | lst_unc_loc_atm (time x nj x ni) | Locally correlated atmospheric uncertainties. |
| | lst_unc_loc_sfc (time x nj x ni) | Locally correlated biome or surface uncertainties. |
| | lst_unc_sys (length_scale) | Large scale systematic uncertainties, which are correlated on all spatial and temporal scales. |
| Retrieval information | satze (time x nj x ni) | The per pixel satellite zenith angle of the observation. |
| | sataz (time x nj x ni) | The per pixel satellite azimuth angle of the observation. |
| | solze (time x nj x ni) | The per pixel solar zenith angle of the observation. |
| | solaz (time x nj x ni) | The per pixel solar azimuth angle of the observation. |
| Quality information | qual_flag (time x nj x ni) | Per pixel quality flags for each LST retrieval. |

### 5.4.4. L3C and L3S 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. 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 16. The data are stored in variables in the NetCDF file with the names given in Table 17. Not all variables will be included in all L2P files.

***Table 16: The dimensions of the data in a L3C file.***

| Dimension Name | Description |
|---|---|
| lat<br>lon | These are the dimensions of the regular latitude-longitude grid on which the data are stored. |
| 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 17: Data arrays stored in L3C 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 16.***

| 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. |
| | fv (time x lat x lon) | Fractional vegetation value of the pixel. |
| | lwm (time x lat x lon) | Land Water Mask. |
| | ndvi (time x lat x lon) | Normalised Difference Vegetation Index of the pixel. |
| | emis (time x channel x lat x lon) | Land Surface Emissivity of the pixel. |
| | t2m (time x lat x lon) | Surface Air Temperature at the pixel (2 m height). |
| | sh2m (time x lat x lon) | Humidity at the pixel (2 m height). |
| | ws2m (time x lat x lon) | Wind speed at the pixel (2 m height). |
| | lcc (time x lat x lon) | Land cover classification of the pixel (biome). |
| | tcwv (time x lat x lon) | Total Column Water Vapour of the pixel. |

| Category | Name of data (size of array) | Description |
|---|---|---|
| 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_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. |
| | ncld (time x lat x lon) | Number of L2P pixels flagged as cloud which were not used to calculate the L3 pixel LST. |
| | variance (time x lat x lon) | Variance of LST in of L2P pixels used in the retrieval. |
| 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 open algorithm intercomparison round-robin. 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. 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 will be 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:

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

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 will be used for the MODIS and SEVIRI LST ECV products and for the ATSR-MODIS-SEVIRI 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 will be 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, $\varepsilon_{mean}$, is derived as:

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

Where $\varepsilon_{mean}$ 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 will be of width 15 kg·m$^{-2}$ so that the first water vapour band is from [0,15) kg·m$^{-2}$. The bands for satellite zenith angle will be 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 of 10 nodes, and one output node (the LST), will be 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:

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

where Z is the number of samples in the calibration database, ⟦ ⟧is the standard 2-norm, and $u\left(y^l\right)$ 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.

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 ~30 km, corresponding to the resolution of those channels.

## 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, which are internal to the project, 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 with the smallest satellite zenith angle 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, add then the temporal correction detailed in ATBD is added to any sensor not nominally at the LECT of the chosen sensor.

# 7. Appendix 2: Sample Listings of File Contents

## 7.1. Header from an L2P file

```
netcdf ESACCI-LST-L2P-LST-ATSR_3-20100101002328-fv1.00 {

dimensions:

        time = 1 ;

        length_scale = 1 ;

        channel = 2 ;

        nj = 43520 ;

        ni = 512 ;

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, nj, ni) ;

                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 = "nj ni" ;

        float lat(nj, ni) ;

                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(nj, ni) ;
        lon:long_name = "longitude_coordinates" ;
        lon:standard_name = "latitude" ;
        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, nj, ni) ;
        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 = "nj ni" ;
short sataz(time, nj, ni) ;
        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 = "nj ni" ;
	short solze(time, nj, ni) ;
		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 = "nj ni" ;
	short solaz(time, nj, ni) ;
		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 = "nj ni" ;
	short qual_flag(time, nj, ni) ;
		qual_flag:long_name = "Quality Flags" ;
		qual_flag:flag_meanings = "day_or_night-1_is_night summary_cloud-1_is_cloudy summary_confidence-1_is_low_confidence aerosol_mask-1_is_aerosol_detected ocean_flag land_flag lake_flag coast_flag tidal_flag seaice_flag" ;
		qual_flag:flag_masks = 1s, 2s, 4s, 8s, 16s, 32s, 64s, 128s, 256s, 512s ;
```

```
        qual_flag:_FillValue = -32768s ;
        qual_flag:valid_min = 0s ;
        qual_flag:valid_max = 1023s ;
        qual_flag:coordinates = "nj ni" ;
short lst(time, nj, ni) ;
        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 = "nj ni" ;
short lst_uncertainty(time, nj, ni) ;
        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 = "nj ni" ;
short lst_unc_ran(time, nj, ni) ;
        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 = "nj ni" ;
        short lst_unc_loc_atm(time, nj, ni) ;
                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 = "nj ni" ;
        short lst_unc_loc_sfc(time, nj, ni) ;
                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 = "nj ni" ;
        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 ;

lst_unc_sys:coordinates = "nj ni" ;

short lcc(time, nj, ni) ;

lcc:long_name = "land cover class" ;

lcc:units = "1" ;

lcc:flag_meanings = "Post-flooding_OR_irrigated_croplands Rainfed_croplands Mosaic_Cropland_(50-70percent)_OR_Vegetation_(grassland,_shrubland,_forest)_(20-50percent) Mosaic_Vegetation_(grassland,_shrubland,_forest)_(50-70percent)_OR_Cropland_(20-50percent) Closed_to_open_(>15percent)_broadleaved_evergreen_and_or_semi-deciduous_forest_(>5m) Closed_(>40percent)_broadleaved_deciduous_forest_(>5m) Open_(15-40percent)_broadleaved_deciduous_forest_(>5m) Closed_(>40percent)_needleleaved_evergreen_forest_(>5m) Open_(15-40percent)_needleleaved_deciduous_or_evergreen_forest_(>5m) Closed_to_open_(>15percent)_mixed_broadleaved_and_needleleaved_forest_(>5m) Mosaic_Forest_OR_Shrubland_(50-70percent)_OR_Grassland_(20-50percent) Mosaic_Grassland_(50-70percent)_OR_Forest_OR_Shrubland_(20-50percent) Closed_to_open_(>15percent)_shrubland_(<5m) Closed_to_open_(>15percent)_grassland Sparse_(>15percent)_vegetation_(woody_vegetation,_shrubs,_grassland) Closed_(>40percent)_broadleaved_forest_regularly_flooded_-Fresh_water Closed_(>40percent)_broadleaved_semi-deciduous_and_or_evergreen_forest_regularly_flooded_-Saline_water Closed_to_open_(>15percent)_vegetation_(grassland,_shrubland,_woody_vegetation)_on_regularly_flooded_or_waterlogged_soil_-Fresh,_brackish_or_saline_water Artificial_surfaces_and_associated_areas_(urban_areas_>50percent) Bare_areas_of_soil_types_not_contained_in_biomes_21_to_25 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_bodies_(inland_lakes,_rivers,_sea:_max_10km_away_from_coast) Permanent_snow_and_ice" ;

lcc:flag_values = 1s, 2s, 3s, 4s, 5s, 6s, 7s, 8s, 9s, 10s, 11s, 12s, 13s, 14s, 15s, 16s, 17s, 18s, 19s, 20s, 21s, 22s, 23s, 24s, 25s, 26s, 27s ;

lcc:_FillValue = -32768s ;

lcc:valid_min = 1 ;

lcc:valid_max = 27 ;

lcc:coordinates = "nj ni" ;

```
short fv(time, nj, ni) ;
        fv:long_name = "fractional vegetation cover" ;
        fv:units = "1" ;
        fv:_FillValue = -32768s ;
        fv:add_offset = 0.f ;
        fv:scale_factor = 0.0001f ;
        fv:valid_min = 0s ;
        fv:valid_max = 10000s ;
        fv:source = "CGLPS FCOVER 1 km dataset v2.0, which has been brokered to C3S:https://land.copernicus.eu/global/products/fcover" ;
        fv:coordinates = "nj ni" ;
short tcwv(time, nj, ni) ;
        tcwv:long_name = "total column water vapour" ;
        tcwv:units = "kg m-2" ;
        tcwv:_FillValue = -32768s ;
        tcwv:add_offset = 0.f ;
        tcwv:scale_factor = 0.004f ;
        tcwv:valid_min = 0s ;
        tcwv:valid_max = 20000s ;
        tcwv:source = "ECMWF ERA-Interim dataset: https://www.ecmwf.int/en/forecasts/datasets/reanalysis-datasets/era-interim" ;
        tcwv:coordinates = "nj ni" ;
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 ;

channel:coordinates = "nj ni" ;

// global attributes:

:title = "ESA LST CCI land surface temperature level L2P from Advanced Along-Track Scanning Radiometer" ;

:institution = "University of Leicester" ;

:source = "ESA AATSR L1 V3.0" ;

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

:references = "http://cci.esa.int/lst" ;

:tracking_id = "1fb817c8-d061-4bc2-b175-8fbce1d7c678" ;

:Conventions = "CF-1.7" ;

:product_version = "1.00" ;

:summary = "This file contains level L1C global land surface temperatures from ATSR_ satellite observations. Level 1C data are level 1B data that have been further processed prior to deriving geophysical variables from the data" ;

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

:id = "ESACCI-LST-L2P-LST-ATSR_3-20100101002328-fv1.00.nc" ;

:naming_authority = "le.ac.uk" ;

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

:cdm_data_type = "Swath" ;

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

:date_created = "20190810T205637Z" ;

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

:creator_url = "http://cci.esa.int/lst" ;

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

:project = "Climate Change Initiative - European Space Agency" ;

:geospatial_lat_min = -83.78179f ;

:geospatial_lat_max = 83.78148f ;

:geospatial_lon_min = -180.f ;

:geospatial_lon_max = 179.9999f ;

:geospatial_vertical_min = 0.f ;

:geospatial_vertical_max = 0.f ;

:time_coverage_start = "20100101T002328Z" ;

:time_coverage_end = "20100101T021215Z" ;

:time_coverage_duration = "PT01H48M47S" ;

:time_coverage_resolution = "satellite_orbit_frequency" ;

:standard_name_vocabulary = "NetCDF Climate and Forecast (CF) Metadata Convention version 1.7" ;

:license = "ESA CCI Data Policy: free and open access" ;

:platform = "Envisat" ;

:sensor = "ATSR_3" ;

:spatial_resolution = "1 km at nadir" ;

:geospatial_lat_units = "degrees_north" ;

:geospatial_lon_units = "degrees_east" ;

:key_variables = "land_surface_temperature" ;

}

## 7.2. Header from an L3C file

netcdf ESACCI-LST-L3C-LST-ATSR_3-0.05deg_1DAILY_DAY-20100101000000-fv1.00 {

dimensions:

time = 1 ;

length_scale = 1 ;

```
        channel = 2 ;
        lat = 3600 ;
        lon = 7200 ;
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" ;
        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 = "latitude" ;
        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" ;
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" ;
	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" ;
	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" ;
	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" ;

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" ;

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" ;

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" ;
      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" ;
      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 ;
            lst_unc_sys:coordinates = "lon lat" ;
```

short lcc(time, lat, lon) ;

lcc:long_name = "land cover class" ;

lcc:units = "1" ;

lcc:flag_meanings = "Post-flooding_OR_irrigated_croplands Rainfed_croplands Mosaic_Cropland_(50-70percent)_OR_Vegetation_(grassland,_shrubland,_forest)_(20-50percent) Mosaic_Vegetation_(grassland,_shrubland,_forest)_(50-70percent)_OR_Cropland_(20-50percent) Closed_to_open_(>15percent)_broadleaved_evergreen_and_or_semi-deciduous_forest_(>5m) Closed_(>40percent)_broadleaved_deciduous_forest_(>5m) Open_(15-40percent)_broadleaved_deciduous_forest_(>5m) Closed_(>40percent)_needleleaved_evergreen_forest_(>5m) Open_(15-40percent)_needleleaved_deciduous_or_evergreen_forest_(>5m) Closed_to_open_(>15percent)_mixed_broadleaved_and_needleleaved_forest_(>5m) Mosaic_Forest_OR_Shrubland_(50-70percent)_OR_Grassland_(20-50percent) Mosaic_Grassland_(50-70percent)_OR_Forest_OR_Shrubland_(20-50percent) Closed_to_open_(>15percent)_shrubland_(<5m) Closed_to_open_(>15percent)_grassland Sparse_(>15percent)_vegetation_(woody_vegetation,_shrubs,_grassland) Closed_(>40percent)_broadleaved_forest_regularly_flooded_-Fresh_water Closed_(>40percent)_broadleaved_semi-deciduous_and_or_evergreen_forest_regularly_flooded_-Saline_water Closed_to_open_(>15percent)_vegetation_(grassland,_shrubland,_woody_vegetation)_on_regularly_flooded_or_waterlogged_soil_-Fresh,_brackish_or_saline_water Artificial_surfaces_and_associated_areas_(urban_areas_>50percent) Bare_areas_of_soil_types_not_contained_in_biomes_21_to_25 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_bodies_(inland_lakes,_rivers,_sea:_max_10km_away_from_coast) Permanent_snow_and_ice" ;

lcc:flag_values = 1s, 2s, 3s, 4s, 5s, 6s, 7s, 8s, 9s, 10s, 11s, 12s, 13s, 14s, 15s, 16s, 17s, 18s, 19s, 20s, 21s, 22s, 23s, 24s, 25s, 26s, 27s ;

lcc:_FillValue = -32768s ;

lcc:valid_min = 1 ;

lcc:valid_max = 27 ;

lcc:coordinates = "lon lat" ;

short fv(time, lat, lon) ;

fv:long_name = "fractional vegetation cover" ;

fv:units = "1" ;

fv:_FillValue = -32768s ;

fv:add_offset = 0.f ;

fv:scale_factor = 0.0001f ;

fv:valid_min = 0s ;

fv:valid_max = 10000s ;

fv:source = "CGLPS FCOVER 1 km dataset v2.0, which has been brokered to C3S:https://land.copernicus.eu/global/products/fcover" ;

fv:coordinates = "lon lat" ;

short tcwv(time, lat, lon) ;

tcwv:long_name = "total column water vapour" ;

tcwv:units = "kg m-2" ;

tcwv:_FillValue = -32768s ;

tcwv:add_offset = 0.f ;

tcwv:scale_factor = 0.004f ;

tcwv:valid_min = 0s ;

tcwv:valid_max = 20000s ;

tcwv:source = "ECMWF ERA-Interim dataset: https://www.ecmwf.int/en/forecasts/datasets/reanalysis-datasets/era-interim" ;

tcwv:coordinates = "lon lat" ;

short n(time, lat, lon) ;

n:long_name = "number of clear-sky pixels" ;

n:_FillValue = -32768s ;

n:valid_min = 0s ;

n:valid_max = 18750s ;

n:coordinates = "lon lat" ;

short ncld(time, lat, lon) ;

```
        ncld:long_name = "number of cloudy pixels" ;
        ncld:_FillValue = -32768s ;
        ncld:valid_min = 0s ;
        ncld:valid_max = 18750s ;
        ncld:coordinates = "lon lat" ;
    short lwm(time, lat, lon) ;
        lwm:long_name = "land water mask fractional cover" ;
        lwm:units = "1" ;
        lwm:_FillValue = -32768s ;
        lwm:add_offset = 0.f ;
        lwm:scale_factor = 0.0001f ;
        lwm:valid_min = 0s ;
        lwm:valid_max = 10000s ;
        lwm:coordinates = "lon lat" ;
    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 ;
        channel:coordinates = "lon lat" ;

// global attributes:
```

:title = "" ;

:institution = "University of Leicester" ;

:source = "ESA AATSR L1 V3.0" ;

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

:references = "" ;

:tracking_id = "" ;

:Conventions = "CF-1.7" ;

:product_version = "1.00" ;

:summary = "This file contains level L1C global land surface temperatures from ATSR_ satellite observations. Level 1C data are level 1B data that have been further processed prior to deriving geophysical variables from the data" ;

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

:id = "" ;

:naming_authority = "le.ac.uk" ;

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

:cdm_data_type = "Swath" ;

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

:date_created = "20190823T171207Z" ;

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

:creator_url = "http://cci.esa.int/lst" ;

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

:project = "Climate Change Initiative - European Space Agency" ;

:geospatial_lat_min = -83.78175f ;

:geospatial_lat_max = 83.78173f ;

:geospatial_lon_min = -180.f ;

:geospatial_lon_max = 180.f ;

:geospatial_vertical_min = 0.f ;

:geospatial_vertical_max = 0.f ;

:time_coverage_start = "20100102T013648" ;

:time_coverage_end = "20100102T013805" ;

:time_coverage_duration = "PT01M16S" ;

:time_coverage_resolution = "" ;

:standard_name_vocabulary = "NetCDF Climate and Forecast (CF) Metadata Convention version 1.7" ;

:license = "ESA CCI Data Policy: free and open access" ;

:platform = "Envisat" ;

:sensor = "ATSR_3" ;

:spatial_resolution = "1 km at nadir" ;

:geospatial_lat_units = "degrees_north" ;

:geospatial_lon_units = "degrees_east" ;

:geospatial_lon_resolution = 0.05f ;

:geospatial_lat_resolution = 0.05f ;

:key_variables = "land_surface_temperature" ;

:svn_version = 0 ;

:format_version = "CCI Data Standards v2.1" ;

}

***End of document***