EUMETSAT Satellite Application Facility on Climate Monitoring

Product User Manual
CM SAF Latent and Sensible Heat Flux

Climate Data Record

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Meteosat Latent and Sensible Heat Flux CM-23811

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	Name	Function	Signature	Date
Authors	William Moutier Nicolas Clerbaux Françoise Gellens-Meulenberghs Alirio Arboleda Miguel Barrios	CM SAF scientist CM SAF scientist CM SAF scientist CM SAF scientist CM SAF scientist		30.05.2023
Editor	Marc Schröder	CM SAF Science Coordinator		xx.xx.2023
Approval	CM SAF Steering Group			
Release	Rainer Hollmann	CM SAF Project Manager		xx.xx.2023

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Applicable Documents

The following documents, of the exact issue shown, form part of this document to the extent specified herein. Applicable documents are those referenced in the Contract or approved by the Approval Authority. They are referenced in this document in the form [AD X].

Reference	Title	Code, Version, Date
AD 1	CM SAF Product Requirements Document	SAF/CM/DWD/PRD/3.9

Reference Documents

The reference documents contain useful information related to the subject of the project. These reference documents complement the applicable ones, and can be looked up to enhance the information included in this document if it is desired. They are referenced in this document in the form [RD X].

Reference	Title	Code, Version, Date
RD 1	CM SAF Validation Report Meteosat Latent and Sensible heat fluxes - Edition 1	SAF/CM/RMIB/VAL/LEH/1.0
RD 2	CM SAF Algorithm Theoretical Basis Document. Meteosat Latent and Sensible heat fluxes - Edition 1	SAF/CM/RMIB/ATBD/MET/LEH/1.1
RD 3	CM SAF Validation Report Meteosat Radiative Balance -Edition 1	SAF/CM/MET/VAL/SRB/1.0

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List of acronyms

CF	Climate and Forecast
CDOP	Continuous Development and Operations
CDR	Climate Data Record
CM SAF	Satellite Application Facility on Climate Monitoring
DWD	Deutscher Wetterdienst (German MetService)
ECMWF	European Center for Medium-Range Weather Forecasts
ECV	Essential Climate Variables
ERA	ECMWF Re-Analysis
ESA-CCI	European Space Agency (ESA) Climate Change Initiative (CCI)
ET	EvapoTranspiration
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
FCDR	Fundamental Climate Data Record
FMI	Finnish Meteorological Institute
GCOS	Global Climate Observing System
GLDAS	Global Land Data Assimilation System
GLEAM	Global Land Evaporation Amsterdam Model
GLOBMAP	Global Mapping
H	Sensible heat flux
HOLAPS	High res-Olution Land Atmosphere Parameters from Space
HTESSEL	land Hydrology Tiled ECMWF Scheme for Surface Exchanges over Land
h_{tree}	Tree height
ICOS	Integrated Carbon Observation System
JPL	Jet Propulsion Laboratory
KNMI	Koninklijk Nederlands Meteorologisch Instituut
LAI	Leaf Area Index
LC	Land Cover
LE	Latent heat flux
LSA SAF	Land Surface Analysis Satellite Application Facility
LSM	Land Surface Model
LST	Land Surface Temperature
Meteosat	Meteorological Satellite(s) series operated by EUMETSAT
MeteoSwiss	Swiss Federal Office of Meteorology and Climatology
MFG	Meteosat First Generation
MSG	Meteosat Second Generation
MVIRI	Meteosat Visible and Infrared Imager
N	Number
NASA	National Aeronautics and Space Administration
NetCDF	Network Common Data Form

NMHSs	National Meteorological and Hydrological Services
NWP	Numerical Weather Prediction
Opt	Optimal requirement
Pa	Air pressure
PRD	Product Requirement Document
PUM	Product User Manual
RMIB	Royal Meteorological Institute of Belgium
RMSD	Root Mean Square Difference
RR	Requirements Review
SAF	Satellite Application Facility
SAL	Surface Albedo
SCOPE-CM	Sustained COordinated Processing of Environmental satellite data for Climate Monitoring
SDL	Surface Downward Longwave radiation
SEVIRI	Spinning Enhanced Visible and Infrared Imager
SIS	Surface Incoming Solar radiation
SMHI	Swedish Meteorological and Hydrological Institute
SRB	Surface Radiation Budget
Ta	2-meter air temperature
Tar	Target requirement
TCDR	Thematic Climate Data Record
Td	2-meter dew-point temperature
Thr	Threshold requirement
U	U component 10-meter wind
UK MetOffice	Meteorological Service of the United Kingdom
uRMSD	Unbiased root mean square difference
V	V component 10-meter wind
WCRP	World Climate Reasearch Programme
WMO	World Meteorological Organization

Executive Summary

Product presented:

Meteosat Latent and Sensible Heat Flux **CM-23811**

This Product User Manual provides information on the sensible (H) and latent (LE) heat fluxes climate data record (CM-23811). Retrievals are obtained thanks to an adapted version of the methodology developed by the Land Surface Analysis Satellite Application Facility (LSA SAF v3) CDR (RD 2). Radiation component inputs are jointly retrieved using the CM SAF software “GeoSatClim” (RD 3) and based on observations from the Meteosat Visible and InfraRed Imager (MVIRI) and the Spinning Enhanced Visible and Infrared Imager (SEVIRI), onboard of respectively Meteosat First and Second Generation (MFG and MSG). The product is provided over the Meteosat disk at hourly, daily, monthly and monthly mean diurnal cycle time-step at a spatial resolution of 0.05 degrees (regular grid). The record covers 38 years; from 1983-01-01 to 2020-12-31.

Important features:

- Unique combination of high spatial (0.05°) and temporal (hourly) resolutions. This particularity allows regional climate analysis.
- The covered time period of 38 years is highly suitable for climate monitoring.
- The, diurnal cycle, via hourly data or the monthly mean diurnal cycle, can be analyzed.
- The Meteosat field of view covers a large domain of the globe centered around a longitude of 0° allows analysis over Europe, Africa, part of South America.
- This dataset is highly complementary with other global datasets with lower spatial and/or temporal resolution or covering lower time period (e.g. GLEAM, ERA-5, LSA SAF).

Both products (LE and H) have been validated against reference data records from observation sources (30 stations from Fluxnet2015 and ICOS datasets), reanalysis (ERA-5 and GLDAS) and satellite-based products (LSA SAF and GLEAM). Full description of the evaluation is presented in RD 1 with a check of their compliance with the optimal, target and threshold requirements of accuracy and precisions as defined in the CM SAF product requirement document [AD 1].

1 The EUMETSAT SAF on Climate Monitoring

The importance of climate monitoring with satellites was recognized in 2000 by EUMETSAT Member States when they amended the EUMETSAT Convention to affirm that the EUMETSAT mandate is also to “contribute to the operational monitoring of the climate and the detection of global climatic changes”. Following this, EUMETSAT established within its Satellite Application Facility (SAF) network a dedicated center, the SAF on Climate Monitoring (CM SAF, http://www.cmsaf.eu).

The consortium of CM SAF currently comprises the Deutscher Wetterdienst (DWD) as host institute, and the partners from the Royal Meteorological Institute of Belgium (RMIB), the Finnish Meteorological Institute (FMI), the Royal Meteorological Institute of the Netherlands (KNMI), the Swedish Meteorological and Hydrological Institute (SMHI), the Swiss Federal Office of Meteorology and Climatology (MeteoSwiss), and the Meteorological Service of the United Kingdom (UK MetOffice). Since the beginning in 1999, the EUMETSAT Satellite Application Facility on Climate Monitoring (CM SAF) has developed and will continue to develop capabilities for a sustained generation and provision of Climate Data Records (CDR’s) derived from operational meteorological satellites.

In particular, the generation of long-term data sets is pursued. The ultimate aim is to make the resulting data sets suitable for the analysis of climate variability and potentially the detection of climate trends. CM SAF works in close collaboration with the EUMETSAT Central Facility and liaises with other satellite operators to advance the availability, quality and usability of Fundamental Climate Data Records (FCDRs) as defined by the Global Climate Observing System (GCOS). As a major task, the CM SAF utilizes FCDRs to produce records of Essential Climate Variables (ECVs) as defined by GCOS. Thematically, the focus of CM SAF is on ECVs associated with the global energy and water cycle.

Another essential task of CM SAF is to produce data sets that can serve applications related to the new Global Framework of Climate Services initiated by the WMO World Climate Conference-3 in 2009. CM SAF is supporting climate services at national meteorological and hydrological services (NMHSs) with long-term data records but also with data sets produced close to real time that can be used to prepare monthly/annual updates of the state of the climate. Both types of products together allow for a consistent description of mean values, anomalies, variability and potential trends for the chosen ECVs. CM SAF ECV data sets also serve the improvement of climate models both at global and regional scale.

As an essential partner in the related international frameworks, in particular WMO Sustained Coordinated Processing of Environmental satellite data for Climate Monitoring (SCOPE-CM), the CM SAF – together with the EUMETSAT Central Facility, assumes the role as main implementer of EUMETSAT’s commitments in support to global climate monitoring. This is achieved through:

- Application of highest standards and guidelines as lined out by GCOS for the satellite data processing,
- Processing of satellite data within a true international collaboration benefiting from developments at international level and pollinating the partnership with own ideas and standards,
- Intensive validation and improvement of the CM SAF climate data records,
- Taking a major role in data set assessments performed by research organizations such as WCRP. This role provides the CM SAF with deep contacts to research organizations that form a substantial user group for the CM SAF CDRs,
- Maintaining and providing an operational and sustained infrastructure that can serve the community within the transition of mature CDR products from the research community into operational environments.

2 Introduction

This CM SAF Product User Manual (PUM) provides information on the Climate Data Record (CDR) of sensible and latent heat fluxes at surface (CM-23811).

The sensible heat flux represents the amount of energy transferred by convection and/or conduction from the surface to the atmosphere (Mito et al., 2012; Pipunic et al., 2008). The amount of energy and water consumed by evaporation and transpiration corresponds to the latent heat flux and the evapotranspiration process (Pipunic et al., 2008; Katul et al., 2012). By materializing the exchange of water and energy from the earth surface to the atmosphere, the latent and sensible heat fluxes control the development of the planetary boundary layer and govern land-atmosphere interaction (Michel et al., 2016; Behrendt et al., 2020). They play a major role in the hydrological cycle (Oki et al., 2006), carbon cycle (Sellers et al., 1997) and surface energy balance (Trenberth et al., 2009). Various applications as water resource management, agricultural planning, weather forecasting, drought/flood detection, etc., are possible thanks to their estimations (Fisher, 2017; Liou et al., 2014 and reference there in). For instance, monitoring of H/LE allows the detection of desertification, monsoon circulation and climate change (e.g., Yang et al., 2009; Wang and Li 2011; Shan et al., 2016).

The present document aims at providing technical description of the dataset including information on the file format and the data access. Full description of the implementation and the processing chain can be found in Algorithm Theoretical Basis Document [RD 2]. Requirements mentioned in this document are fully described in the product requirements document [AD 1]. Lastly, the Validation Report [RD 1] provides access to more thorough validation [RD 1].

3 Product description

In this section, the dataset is described shortly regarding retrieval methods, file content and limitations. Validation results are also summarized.

3.1 Short algorithm description

Surface latent and sensible heat fluxes, and the evapotranspiration are retrieved by using an adapted version of the methodology developed by the Land Surface Analysis Satellite Application Facility (LSA SAF v3) [RD 1]. It consists in a Surface Vegetation-Atmosphere Transfer (SVAT) scheme modified to accept input data from external sources (Gellens-Meulenberghs et al., 2006, 2007). The algorithm has been adapted from the Tiled ECMWF (European Centre for Medium-Range Weather Forecasts) Scheme for Surface Exchanges over Land (TESSEL) model (Van den Hurk et al., 2000; Viterbo and Beljaars, 1995) and H-TESSEL (Balsamo et al, 2009) allowing the use of satellite-based data and numerical weather prediction (NWP) models' outputs as forcing.

Table 3-1: Main features of the CM-23811 data records.

Sensors	MVIRI & SEVIRI.
Methodology	Adaptation from LSA SAF v3.
Covered period	1983-01-01 to 2020-12-31.
Area Covered	Meteosat Disk (60°N – 60°S; 60°W-60°E).
Temporal characteristics	hourly mean, daily mean, monthly mean and the monthly mean diurnal cycle.
Spatial resolution	Regular lat-lon grid with a spatial resolution of (0.05°), i.e., about (5.5 km)^2 at sub-satellite point.
Output quantities	Latent and sensible heat fluxes (W m^{-2}) and evapotranspiration (mm h^{-1}, mm day^{-1} or mm month^{-1}).
Format	NetCDF file following the CF convention.

Observations from the Meteosat Visible and InfraRed Imager (MVIRI) and the Spinning Enhanced Visible and Infrared Imager (SEVIRI), onboard of respectively Meteosat First and Second Generation (MFG and MSG), are used as inputs for all radiation components (Figure 1). Downward Longwave radiation (SDL) are jointly retrieved using the CM SAF software "GeoSatClim" [RD 3]. Concerning the physical model approach, each elementary spatial unit of the algorithm is called pixel in reference to the basic unit of the MVIRI/SEVIRI instruments on board of MFG/MSG satellites. Considering the fact that evapotranspiration process and heat exchanges depend on the land cover (surface type), each pixel is split up into a maximum of 4 tiles. The fluxes are calculated separately for each tile and the final pixel value is obtained by a weighted contribution of all tiles composing it (Figure 2). Given the non-linear interdependency between the unknowns, an iterative procedure is used to solve the system. Iteration is stopped when pixel estimates of latent and sensible heat fluxes are numerically stabilized. Please note that a full description of the algorithm is provided in [RD 2].

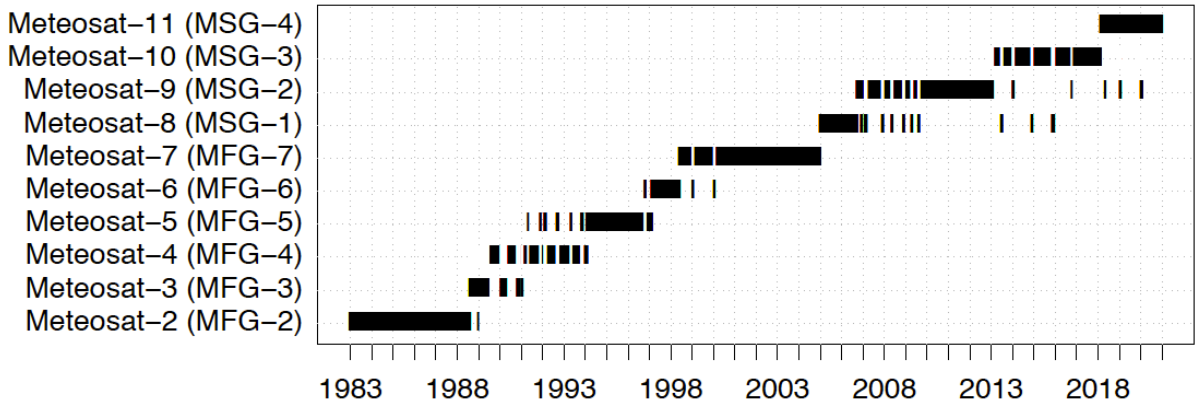

Figure 1: Overview of Meteosat satellites used as input for the generation of the land surface flux CDR.

The main features and inputs of the CM-23811 data records are summarized in Tables 3-1 and 3-2.

Table 3-2: Main inputs variables used in the CM SAF algorithm.

Dataset name (short name; unit)	Sources
Surface Incoming Shortwave radiation (*SIS*; W m^{-2}) Surface Downward Longwave radiation (*SDL*; W m^{-2}) Surface Albedo (*SAL*)	CM-23271 [*RD 2*]
Leaf Area Index (*LAI*; m^{2} m^{-2})	GLOBMAP (*Liu et al., 2012, 2017*)
Land Cover (*LC*)	ESA-CCI (*ESA 2017 ; Bontemps et al., 2012*)
Tree height (h_{tree}, m)	NASA/JPL (*Simard et al., 2011*)
Meteorological data (Ta, Td, U, V, Pa,) & Surface soil moisture	ERA-5 (Hersbach et al., 2019)

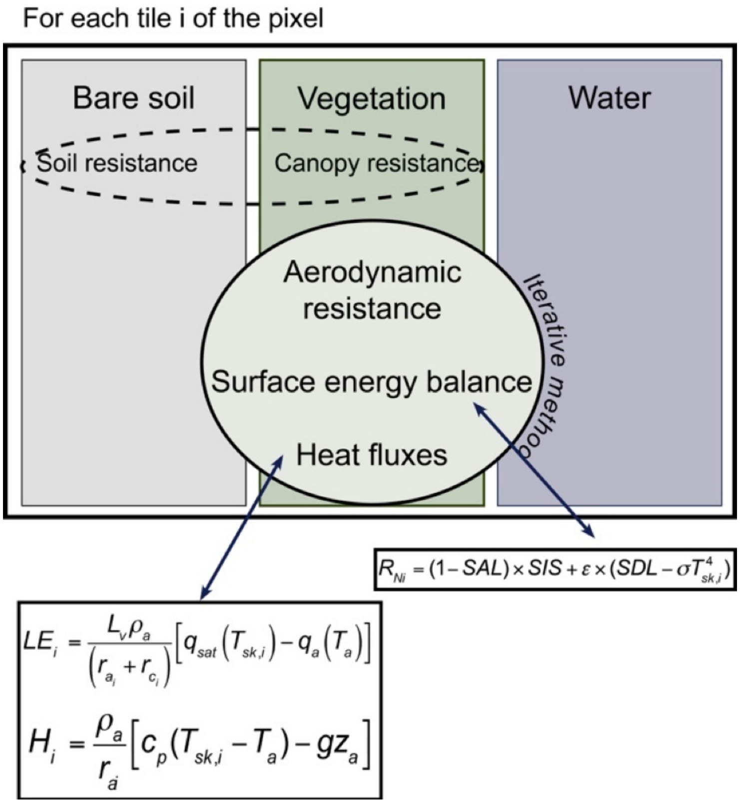

Figure 2: Schematic of LE/H retrieval steps at the tile level (see details in [RD 2]).

3.2 Product illustrations

Figure Figure 3 displays typical example of LE/H monthly mean product and the the number of observations used ("LEH_NUMO" product). Figure 4 shows an illustration of the hourly monthly mean diurnal cycle of LE for January 2005.

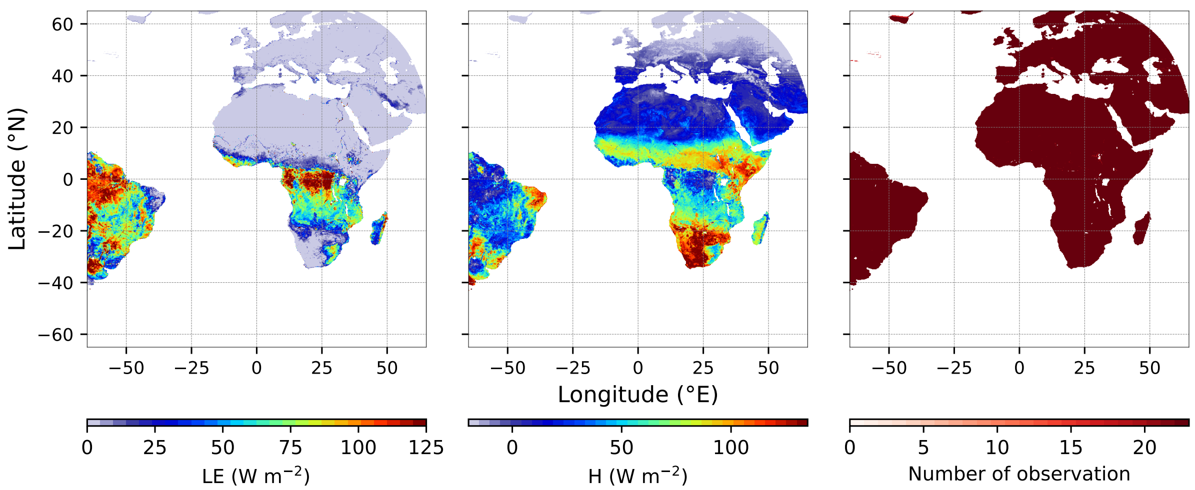

Figure 3: Map of monthly mean latent (left) and sensible (center) heat flux and the number of observations (LEH_NUMO product; right) or January 2005.

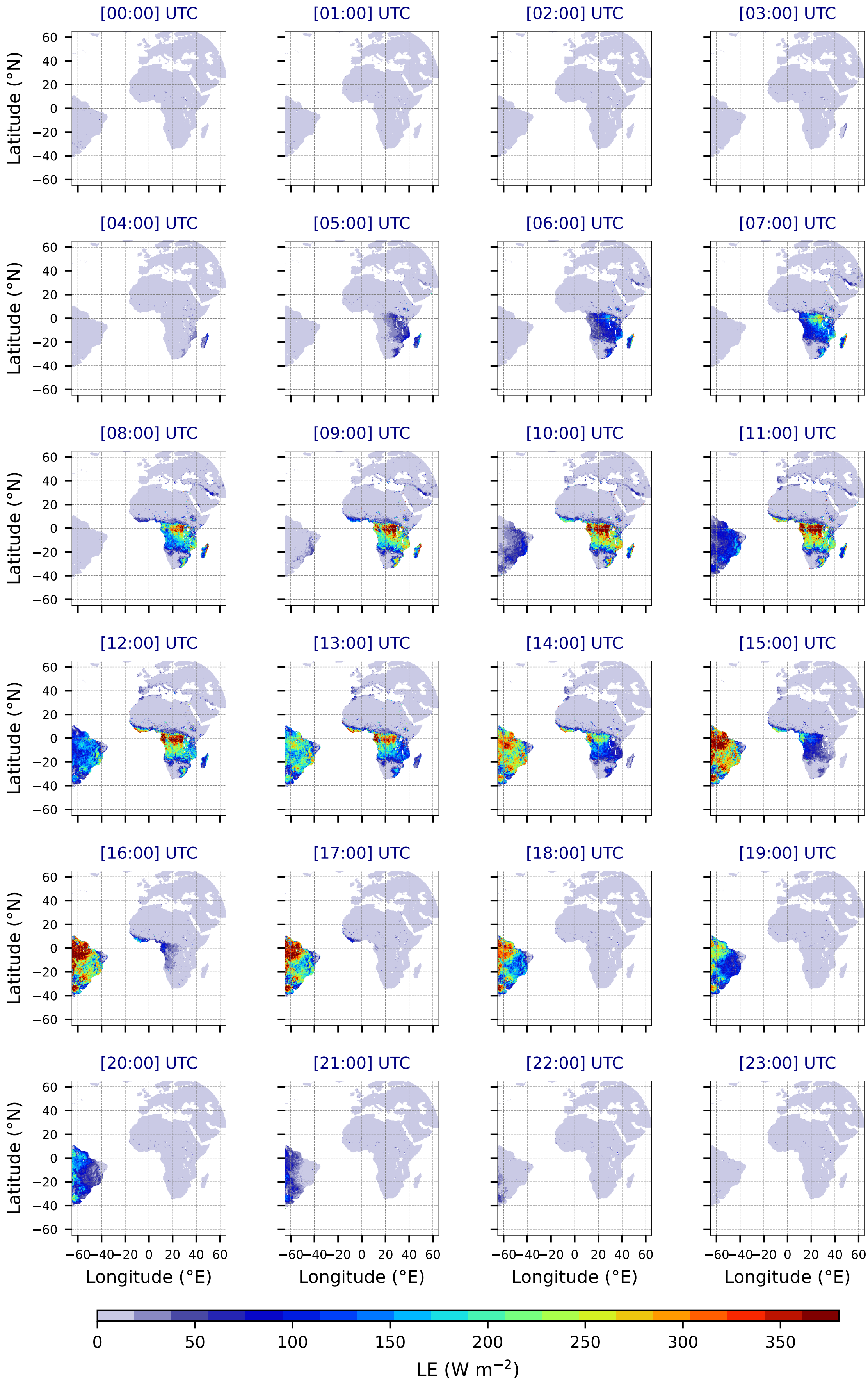

Figure 4: Maps of each hour composing the latent heat flux monthly mean diurnal cycle for January 2005.

3.3 Summary of validation results

The CDR has been validated by comparing estimations at 30 stations with reference data records from the FLUXNET2015 and ICOS observations networks. In addition, the robustness of the results has been ensured with inter-comparisons with other products: ERA-5, GLDAS, LSA SAF and GLEAM. Full description of the evaluation is presented in [RD 1] with a check their compliance with the optimal, target and threshold requirements of accuracy and precisions as defined in [AD 1].

Tables 3-3 and 3-4 summarize qualitatively validation results obtained by comparing estimations with *in-situ* observations at 30 stations and inter-product comparisons for stability for latent and sensible heat flux respectively[1]. Both products comply with the threshold requirements for all temporal aggregations and for the stability. However, they do not comply target requirements for all cases. Worth noting that while the uncertainty target requirements are not always reached, uRMSD values obtained are in the same order of magnitude referenced in the literature. In addition, similar range of uRMSD, as compared to *in-situ* data, are calculated for other tested products. Grid-based comparisons showed good agreements in the northern part of the Meteosat disk (latitudes higher than 16°N) but systematic differences have been observed in the southern regions. Finally, decadal stability target requirement is only complied for the latent heat flux and for the sensible heat flux over Europe area.

From a quantitative perspective, Tables 3-5 and 3-6 present the performance metrics between CM SAF and Fluxnet 2015/ICOS data including all possible matchups for all stations for different time resolutions for latent and sensible heat flux. Results are in the same order of magnitude than the literature (e.g., Loew et al., 2016, Martens et al., 2017, Zhang et al., 2017, Albergel et al., 2018, Siemann et al., 2018, Peng et al., 2020, Guo et al., 2022, , Xin et al., 2022). For instance, by comparing estimations from 7 land surface models to eddy correlation measurements in China, Guo et al., (2022) calculated bias values, with a variation from -14.27 to -2.93 W m^{-2} and uRMSD ranged from 29.8 W m^{-2} to 39.3 W m^{-2}.

Table 3-3: Summary of requirement compliance for the latent heat flux.

	Optimal Bias / uRMSD	Target Bias / uRMSD	Threshold Bias / uRMSD
Hourly	✗ / ✗	✓ / ✓	✓ / ✓
Daily	✗ / ✗	✓ / ✗*	✓ / ✓
Monthly	✗ / ✗	✓ / ✓**	✓ / ✓
Monthly mean diurnal cycle	✗ / ✗	✓ / ✓	✓ / ✓
Stability	✗ / ✗	✓ / ✓	✓ / ✓

(*) ✗: Comply with the target for 60% of the stations (N=30 stations).
(**) ✓**:** Comply with the target for 77% of the stations (N=30 stations).

[1] Conclusion for latent heat flux are also valid for the evapotranspiration (ET=LE λ; where λ is the latent heat of vaporization which depend on the temperature)

Table 3-4: Same as Table 3-3 but for the sensible heat flux products.

	Optimal Bias / uRMSD	Target Bias / uRMSD	Threshold Bias / uRMSD
Hourly	✗ / ✗	✓ / ✓	✓ / ✓
Daily	✗ / ✗	✓ / ✗	✓ / ✓
Monthly	✗ / ✗	✓ / ✗*	✓ / ✓
Monthly mean diurnal cycle	✗ / ✗	✓ / ✓	✓ / ✓
Stability	✗ / ✗	✗ / ✗	✓ / ✓

(*)✗: Comply with the target for 63% of the stations (N=30 stations).

Table 3-5: Performance statistics of hourly, daily and monthly CM SAF latent heat flux dataset as compared to FLUXNET2015/ICOS observations at 30 stations.

	N	<FLUXNET2015/ICOS> *($W\ m^{-2}$)*	<CMSAF> *($W\ m^{-2}$)*	Bias *($W\ m^{-2}$)* ± (Opt / Tar / Thr)**	uRMSD *($W\ m^{-2}$)* (Opt / Tar / Thr)**
Hourly	565880	24.2	14.5	-9.7 (2.5 / 15 / 30)	32.5 (2.5 / 45 / 90)
Daily	105123	39.4	28.6	-10.8 (4 / 17.9 / 35.8)	24.7 (4 / 22.9 / 35.8)
Monthly	3295	41.2	28.8	-12.32 (4.1 / 18.3 / 36.5)	19.7 (4.1 / 18.3 / 36.5)

(**) Opt: Optimal requirement; Tar: Target requirement; Thr: Threshold requirement.

Table 3-6: Performance statistics of hourly, daily and monthly CM SAF sensible heat flux dataset as compared to FLUNET2015/ICOS observations at 30 stations.

	N	< FLUXNET2015/ICOS > *($W\ m^{-2}$)*	<CMSAF> *($W\ m^{-2}$)*	Bias *($W\ m^{-2}$)* ± (Opt / Tar / Thr)**	uRMSD *($W\ m^{-2}$)* (Opt / Tar / Thr)**
			Hourly		
Hourly	413234	5.4	6.3	+1 (4 / 22.1 / 44.2)	48.5 (4 / 62.1 / 124.2)
Daily	109867	24.3	21.7	-2.6 (3.4 / 20.2 / 40.5)	34.1 (3.4 / 25.2 / 50.5)
Monthly	3512	24	21.2	-2.8 (3.1 / 19.3 / 38.6)	23.6 (3.1 / 19.3 / 38.6)

(**)Opt: Optimal requirement; Tar: Target requirement; Thr: Threshold requirement.

3.4 Known limitations

While the project team tried to provide the best possible quality product, several known limitations should be considered by the users:

- While accuracy target requirements are meet for all temporal aggregations, the latent heat flux is likely underestimated.
- Systematic differences with other products (ERA5, LSA SAF, GLDAS and GLEAM) are observed in the southern regions (latitudes lower than 16°N).
- Stability requirement is not met for the sensible heat flux over desert regions.
- The land cover is available yearly and, it does not consider potential variation of the land cover over the year. In addition, the land cover is considered constant between 1983 and 1992.
- The use of daily soil moisture can be an important limitation in hourly outputs when strong precipitation events occurred during the day.
- Border of the disk may suffer of errors due to the higher satellite zenith viewing angle. Higher number of missing values can also be observed in those areas due to the no convergence during the iterative procedure.
- Ground flux variable is provided as auxiliary data but should be used carefully as it has not been validated.

3.5 Outlook

Future tasks will involve the improvement of the sensible heat flux stability over desert regions, which is important for applications regarding local and global trend analysis (Schröder et al., 2016). The energy repartition will also be investigated in order to decrease the latent heat flux underestimation.

Moreover, In the next phase (CDOP4), a prototype will be developed to get data globally over land and sea. The HOAPS (Fennig et al., 2012) dataset will be used for estimation over sea and, Meteosat data will be combined with other satellite measurements to estimate radiation inputs. Thus, all necessary inputs will be available to estimate land heat fluxes globally.

4 Data format description

The CM-23811 climate data record is provided as NetCDF (Network Common Data Format) files (http://www.unidata.ucar.edu/software/netcdf/). Files are created following NetCDF Climate and Forecast (CF) Metadata Convention version 1.7 (https://cfconventions.org) and NetCDF Attribute Convention for Data Discovery (ACDD) version 1.3 (https://wiki.esipfed.org/Attribute_convention_for_Data_Discovery_1-3). A NetCDF file contains dimensions, variables and attributes, which are all identified by a specific name (and an ID number). These components can be used together to capture the meaning of data and relations among data fields. File naming convention and specific content of the NetCDF files is described in the following subsections.

4.1 File naming

The product filenames follow the CM SAF filename convention[2] and are consequently built following the structure:

PROtsyyyymmddhhmmVerGrSourcLvAr

The Table 4-1 describes all elements composing the filename structure separately.

Table 4-1: Description of each element composing the filename.

Character	Meaning	CM-23811
PRO	Three-character coding of product type	LEH
t	Time interval of product	"h" for hourly, "d" for daily and "m" for monthly
s	Statistics	"m" for mean or "d" for mean diurnal cycle
yyyymmddhhmm	Date and time (lower boundary of the covered temporal interval). For monthly products (mm and md), the first day of the month (01) is used for "dd". The time value ("hhmm") is set to "0000" for daily and monthly products.	
Ver	Version number or release number	001
Gr	Grid	23
Sourc	Data source	10001
Lv	Level	01
Ar	Area	"MA"

[2] Available at: https://www.cmsaf.eu/EN/Products/NamingConvention/Naming_Convention_node.html

4.2 Dimensions

The NetCDF file contains the following dimensions as shown in Table 4-2.

Table 4-2: Dimensions used in the NetCDF files.

Name	Description
time	Number of data points along the time axis, i.e. time=1 for hourly, daily and monthly products and time=24 for monthly mean diurnal cycle product
lat	Number of data points along the latitude axis, i.e. lat=2600
lon	Number of data points along the longitude axis, i.e. lon=2600
bounds	Number of values needed to define time, latitude and longitude boundaries, i.e. bounds=2

4.3 General variables

Each NetCDF file contains the following general variables as shown in Table 4-3.

Table 4-3: Overview of general variables of NetCDF files and possible corresponding values.

Variable name (dimension)	Description
time (time)	Start of averaging/composite time period [seconds since 1970-01-01 00:00:00]
lat (lat)	Geographical latitude of grid-box center [degree_north]
lon (lon)	Geographical longitude of grid-box center [degree_east]
lat_bnds (lat, bounds)	Latitude grid cell boundaries
lon_bnds (lon, bounds)	Longitude grid cell boundaries
record_status (time)	Overall status of each record (timestamp) with values of: 0 (OK), 1 (void) and 2 (bad quality)
time_bnds (time, bounds)	Two-dimensional array defining the avering/composite time period [seconds since 1970-01-01 00:00:00]
SATID (time)	Spacecraft ID (unique number defined by MSGGS or GSDS or NORAD or COSPAR): 15=MFG-2; 16=MFG-3; 19=MFG-4; 20=MFG-5; 21=MFG-6; 22=MFG-7; 321=MSG-1; 322=MSG-2; 323=MSG-3; 324=MSG-4

4.4 Main variables

All NetCDF file contains the following main variables as shown in Table 4-4. They are all 3 dimensional (time, lat, lon) variables and provided on a regular latitude and longitude grid (0.05°).

Table 4-4: Overview of main variables of NetCDF files and units.

Variable name (dimension)	Description
LE (time, lat, lon)	Surface latent heat flux [W m^{-2}]
H (time, lat, lon)	Surface sensible heat flux [W m^{-2}]
G (time, lat, lon)	Ground heat flux [W m^{-2}]
ET (time, lat, lon)	Evapotranspiration [mm h^{-1} for hourly, mm day^{-1} for daily, mm mth^{-1} for monthly and monthly mean diurnal cycle]
Flag (time, lat, lon)	Flag values (0 or 1)*
LEH_NUMO (time, lat, lon)	Number of observations counted during the average period

*Quality flag value is set to 1 if some values have been interpolated during the post-processing (see detail in [RD 2]).

4.5 Global attributes

Table 4-5 contains the global attributes of the product files.

Table 4-5: Overview of global attributes of NetCDF files.

Name	Description / Value in CM-23811
title	Surface Radiation Flux (SRF)
summary	This file contains time space aggregated Thematic Climate Data Records (TCDR) of Latent and Sensible heat fluxes compiled by RMIB within the Satellite Application Facility on Climate Monitoring (CMSAF)
id	DOI:10.5676/EUM_SAF_CM/SLF_METEOSAT/V001
product_version	1.0
creator_name	BE/RMIB
creator_email	contact.cmsaf@dwd.de
creator_url	http://www.cmsaf.eu

institution	EUMETSAT/CMSAF
project	Satellite Application Facility on Climate Monitoring (CM SAF)
references	https://doi.org/10.5676/EUM_SAF_CM/SLF_METEOSAT/V001
keywords_vocabulary	GCMD Science Keywords, Version 8.6
keywords	EARTH SCIENCE > ATMOSPHERE > ATMOSPHERIC RADIATION > HEAT FLUX
Conventions	CF-1.7, ACDD-1.3
standard_name_vocabulary	Standard Name Table (v57, 11 July 2018)
date_created	ISO 8601:2004 Time when the NetCDF file was generated, as character string YYYY-MM-DDThh:mm:ss<zone> e.g. "202203-15T15:46:30Z"
date_modified	ISO 8601:2004 Time when the NetCDF file was modified, as character string YYYY-MM-DDThh:mm:ss<zone> e.g. "202203-15T15:46:30Z"
geospatial_lat_units	Degrees north
geospatial_lat_min	-65
geospatial_lat_max	65
geospatial_lat_resolution	0.05 degree
geospatial_lon_units	Degrees east
geospatial_lon_min	-65
geospatial_lon_max	65
geospatial_lon_resolution	0.05 degree
time_coverage_start	ISO 8601:2004 Start of the time period as character string YYYY-MM-DDThh:mm:ss<zone> e.g. "2014-04-05T00:00:00Z"
time_coverage_end	ISO 8601:2004 End of the time period as character string YYYYMM-DDThh:mm:ss<zone> e.g. "2014-04-06T00:00:00Z"
time_coverage_duration	PT1H for hourly, P1D for daily, P1M for monthly and monthly mean diurnal cycle
time_coverage_resolution	PT1H for hourly, P1D for daily, P1M for monthly and PT1H for monthly mean diurnal cycle
platform	Satellite i.e. MFG or MSG
platform_vocabulary	GCMD Platforms, Version 8.6
instrument	i.e. MVIRI or SEVIRI
instrument_vocabulary	GCMD Instruments, Version 8.6
variable_id	LE,H
license	The CM SAF data are owned by EUMETSAT and are available to all users free of charge and with no conditions to use. If you wish to use these products, EUMETSAT\'s copyright credit

	must be shown by displaying the words \"Copyright (c) (2022) EUMETSAT\" under/in each of these SAF Products used in a project or shown in a publication or website.\n\nPlease follow the citation guidelines given at https://doi.org/10.5676/EUM_SAF_CM/SLF_METEOSAT/V001 and also register as a user at http://cm-saf.eumetsat.int/ to receive latest information on CM SAF services and to get access to the CM SAF User Help Desk.
sources	CM-23271 : CM-23922 : ERA-5 : GLOBMAP (v3): ESA-CCI LC (v2.1.1)

5 Data ordering via the Web User Interface (WUI)

The internet address http://wui.cmsaf.eu/ allows direct access to the CM SAF data ordering interface. On this webpage a detailed description how to use the interface for product search and ordering is given. We refer the user to this description since it is the central and most up to date documentation. However, some of the key features and services are briefly described in the following sections.

Further user service including information and documentation about CM SAF and the CM SAF products are available from the CM SAF home page (http://www.cmsaf.eu/).

5.1 Product ordering process

You need to be registered and logged in to order products. A login is provided upon registration, all products are delivered free of charge (Please note the copyright disclaimer given in Section 7). After the selection of the product, the desired way of data transfer can be chosen. This is either via a temporary https account (the default setting), or email. Each order will be confirmed via email, and the user will get another email once the data have been prepared. If the https data transfer was selected, this second email will provide the information on how to access the https server.

5.2 Contact User Help Desk staff

In case of questions the contact information of the User Help Desk (e-mail address contact.cmsaf@dwd.de) are available via the CM SAF home webpage (http://www.cmsaf.eu/) or the home page of the Web User Interface (http://www.cmsaf.eu/).

5.3 User Problem Report

Users of CM SAF products and services are encouraged to provide feedback on the CM SAF products and services to the CM SAF team. Users can either contact the User Help Desk (see Section 5.2) or use the “User Problem Report” page. A link to the “User Problem Report” is available from either the CM SAF home page (http://www.cmsaf.eu/) or the Web User Interface (http://wui.cmsaf.eu/).

5.4 Service Messages / log of changes

Service messages and a log of changes are also accessible from the CM SAF homepage (http://www.cmsaf.eu/) and provide useful information on product status, versioning and known deficiencies.

6 Feedback

6.1 User feedback

Users of CM SAF products and services are encouraged to provide feedback on the CM SAF product and services to the CM SAF team. We are keen to learn of what use the CM SAF data are. So please feedback your experiences as well as your application area of the CM SAF data.

EUMETSAT CM SAF is a user driven service and is committed to consider the needs and requirements of its users in the planning for product improvements and additions. Please provide your feedback e.g. to our User Help Desk (e-mail address contact.cmsaf@dwd.de).

6.2 Specific requirements for future products

Beside your general feedback you are cordially invited to provide your specific requirements on future products for your applications. Please provide your requirements e.g. to our staff or via our User Help Desk (e-mail address contact.cmsaf@dwd.de).

6.3 User Workshops

CM SAF is organizing training workshops on a regular basis in order to facilitate the use of our data. Furthermore, through our regular (approximately every four years) user’s workshop we revisit our product baseline. Your participation in any of these workshops is highly appreciated. Please have a look at on the CM SAF home web page (http://www.cmsaf.eu/) to get the latest news on upcoming events.

7 Copyright and Disclaimer

The user of CM SAF data agrees to respect the following regulations:

7.1 Copyright

All intellectual property rights of the CM SAF products belong to EUMETSAT. The use of these products is granted to every interested user, free of charge. If you wish to use these products in publications, presentations, web pages etc., EUMETSAT's copyright credit must be shown by displaying the words "copyright (year) EUMETSAT" on each of the products used.

7.2 Acknowledgement and Identification

When exploiting EUMETSAT/CM SAF data you are kindly requested to acknowledge this contribution accordingly and make reference to the CM SAF, e.g. by stating "The work performed was done (i.a.) by using data from EUMETSAT's Satellite Application Facility on Climate Monitoring (CM SAF)". It is highly recommended to clearly identify the product version used. An effective way to do this is the citation of CM SAF data records via the digital object identifier (DOI). All information can be retrieved through (http://www.cmsaf.eu/DOI/). The DOI for this data set is provided on the title page of this document.

7.3 Re-distribution of CM SAF data

Please do not re-distribute CM SAF data to 3rd parties. The use of the CM SAF products is granted free of charge to every interested user, but we have an essential interest to know how many and what users the CM SAF has. This helps to ensure of the CM SAF operational services as well as its evolution according to user's needs and requirements. Each new user shall register at CM SAF in order to retrieve the data.

8 References

Albergel, C., Munier, S., Bocher, A., Bonan, B., Zheng, Y., Draper, C., ... & Calvet, J. C. (2018). LDAS-Monde sequential assimilation of satellite derived observations applied to the contiguous US: An ERA-5 driven reanalysis of the land surface variables. *Remote Sensing*, *10*(10), 1627.

Balsamo, G., Beljaars, A., Scipal, K., Viterbo, P., van den Hurk, B., Hirschi, M., & Betts, A. K. (2009). A revised hydrology for the ECMWF model: Verification from field site to terrestrial water storage and impact in the Integrated Forecast System. *Journal of hydrometeorology*, *10*(3), 623-643.

Behrendt, A., Wulfmeyer, V., Senff, C., Muppa, S. K., Späth, F., Lange, D., ... & Wieser, A. (2020). Observation of sensible and latent heat flux profiles with lidar. *Atmospheric Measurement Techniques*, *13*(6), 3221-3233.

Bontemps, S., Herold, M., Kooistra, L., Van Groenestijn, A., Hartley, A., Arino, O., Moreau, I., & Defourny, P. (2012). Revisiting land cover observation to address the needs of the climate modeling community. Biogeosciences, 9(6), doi:10.5194/bg-9-2145-2012
Bowen, I. S. (1926). The ratio of heat losses by conduction and by evaporation from any water surface. *Physical review*, *27*(6), 779.

ESA. Land Cover CCI Product User Guide Version 2. Tech. Rep. (2017). Available at: maps.elie.ucl.ac.be/CCI/viewer/download/ESACCI-LC-Ph2-PUGv2_2.0.pdf

Fennig, Karsten; Andersson, Axel; Bakan, Stephan; Klepp, Christian-Phillip; Schröder, Marc (2012): Hamburg Ocean Atmosphere Parameters and Fluxes from Satellite Data - HOAPS 3.2 - Monthly Means / 6-Hourly Composites, Satellite Application Facility on Climate Monitoring, DOI:10.5676/EUM_SAF_CM/HOAPS/V001, doi :10.5676/EUM_SAF_CM/HOAPS/V001.

Fisher, J. B., Melton, F., Middleton, E., Hain, C., Anderson, M., Allen, R., ... & Kilic, A. (2017). The future of evapotranspiration: Global requirements for ecosystem functioning, carbon and climate feedbacks, agricultural management, and water resources. Water Resources Research, 53(4), 2618-2626.

Gellens-Meulenberghs, F., Arboleda, A., & Ghilain, N. (2006, March). Status of development of the LSA–SAF evapotranspiration product. In Proc. 2nd LSA–SAF Training Workshop (pp. 8-10).

Gellens-Meulenberghs, F., Arboleda, A., & Ghailain, N. (2007). Towards a continuous monitoring of evapotranspiration based on MSG data. *IAHS PUBLICATION*, *316*, 228.

Guo, X., Meng, D., Chen, X., & Li, X. (2022). Validation and Comparison of Seven Land Surface Evapotranspiration Products in the Haihe River Basin, China. *Remote Sensing*, *14*(17), 4308.

Hersbach, H., Bell, B., Berrisford, P., Biavati, G., Dee, D., Horányi, A., ... & Vamborg, F. (2019, January). The ERA5 Global Atmospheric Reanalysis at ECMWF as a comprehensive dataset for climate data homogenization, climate variability, trends and extremes. In *Geophysical Research Abstracts* (Vol. 21).

Katul, G. G., Oren, R., Manzoni, S., Higgins, C., & Parlange, M. B. (2012). Evapotranspiration: a process driving mass transport and energy exchange in the soil-plant-atmosphere-climate system. Reviews of Geophysics, 50(3).

Liou, Y. A., & Kar, S. K. (2014). Evapotranspiration estimation with remote sensing and various surface energy balance algorithms—A review. Energies, 7(5), 2821-2849.

Liu, Y., Liu, R., & Chen, J. M. (2012). Retrospective retrieval of long-term consistent global leaf area index (1981–2011) from combined AVHRR and MODIS data. Journal of Geophysical Research: Biogeosciences, 117(G4), doi:10.1029/2012JG002084

Liu, Y., Liu, R., Pisek, J., & Chen, J. M. (2017). Separating overstory and understory leaf area indices for global needleleaf and deciduous broadleaf forests by fusion of MODIS and MISR data. Biogeosciences, 14(5), 1093, doi:10.5194/bg-14-1093-2017

Loew, A., Peng, J., & Borsche, M. (2016). High-resolution land surface fluxes from satellite and reanalysis data (HOLAPS v1. 0): evaluation and uncertainty assessment. *Geoscientific Model Development*, *9*(7), 2499-2532.

Martens, B., Miralles, D.G., Lievens, H., van der Schalie, R., de Jeu, R.A.M., Fernández-Prieto, D., Beck, H.E., Dorigo, W.A., & Verhoest, N.E.C. (2017). GLEAM v3: satellite-based land evaporation and root-zone soil moisture, Geoscientific Model Development, 10, 1903–1925.

Michel, D., Jiménez, C., Miralles, D. G., Jung, M., Hirschi, M., Ershadi, A., ... & Seneviratne, S. I. (2016). The WACMOS-ET project–Part 1: Tower-scale evaluation of four remote-sensing-based evapotranspiration algorithms. Hydrology and Earth System Sciences, 20(2), 803-822.

Mito, C. O., Boiyo, R. K., & Laneve, G. (2012). A simple algorithm to estimate sensible heat flux from remotely sensed MODIS data. International journal of remote sensing, 33(19), 6109-6121.

Oki, T., & Kanae, S. (2006). Global hydrological cycles and world water resources. science, 313(5790), 1068-1072.

Peng, J., Kharbouche, S., Muller, J. P., Danne, O., Blessing, S., Giering, R., ... & Dadson, S. (2020). Influences of leaf area index and albedo on estimating energy fluxes with HOLAPS framework. *Journal of Hydrology*, *580*, 124245.

Pipunic, R. C., Walker, J. P., & Western, A. (2008). Assimilation of remotely sensed data for improved latent and sensible heat flux prediction: A comparative synthetic study. Remote Sensing of Environment, 112(4), 1295-1305.

Schröder, M., Lockhoff, M., Forsythe, J. M., Cronk, H. Q., Vonder Haar, T. H., & Bennartz, R. (2016). The GEWEX water vapor assessment: Results from intercomparison, trend, and homogeneity analysis of total column water vapor. *Journal of Applied Meteorology and Climatology*, *55*(7), 1633-1649.

Sellers, P. J., Dickinson, R. E., Randall, D. A., Betts, A. K., Hall, F. G., Berry, J. A., ... & Sato, N. (1997). Modeling the exchanges of energy, water, and carbon between continents and the atmosphere. Science, 275(5299), 502-509.

Shan, N., Shi, Z., Yang, X., Zhang, X., Guo, H., Zhang, B., & Zhang, Z. (2016). Trends in potential evapotranspiration from 1960 to 2013 for a desertification-prone region of China. International Journal of Climatology, 36(10), 3434-3445.

Siemann, A. L., Chaney, N., & Wood, E. F. (2018). Development and validation of a long-term, global, terrestrial sensible heat flux dataset. *Journal of Climate*, *31*(15), 6073-6095.

Simard, M., Pinto, N., Fisher, J. B., & Baccini, A. (2011). Mapping forest canopy height globally with spaceborne lidar. *Journal of Geophysical Research: Biogeosciences*, *116*(G4), doi: 10.1029/2011JG001708

Trenberth, K. E., Fasullo, J. T., & Kiehl, J. (2009). Earth's global energy budget. Bulletin of the American Meteorological Society, 90(3), 311-324.

Van den Hurk, B. J. J. M., Viterbo, P., Beljaars, A. C. M., & Betts, A. K. (2000). Offline validation of the ERA40 surface scheme, ECMWF TechMemo 295. Reading, UK.

Viterbo, P., & Beljaars, A. C. (1995). An improved land surface parameterization scheme in the ECMWF model and its validation. Journal of climate, 8(11), 2716-2748, 10.1175/1520-0442(1995)008<2716:AILSPS>2.0.CO;2

Wang, H., & Li, D. (2011). Correlation of surface sensible heat flux in the arid region of northwestern China with the northern boundary of the East Asian summer monsoon and Chinese summer precipitation. Journal of Geophysical Research: Atmospheres, 116(D19).

Xin, Y., Liu, J., Liu, X., Liu, G., Cheng, X., & Chen, Y. (2022). Reduction of uncertainties in surface heat flux over the Tibetan Plateau from ERA-Interim to ERA5. *International Journal of Climatology*.

Yang, K., Qin, J., Guo, X., Zhou, D., & Ma, Y. (2009). Method development for estimating sensible heat flux over the Tibetan Plateau from CMA data. Journal of applied meteorology and climatology, 48(12), 2474-2486.

Zhang, X., Dai, Y., Cui, H., Dickinson, R. E., Zhu, S., Wei, N., ... & Fu, W. (2017). Evaluating common land model energy fluxes using FLUXNET data. *Advances in atmospheric Sciences*, *34*(9), 1035-1046.