EUMETSAT Satellite Application Facility on
Climate Monitoring

The EUMETSAT Network of Satellite Application Facilities

CM SAF
Climate Monitoring

Data Set Generation Capability Description Document

Meteosat Latent and Sensible heat fluxes Algorithm Edition 1.1

CM-23811

Reference Number:	SAF/CM/RMIB/DGCDD/MET/LEH/1.1
Issue/Revision Index:	1.1
Date:	16.06.2020

Document Signature Table

	Name	Function	Signature	Date
Author Approval	William Moutier	CM SAF scientist		
	Françoise Gellens-Meulenberghs	CM/LSA SAF Scientist		
	Alirio Arboleda	CM/LSA SAF Scientist		
	Miguel Barrios	CM/LSA SAF Scientist		
	Nicolas Ghilain	CM SAF Scientist		
	Nicolas Clerbaux	CM SAF Scientist		

Distribution List

Internal Distribution	
Name	No. Copies
DWD archive	1

External Distribution		
Company	Name	No. Copies
EUMETSAT		4

Non-public document
DRP: PF

Document Change Record

Issue/ Revision	Date	DCN No.	Changed Pages/Paragraphs
1.0	30.05.2020	SAF/CM/RMIB/DGCDD/MET/LEH/1	Draft
1.1	16.06.2020	SAF/CM/RMIB/DGCDD/MET/LEH/1.1	Revised after comments from CMSAF operation team

Table of Contents

List of appendices

List of figures

List of tables

1

1. Introduction

1.1. Purpose

The major purpose of the Data set Generation Capability Description Document (DGCDD) is to describe the general design of the processing chain for the sensible and latent heat fluxes and the evapotranspiration (CM-23811) retrieval and to specify the system in terms of all hardware and software components.

1.1.1. Applicable Documents

Reference	Title	Code
AD 1	CM SAF Product Requirements Document	SAF/CM/DWD/PRD/3.5

1.1.2. Reference Documents

Reference	Title	Code
RD 1	Algorithm Theoretical Basis Document Meteosat Latent and Sensible Heat fluxes Edition 1	SAF/CM/RMI/ATBD/MET/LEH/1
RD 2	Algorithm Theoretical Basis Document. Meteosat Surface Radiative Balance Edition 1	SAF/CM/MeteoSwiss/ATBD/MET/SRB/1
RD 3	Algorithm Theoretical Basis Document. Meteosat Land Surface Temperature Edition 2	SAF/CM/MeteoSwiss/ATBD/MET/LST/2
RD 4	Data Set Generation Capability Description DocumentGeoSatClim Edition 2	SAF/CM/MeteoSwiss/DGCDD/GeoSatClim

2 General Description

2.1 System Overview

This CM SAF Data set Generation Capability Description Document (DGCDD) describes the processing chain implemented for generating the CM SAF latent (Evapotranspiration) and sensible heat fluxes TCDR (product id. CM-23811; RD1).

The document also provides information on the hardware and software environment used to construct the dataset. The list of all parameters calculated with the algorithm is shown in Table 1. An overview of the system and its context is provided as a flow diagram in Figure 1.

Table 1: List of TCDRs from the algorithm

Product-Identifier	Product Name	Product acronym	Characteristics and Methods	availability
CM-23811	Latent heat flux	LE (W/m²)	Hourly means, daily means, monthly means and and monthly mean diurnal cycle	1983-2020
CM-23811	Sensible heat flux	H (W/m²)	hourly means, daily means, monthly means and and monthly mean diurnal cycle	1983-2020
CM-23811	Evapotranspiration	ET (mm)	Hourly, daily, monthly, and monthly diurnal cycle accumulated	1983-2020

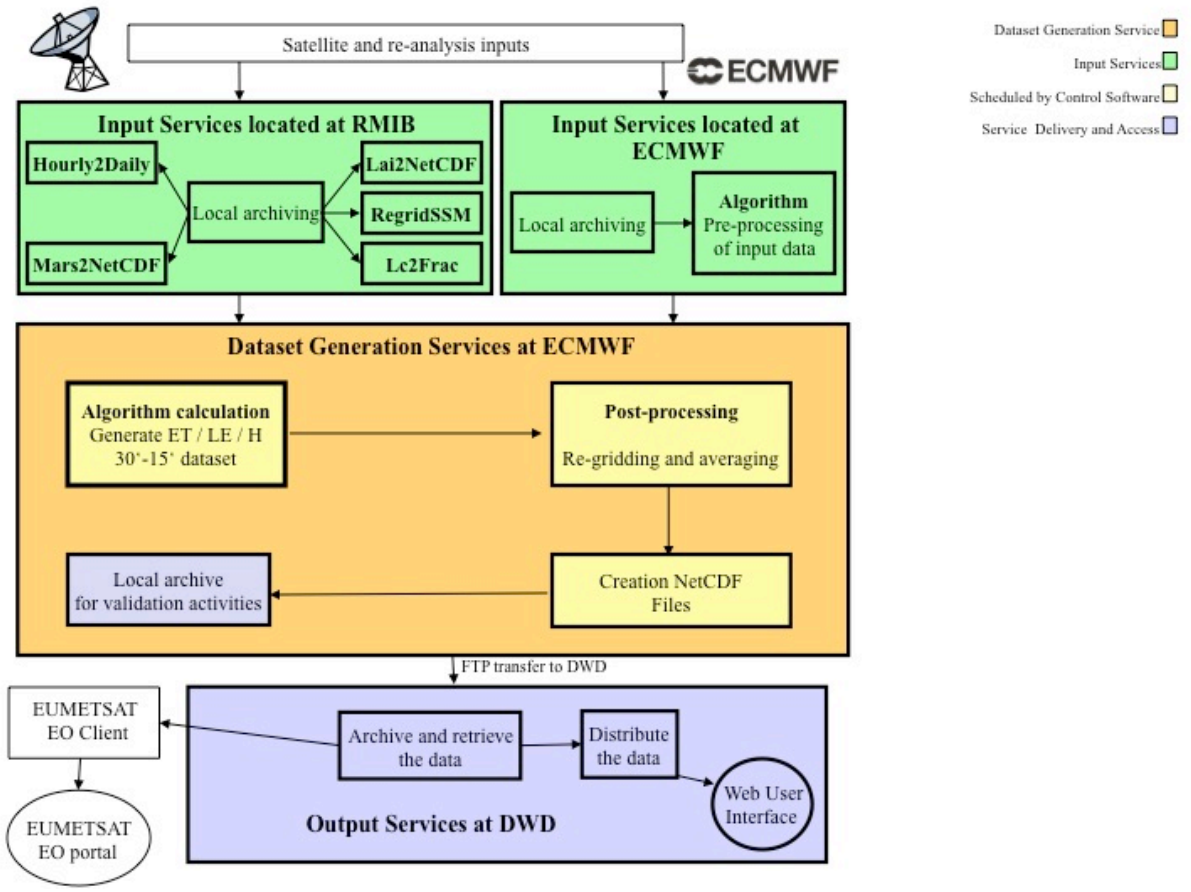

Figure 1: System architecture for the algorithm Processing

2.2 System context

The up-stream pre-processing, the pre-processing, the algorithm and, the post-processing are designed to configure, build and run on the Unix operating system. The up-stream pre-processing is executed at RMIB and the rest at the European Centre for Medium Weather Forecasting (ECMWF) high performance computing (HPC) environment.

2.3 Hardware system configuration

The main LE/H processing takes place on the ECMWF CCA Cray XC30 HPC architecture (https://software.ecmwf.int/wiki/display/UDOC/HPCF).

2.4 Requirements and system performance

Data inputs pre-processing at RMIB are made using 8 CPU cores and 32 GB of memory. User time needed to process one file is of 1s for Mars2NetCDF, less than 2s for Hourly2Daily, 9s (MFG grid) - 5s (MSG grid) for LAI2NetCDF, 7.4s (MFG grid) - 4.2s (MSG grid) for RegridSSM and 4h (MFG grid) – 3h40 (MSG grid) for LC2Frac.

The LE/H processing is executed using 1024 cores and 500 GB of memory (500 MB per core). It can process an image within less than 2 minutes of wall time. This includes reading input data and writing output data but does not include retrieving input data from the archive and archiving of the output data. The code can be run in parallel to process the full dataset in reasonable time.

2.5 System Design

2.5.1 System Decomposition

This section describes input data, components and the processing concept. Please note that all input datasets will be updated in case of extension of them (e.g 2019-2020).

2.5.2 Input data description

2.5.2.1 Input satellite product

Surface Incoming Shortwave radiation (SIS; CM-23271; RD2), Surface Downward Longwave radiation (SDL; CM-23271; RD2), Surface Albedo (SAL; CM-23271; RD2) and Land Surface Temperature and emissivity (LST and; CM-23922; RD3) are used. The Called the Combined ASTER MODIS Emissivity over Land (CAMEL) Emissivity (ε) database is used. A detailed description of the CAMEL Database is provided in Feltz et al. (2018).
During the MFG period, they are provided as images of 5000 x 5000 pixels at a spatial resolution of 2.5 km x 2.5 km every 30 min. MSG images are composed of 3712 x 3712 pixels at a spatial resolution of 3 km at nadir every 15 min. All data are stored at the ECMWF ECFS archiving system.

2.5.2.2 Meteorological data from re-analysis

Hourly 2 m air temperature (Ta), 2 metre dew-point temperature (Td), 10 m wind speed (U, V), mean sea level pressure (MSL), soil type (SLT), soil temperature level (1 to 4; stl_l), volumetric soil water content layer (1 to 4; $swvl_l$) and geopotential of ERA5 Re-Analysis are required (Hersbach & Dee 2016). They are extracted from ECMWF MARS with latitude and longitude grid limits of [-79.875°; 79.875°] and a spatial resolution of 0.25°.

2.5.2.3 Land cover

We used the European Spatial Agency (ESA) Climate Change Initiative Land Cover (CCI-LC,) climate data record (Bontemps et al., 2012). The land cover map product is provided globally from 1992 to 2019 at 300m/yearly spatial-temporal resolutions in a Plate Carrée projection. Versions 2.0.7 and 2.1.1 are used for the period 1992-2015 and 2016-2019 respectively. Data for 2020 will be incorporated before processing just after the release of them.

2.5.2.4 Leaf area index

The long term Global Mapping (GLOBMAP) LAI Version 3 dataset has been chosen. It has been generated by the Chinese Academy of Sciences, providing half-month (during 1981-2000) or 8 days (during 2001-2019) LAI values over a 35 years' period (1981-2019) with a spatial resolution of 0.08° (~ 8km) (Liu et al. (2012, 2017)). Data for 2020 will be incorporated before processing just after the release of them.

2.5.2.5 Surface soil moisture from ESA-CCI SSM

The European Space Agency multi-decadal global satellite soil moisture (ESA-CCI SSM) dataset has been used. The "*COMBINED"* product (v201912.0.0 while downloading from climate data store), merging soil moisture estimations from active and passive microwave sensors has been selected (Liu et al., 2011; Dorigo et al., 2015, 2017; Wagner et al., 2012). It provides daily surface soil moisture values with a spatial resolution of 0.25° and

covers the period 1978-2019. Data for 2020 will be incorporated before processing just after the release of them.

2.5.2.6 Tree height

Tree height (h_{tree}, m) is a static map over the MFG and MSG period, derived from the global 1km forest canopy height developed at NASA/JPL. This global canopy height map was created using 2005 data from the Geoscience Laser Altimeter System (GLAS) aboard ICESat (Ice, Cloud, and land Elevation Satellite) (Simard et al. 2011). Basically, based on 1 km data, average canopy height has been calculated for each MFG/MSG pixel.

2.5.3 Components description

2.5.3.1 Up- stream pre-processing

Mars2NetCDF

This program convert the ERA5 grib file downloaded from the ECMWF MARS to NetCDF and writes hourly NetCDF files per variable for later use during the main processing. This program consists of a set of shell, python and cdo calls. Please note that this program is different than the one in RD 4 where the name is similar.

Hourly2Daily

This stand-alone python program read hourly ERA5 data and averages them to get daily data. They are then save in NetCDF format.

Lai2NetCDF

This stand-alone C program reads the original LAI data in hdf5 files and re-projects data from Plate-Carrée with a Geographic Lat/Lon representation (GCTP_GEO) at 0.08° resolution (~ 8km) to the Meteosat grid (at the MVIRI VIS or SEVIRI spatial resolution) and writes a NetCDF files for later use.

Lc2Frac

This shell script uses first the ESA-CCI user toolbox (v 3.14) to extract a subset area and convert land cover classes from the Land Cover Classification System to the classes used in the main algorithm. Second, a C program allows a sub-division of each MFG/MSG pixel in 4 tiles to get their surface types and to calculate the area fractions of each one.

RegridSSM

This stand-alone C program reads the original ESA CCI soil moisture data files and re-projects data from regular 0.25°x0.25° Lat/Lon grid to the Meteosat grid (at the MVIRI VIS or SEVIRI spatial resolution) and writes a NetCDF files for later use.

2.5.3.2 Data transfer and access

The up-stream pre-processing of ESA Land Cover, ESA-CCI SSM, meteorological data and LAI data are made at RMIB and then transferred to the ECMWF scratch directory and in the ECMWF archive. The tree height files are copied to the ECMWF scratch directory as

well. MeteoSat satellite products (RD 2 and 3) are available in ECMWF scratch directory and in the ECMWF archive after processing of GeoSatClim which is made in a first step (RD 4). Those later, are directly read by the main code, during the process, at ECMWF.

2.5.3.3 Algorithm

To minimize I/O while keeping a good ratio between data storage and processing time, the main code (algorithm) is subdivided in two parts: a pre-processing part and a processing part.

Pre-Processing

This part of the program includes the (bi-linear) re-projection and the (linear) temporal interpolation of ERA5 each time step and extrapolation of daily LAI values thanks to a Gaussian filter approach.

Main Processing

This is the main executable, which processes input data and, retrieves all downstream physical variables.

The main programme handles the input data in that way:

1. reading configuration file (requested period, input/output paths, various table of static inputs and limit conditions for the iteration process),
2. reading of static (topography, land/sea mask, tree height, grid limits) and dynamic (ECMWF Re-Analysis data) data,
3. reading satellite data (LST, SIS, SDL, albedo, emissivity, surface soil moisture, land cover and fraction of each tile),
4. reading (or calculating if not available) daily average soil moisture from ERA5 data and daily LAI data,
5. writing to a single daily NetCDF file containing daily average soil moisture calculating from ERA5 data and LAI data (if does not already exist),
6. calculating average soil moisture from the LST,
7. correcting the temperatures for the topography,
8. calculating LAI of each tile, estimate wind speed and relative humidity values,
9. calculating LE, ET and H by applying the mathematical approach (this is the core part of the retrieval which is fully detailed in RD1),
10. writing to a single monthly NetCDF file containing all variables and time steps (15 / 30 min).

Post Processing

During the post processing, three C programs (that include cdo calls) are executed for each month to average and re-project the LE, H and ET values. First, based on instantaneous sensible and latent heat fluxes , the hourly mean, daily mean, monthly mean and mean diurnal cycle are calculated and stored in NetCDF files (Figure 2). Second, based on the instantaneous evapotranspiration products, the hourly accumulated, daily accumulated, monthly accumulated and accumulated diurnal cycle are calculated and stored in NetCDF files (Figure 3).
Finally, a third program is executed to re-project the data on the finale lat-lon grid and generates the finale NetCDF files. These steps are illustrated in Figures 2 and 3. The programs LEH_averaging, ET_ accumulation and LEHET_regridding do those processing.

The post processed outputs data are transferred to the ECFS and to the DWD for integration in the WUI.

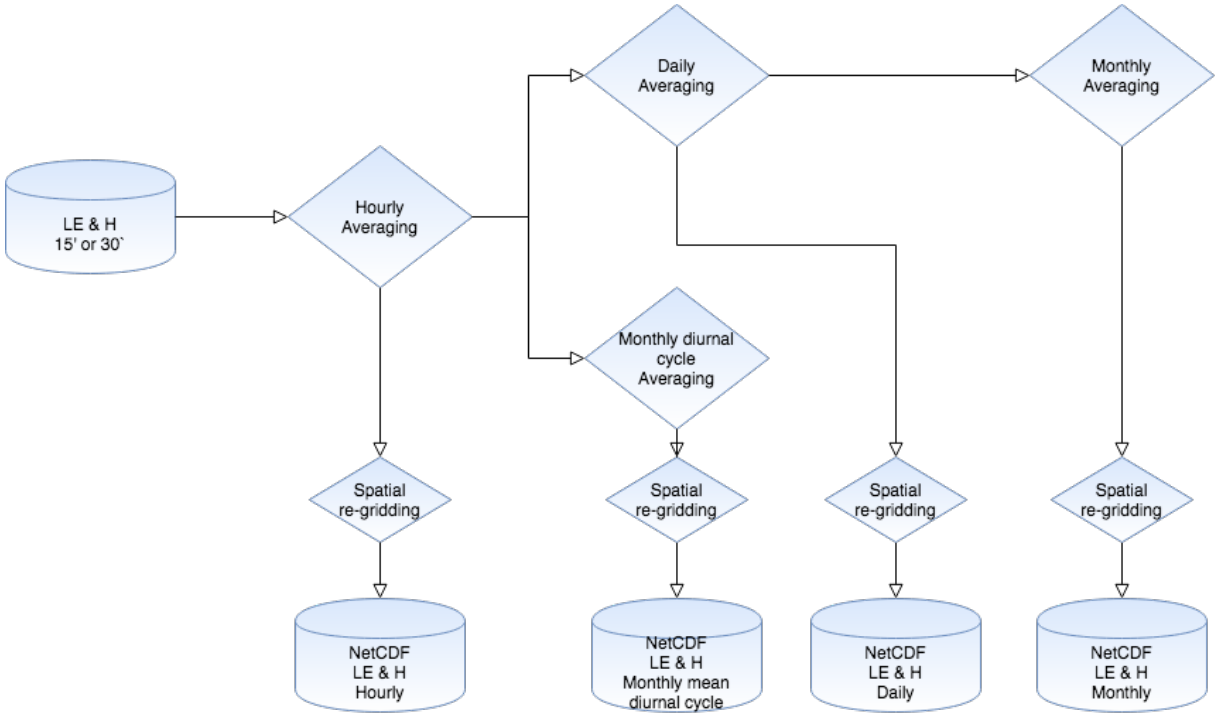

Figure 2: Flowchart for the hourly, daily and monthly mean, monthly mean diurnal cycle and, spatial re-gridding for sensible and latent heat fluxes datasets.

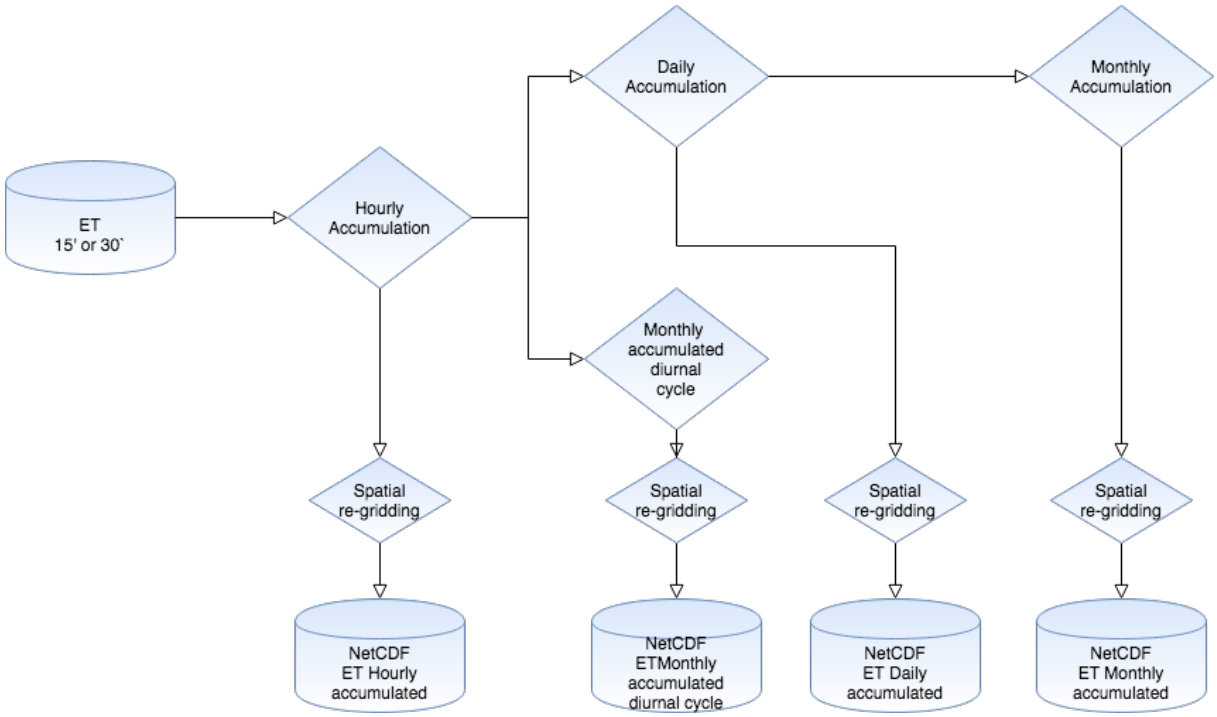

Figure 3: **Flowchart for the hourly, daily and monthly accumulation, monthly accumulated diurnal cycle and, spatial re-gridding for evapotranspiration dataset.**

3 Software configuration at RMIB

For the pre-processing the user toolbox (V 3.14) is needed and standard compilers (gcc version 7.5.0), C libraries (glibc-2.26), make tools (version 3.82), are used.

The NetCDF files are created using version 4.2.1 of the library that is linked on the HDF-5 library (version 1.8.10). The default configuration for the internal NetCDF compression is used. The software version control system is made with git on local RMIB server (htttps://gitlab-me.oma.be/).

4 Hardware configuration for up-stream preprocessing at RMIB

The up-stream preprocessing is made on local machine: 8 cores (4Ghz), 32 Gb of memory. The operating system is OpenSuSE 15.1 64bits.

The “tsunami” fileserver is used for the local archiving of the input data used for the up-stream pre-processing. This fileserver is a glusterfs distributed and redundant cluster network storage across 3 pairs of physical fileservers.

5 References

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

Feltz, M., Borbas, E., Knuteson, R., Hulley, G., & Hook, S. (2018). The Combined ASTER and MODIS Emissivity over Land (CAMEL) Global Broadband Infrared Emissivity Product. Remote Sensing, 10(7), 1027.

Dorigo, W. A., Gruber, A., De Jeu, R. A. M., Wagner, W., Stacke, T., Loew, A., ... & Kidd, R. (2015). Evaluation of the ESA CCI soil moisture product using ground-based observations. Remote Sensing of Environment, 162, 380-395, doi:10.1016/j.rse.2014.07.023

Dorigo, W., Wagner, W., Albergel, C., Albrecht, F., Balsamo, G., Brocca, L., ... & Haas, E. (2017). ESA CCI Soil Moisture for improved Earth system understanding: State-of-the art and future directions. Remote Sensing of Environment, 203, 185-215, doi:10.1016/j.rse.2017.07.001

Hersbach, H., & Dee, D. (2016). ERA5 reanalysis is in production, ECMWF Newsletter 147, ECMWF. Reading, UK.

Liu, Y. Y., Parinussa, R. M., Dorigo, W. A., De Jeu, R. A., Wagner, W., Van Dijk, A.,

... & Evans, J. (2011). Developing an improved soil moisture dataset by blending passive and active microwave satellite-based retrievals, doi:10.5194/hess-15-425-2011

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

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

Wagner, W., Dorigo, W., de Jeu, R., Fernandez, D., Benveniste, J., Haas, E., & Ertl, M. (2012). Fusion of active and passive microwave observations to create an essential climate variable data record on soil moisture. ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences (ISPRS Annals), 7, 315-321.

6 Appendices

Annex 1: List of abbreviations and Acronyms

Abbreviation	Meaning
AD	Applicable Document
ATBD	Algorithm Theoretical Basis Document
CCA	Cluster of ECMWF's HPCF
CAMEL	Called the Combined ASTER MODIS Emissivity over Land
CDO	Climate Data Operators
CDR	Climate Data Record
CM	Climate Monitoring
CM SAF	Satellite Application Facility on Climate Monitoring
DGCDD	Data set Generation Capability Description Document
DWD	Deutscher Wetterdienst
ECFS	ECMWF's File Storage system
ECMWF	European Centre for Medium-Range Weather Forecasts
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

Abbreviation	Meaning
FCDR	Fundamental Climate Data Record
GCTP_GEO	General Cartographic Transformation Package _ Geographic
GLOBMAP	Global Mapping
GLAS	Geoscience Laser Altimeter System
GNU	GNU operating system, software license and components
H	Sensible heat flux
HDF	Hierarchical Data Format
HPC	High Performance Computing
ICESat	Ice, Cloud, and land Elevation Satellite
JPL	Jet Propulsion Laboratory
LAI	Leaf Area Index
LC	Land Cover
LE	Latent heat flux
LST	Land Surface Temperature
MARS	Meteorological Archival and Retrieval System
METEOSAT	Meteorological Satellite(s) series operated by EUMETSAT
MFG	METEOSAT First Generation
MSG	Meteosat Second Generation
MSL	Mean sea level pressure
MVIRI	METEOSAT Visible and Infrared Imager
NASA	National Aeronautics and Space Administration
NetCDF	Network Common Data Format
PBS	Portable Batch System
POE	Parallel Operating Environment
RD	Reference Document
RMIB	Royal Meteorological Institute of Belgium
SAF	Satellite Application Facility
SAL	Surface Albedo
SDL	Surface Downward Longwave radiation
SEVIRI	Spinning Enhanced Visible and Infrared Imager
SIS	Surface Incoming Solar radiation
SSM	Surface Soil Moisture
USGS	U.S. Geological Survey
WUI	Web User Interface (CM SAF)