EUMETSAT Satellite Application Facility on Climate Monitoring

Product User Manual SSM/I and SSMIS data record products

HOAPS version 4.0

Precipitation	CM-12611 (PRE_HOAPS)
Vertically Integrated Water Vapour	CM-12701 (HTW_HOAPS)
Evaporation	CM-12801 (EVA_HOAPS)
Latent Heat Flux	CM-12811 (LHF_HOAPS)
Freshwater Flux	CM-12821 (EMP_HOAPS)
Near Surface Specific Humidity	CM-12901 (NSH_HOAPS)
Near Surface Wind Speed	CM-12911 (SWS_HOAPS)

Reference Number:	SAF/CM/DWD/PUM/HOAPS/2
Issue/Revision Index:	1.1
Date:	31.01.2017

Document Signature Table

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Distribution List

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PUBLIC		1

Document Change Record

Issue/ Revision	Date	DCN No.	Changed Pages/Paragraphs
1.0	14/11/2016	SAF/CM/DWD/PUM/HOAPS/2	Submitted to review.
1,1	31/01/2017	SAF/CM/DWD/PUM/HOAPS/2	RID answers from DRR 2.7 implemented

Applicable Documents

Reference	Title	Code
AD 1	Memorandum of Understanding between CM SAF and the Max-Planck Institute for Meteorology and Meteorological Institute, University of Hamburg	
AD 2	CM SAF Product Requirements Document	SAF/CM/DWD/PRD/2.9
AD 3	Cooperation Agreement	

Reference Documents

Reference	Title	Code
RD 1	Validation Report SSM/I and SSMIS Products HOAPS version 4.0	SAF/CM/VAL/HOAPS/2/1.2
RD 2	Algorithm Theoretical Baseline Document HOAPS version 4.0	SAF/CM/DWD/ATBD/HOAPS/2/2.3
RD 3	Algorithm Theoretical Basis Document HOAPS version 3.2	SAF/CM/DWD/ATBD/HOAPS/1.1
RD 4	Diverse profile datasets from the ECMWF 91-level short-range forecasts	NWPSAF-EC-TR-010 v1

Acronyms and Definitions

Table 1: List of acronyms and definitions.

Symbol	Comment
1D-Var	1 Dimensional Variational
AD	Applicable Document
AFGWC	Air Force Global Weather Center
AMSR-E	Advanced Microwave Scanning Radiometer – Earth Observing System
AMSU	Advanced Microwave Sounding Unit
ARC	ATSR Reprocessing for Climate
ATBD	Algorithm Theoretical Baseline Document
ATSR	Along Track Scanning Radiometer
AVHRR	Advanced Very High Resolution Radiometer
CDO	Climate Data Operators
CDOP	Continuous Development and Operations Phase
CERA	Climate and Environmental Climate and Archive
CF	Climate and Forecast
CM SAF	Satellite Application Facility on Climate Monitoring
COARE	Coupled Ocean Atmosphere Response Experiment
DFG	Deutsche Forschungsgemeinschaft
DMSP	Defense Meteorological Satellite Program
DRI	Delivery Readiness Inspection
DRR	Delivery Readiness Review
DWD	Deutscher Wetterdienst (German MetService)
ECMWF	European Centre for Medium Range Forecast
ECV	Essential Climate Variable

Symbol	Comment
EPS	European Polar System
ESA CCI	European Space Agency Climate Change Initiative
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
FASTEM	Fast Microwave Ocean Emissivity Model
FCDR	Fundamental Climate Data Record
FMI	Finnish Meteorological Institute
FNMOC	Fleet Numerical Meteorology and Oceanography Center
FOV	Field of view
GCOS	Global Climate Observing System
GNU	GNU's Not Unix
GPL	GNU General Public License
HOAPS-C	HOAPS Composite product
HOAPS-G	HOAPS Gridded product
HOAPS-S	HOAPS Scan product
HOAPS	The Hamburg Ocean Atmosphere Fluxes and Parameters from Satellite data
KNMI	Koninklijk Nederlands Meteorologisch Institut
MPI	Max-Planck Institute for Meteorology
MSG	Meteosat Second Generation
NASA	National Aeronautics and Space Administration

Symbol	Comment
NetCDF	Network Common Data Format
NMHSs	National Meteorological and Hydrological Services
NOAA	National Oceanic & Atmospheric Administration
NWP	Numerical Weather Prediction
OSTIA	Operational Sea Surface Temperature and Sea Ice Analysis
PRD	Product Requirement Document
PUM	Product User Manual
RD	Reference Document
RID	Review Item Discrepancy
RMIB	Royal Meteorological Institute of Belgium
RTTOV	Radiative Transfer for TOVS
RSMAS	Rosenstiel School of Marine and Atmospheric Science
SAF	Satellite Application Facility
SEAFLUX	Ocean Surface Turbulent Flux Project
SFB	Sonderforschungs Bereich
SMHI	Swedish Meteorological and Hydrological Institute
SSM/I	Special Sensor Microwave Imager
SSMIS	Special Sensor Microwave Imager Sounder
SST	Sea Surface Temperature
TB	Brightness Temperature
TCWV	Total Column Water Vapour
TIROS	Television Infrared Observation Satellites
TOVS	TIROS Operational Vertical Sounder
WDCC	World Data Center for Climate
WGS 84	World Geodetic System 1984

Symbol	Comment
WMO	World Meteorological Organization
WOCE	World Ocean Circulation Experiment

Table of Contents

List of Tables

1 Introduction

This Product User Manual provides information on the Satellite Application Facility (CM SAF) Hamburg Ocean-Atmosphere Parameters and Fluxes from Satellite Data (HOAPS) version 4.0 data record. The data record is derived from Special Sensor Microwave/Imager (SSM/I) observations onboard Defense Meteorological Satellite Program (DMSP) platforms F08, F10, F11, F13, F14 and F15 and from Special Sensor Microwave Imager/Sounder (SSMIS) observations onboard DMSP platforms F16, F17 and F18. Additionally sea surface temperature (SST) data derived from Advanced Very High Resolution Radiometer (AVHRR) measurements is used (Reynolds et al., 2007; Reynolds, 2009). HOAPS-4.0 includes latent heat flux, evaporation, precipitation, freshwater flux, near surface specific humidity, wind speed and total column water vapour. The latent heat flux retrieval utilizes the COARE aerodynamic bulk flux algorithm after Fairall et al. (1996, 2003) and depends on satellite derived input parameters from the HOAPS data record.

After an introduction to CM SAF this manual briefly describes the HOAPS data record and the current and upcoming versioning for HOAPS products. The product names for the HOAPS parameters are heritage from previous HOAPS releases. The CF-convention (Climate and Forecast) names are included in the attributes of the netCDF-files as well. A technical description of the data records including information on the file format as well as on the data access is provided in section 5 and 6. Furthermore details on the implementation of the retrieval processing chain, and individual algorithm descriptions are available in the Algorithm Theoretical Baseline Document [[RD 2]. Basic accuracy requirements are defined in the product requirements document [AD 1]. A detailed validation of the HOAPS based parameters is available in the Validation Report [RD 1].

1.1 The EUMETSAT SAF on Climate Monitoring (CM SAF)

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 centre, 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 Meteorological Service of Switzerland (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 records is pursued. The ultimate aim is to make the resulting data records 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.

The CM SAF data records can serve applications related to the 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 records 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 records also serve the improvement of climate models both at global and regional scale.

A catalogue of all available CM SAF products is accessible via the CM SAF webpage, http://www.cmsaf.eu/. Here, detailed information about product ordering, add-on tools, sample programs and documentation is provided.

2   Historical overview of the HOAPS data record

Starting in 1987, several groups at the Max-Planck Institute for Meteorology (MPI-M) and the University of Hamburg (UniHH) have been developing retrievals based on microwave observations. The spectral characteristics (resolution and polarization) of the SSM/I instrument channels (Hollinger et al., 1987) allow the derivation of a number of atmospheric and near-surface parameters. The SSM/I instrument is carried among others on the polar orbiting DMSP satellites. The independently developed retrievals were incorporated in a data record, which was named the "**H**amburg **O**cean-**A**tmosphere **P**arameters and Fluxes from **S**atellite Data" (HOAPS). This project was part of the special research initiative on Cyclones and the North Atlantic Climate System (SFB512) funded by Deutsche Forschungsgemeinschaft (DFG).

Table 2: Overview over HOAPS versioning and availability.

CM SAF Version	Year	Publisher	Comment	Available at
1	1998	MPI-M / UniHH	First version	http://cera-www.dkrz.de/CERA/ http://www.hoaps.org/
2	2006	MPI-M / UniHH	New retrievals, including homogenisation, Major software re-design	http://cera-www.dkrz.de/CERA/ http://www.hoaps.org/
3	2007	MPI-M / UniHH	Precipitation retrieval update, new SST data record	http://cera-www.dkrz.de/CERA/ http://www.hoaps.org/
3.1	2009	CM SAF	WVPA only, including error estimates	http://www.cmsaf.eu/
3.2	2010	CM SAF	Latent heat flux, evaporation, precpitation, freshwater flux, near surface specific humidity and wind speed; extended temporal coverage	http://www.cmsaf.eu/
4	2017	CM SAF	Latent heat flux, evaporation, precpitation, freshwater flux, near surface specific humidity and wind speed, total column water vapour; error information for LHF and related parameters; extended temporal coverage into SSMIS era; change to 1D-Var retrieval; use of latest CM SAF SSM/IS FCDR	http://www.cmsaf.eu/
4.1	2021	CM SAF	planned; extended temporal coverage; consideration of data from additional microwave imagers	

The version 1 of the HOAPS data record was released in 1998 (Schulz et al., 1998; Jost et al., 2002) and contained the HOAPS parameters, which were derived from a non-homogenized radiance time series from the first SSM/I instruments. Comparisons with other ocean surface turbulent flux data records within the SEAFLUX project (Kubota et al., 2003; Chou et al., 2004; Curry et al., 2004) indicated that the evaporation in the first HOAPS version was biased substantially low in the tropics. The second version, HOAPS II (Fennig et al., 2006a,b), was available since mid 2004. It included major improvements, such as the concurrent use of all available SSM/I instruments up to December 2002 including inter-calibration and improved algorithms to derive sea surface flux parameters. Further comparisons revealed however, that the global mean precipitation in HOAPS II was significantly lower compared to other climatologies, resulting in an implausibly large global net ocean surface freshwater flux into the atmosphere on the climatological scale. This and a few other issues led to the development of the version 3 of HOAPS (Andersson et al., 2007a,b,c, 2010). The key features and major changes of each version of HOAPS are listed in Table 2.

In 2007, a memorandum of understanding was signed between MPI-M, UniHH and CM SAF to ensure the continuous production, prolongation and development of the HOAPS data record within CM SAF's CDOP [AD 1]. The first parameter from the HOAPS data record released from CM SAF was the total column water vapour data record (CM-127, Jonas et al., 2009; Schröder et al., 2013). This version is referred to as HOAPS version 3.1.

For the version 3.2 (Fennig et al., 2012), the time series of HOAPS-3 has been continued to make use of all available SSM/I data until the end of 2008. The retrieval schemes have not been changed, but the homogenisation of the radiance time series has been improved. It is the implementation of the HOAPS parameters at CM SAF. The version is thus called version 3.2 to indicate that it is not a major new version.

HOAPS version 4.0 is based on updated input data, i.e., the CM SAF SSM/I and SSMIS FCDR (CM-12002) and thus now also includes data from SSMIS, and a new retrieval scheme for TCWV (total column water vapour) and near surface wind speed. Uncertainty estimates are provided for parameters related to LHF. This version is thus a major new revision, carrying version number 4 and onwards. A list of all HOAPS parameters and those released by CM SAF is available in Table 3 in Appendix A.

In a future update the data source for the HOAPS version 4.1 will be extended using measurements of other microwave imager instruments such as AMSR-E.

3   Product definitions

The CM SAF HOAPS data record from SSM/I and SSMIS provides quasi-global coverage over the ice-free ocean surface, i.e., within ±180° longitude and ±80° latitude. Instantaneous SSM/I and SSMIS retrievals at original swath level are used to derive the spatio-temporal averaged data records. The products are available as 6-hourly composites and monthly averages on a regular latitude/longitude grid (equal angle grid) with a spatial resolution of $0.5° \times 0.5°$ degrees. The World Geodetic System 1984 (WGS 84) is used as geodetic reference of coordinates. Grid information refers to the grid centre and time information refers to the start of averaging period in days since 1 January 1987. The temporal coverage of the data records ranges from 9th of July 1987 to 31st of December 2014.

The products covered by this document are:

- Precipitation (*rain, mm/d*, CM-12611)

- Vertically Integrated Water Vapour (*wvpa, kg/m^2*, CM-12701)
- Evaporation (*evap, mm/d*, CM-12801)
- Latent Heat Flux (*late, W/m^2*, CM-12811)
- Freshwater Flux (*budg, mm/d*, CM-12821)
- Near Surface Specific Humidity (*hair, g/kg*, CM-12901)
- Near Surface Wind Speed (*wind, m/s*, CM-12911)

Given in brackets are the parameter names as they appear in the netCDF files (see Table 2 in Appendix A), the units and the CM SAF product ID.

An overview of format, metadata, parameter list and attributes is given in sections 5 and tables in Appendix A.

The product is not available over land and sea-ice surfaces. To avoid any contamination of the data by the abrupt change in surface emissivity between water and land or sea ice covered areas, no geophysical parameters are derived within 50 km of any coastline and sea ice margin (Andersson et al., 2010). All parameters except precipitation are not retrieved in presence of strong scattering such as during strong precipitation. Assumptions and limitations are given in section 3.2 and in RD 2 (section 3.4) as well as validation results are provided in RD 1(summary in section 1).

3.1   Parameter Retrievals

3.1.1   Near surface wind speed and total column water vapour

One of the major improvements in HOAPS 4.0 is the implementation and improvement of a 1D-Var retrieval developed by the NWP SAF and the estimation of uncertainty for evaporation and related parameters. The NWP SAF initially provided three 1D-Var software packages whereat the current version of the NWP SAF 1D-Var (version 1.0, made available in August 2014, http://nwpsaf.eu/site/software/1d-var/) contains the merged capabilities of the previously developed MetOffice, SSMIS and ECMWF 1D-Var schemes. The NWP SAF MetOffice 1D-Var is a variational method that is applied for the retrieval of the HOAPS 4.0 parameters TCWV and near surface wind speed. The SSMIS 1D-Var is a stand-alone 1D-Var scheme for SSM/I, SSMIS and AMSU (Deblonde, 2002) which was originally developed by Phalippou (1996) for SSM/I. Also using elements of the SSMIS 1D-Var the MetOffice 1D-Var retrieval was adapted to the processing of SSM/I and SSMIS data by CM SAF utilizing the microwave imager channels from the CM SAF FCDR. The HOAPS 1D-Var retrieval is an implementation of the NWP SAF MetOffice package with adaption for the processing chain and the extension to handle hydrometeor profiles in precipitating scenes by using the radiative-transfer (model) for TOVS (RTTOV) scattering module as the forward operator (Bauer et al., 2006 and Saunders et al., 2013).

In a variational retrieval the a-priori or background information of the atmosphere and surface, and the measurements (observed brightness temperatures) are combined in a statistically optimal way to estimate the most probable atmospheric state. The retrieval requires a background profile as input to derive a first guess of atmospheric state. This background profile is selected by a Bayesian selection approach from a predefined data base [RD 4].

The geophysical variables from the first guess are mapped into radiance space with the help of RTTOV. RTTOV includes a fast emissivity model of the ocean surface, FASTEM (Deblonde, 2001; Deblonde et al., 2007). A minimization procedure searches for the best estimate of the atmospheric state (called state vector containing the atmospheric and/or surface variables) by weighting the a-priori or background vector and the coincident satellite observation vector according to their uncertainties. If an optimal solution is found, it is written to output retrieval files accompanied with further diagnostic data.

More details on the retrieval and the specific limitations are given in ATBD on HOAPS [RD 2]. Information on the accuracy of the product is contained in the HOAPS validation report [RD 1].

3.1.2   Near surface specific humidity

Since a significant signal of the water vapour in the lower boundary layer is contained in microwave imager measurements it is possible to retrieve q_{air} (near surface specific humidity) from the brightness temperatures. A linear relationship from Bentamy et al. (2003) is used here that is based on the two-step retrieval of Schulz et al. (1993) and the refinement of Schlüssel (1995). It derives q_{air} directly from SSM/I brightness temperatures using the 19 GHz, 22 GHz, and 37 GHz channels. An additional advantage of this multi-channel approach is the possibility of a better separation of wind induced surface signals from the water vapour signal through the 19 and 37 GHz channels, which reduces the errors in the retrieval.

More details on the retrieval and the specific limitations are given in ATBD on the HOAPS near surface specific humidity [RD 2and RD 3]. Information on the accuracy of the product is contained in the HOAPS validation report [RD 1].

3.1.3   Latent heat flux / Evaporation

The latent heat flux is not directly derived from SSM/I and SSMIS radiances. The retrieval is based on the parameterization of the latent heat transfer coefficients from the Coupled Ocean–Atmosphere Response Experiment (COARE) bulk aerodynamic approach of Fairall (1996, 2003).

Using the bulk aerodynamic formula the latent heat flux is estimated from wind speed and sea-air humidity differences as follows:

$$Q_l = \rho L_E C_E u (q_s - q_a)$$

where ρ is air density, u is the wind speed at 10 meters height, L_E is the specific latent heat of evaporation, C_E is the Dalton number (transfer coefficient), q_s is the saturation specific humidity at the sea surface, and, q_a is the specific humidity at the 10 m atmospheric measurement level. Nearly all of these geophysical parameters needed to derive the fluxes can be retrieved directly or indirectly from satellite observations.

The physical parameters used to derive the latent heat flux / evaporation are available as individual products through CM SAF. Sea surface temperature and sea surface saturation specific humidity are available as auxiliary products.

More details on the latent heat flux retrieval and the specific limitations are given in ATBD on the HOAPS turbulent flux retrieval [RD 2, RD 3]. Information on the accuracy of the product is contained in the HOAPS validation report [RD 1].

3.1.4   Precipitation

A neural network based statistical retrieval is used to derive the precipitation from SSM/I and SSMIS brightness temperatures. The neural network was trained with precipitation rates retrieved from assimilated brightness temperatures in a 1D-Var scheme from the ECMWF. The resulting HOAPS precipitation retrieval algorithm only depends on SSM/I and SSMIS brightness temperatures as input and does not need first guess or other ancillary data.

More details on the retrieval and the specific limitations are given in ATBD on HOAPS precipitation retrieval [RD 3]. Information on the accuracy of the product is contained in the HOAPS validation report [RD 1].

3.1.5   Freshwater flux

The gridded freshwater flux products are not computed directly from the SSM/I and SSMIS swath data, since the concurrent retrieval of precipitation and evaporation is not possible for the most cases with precipitation.

In order to retrieve the freshwater flux, the input parameters precipitation and evaporation are averaged separately. Then the freshwater flux is computed from the gridded data products for each grid box as the difference between the spatio-temporal means of evaporation and precipitation.

More details on the retrieval and the specific limitations are given in ATBD on the freshwater flux [RD 2, RD 3]. Information on the accuracy of the product is contained in the HOAPS validation report [RD 1].

3.2   General limitations of the HOAPS data record

The HOAPS retrievals are not valid over land surfaces and ice covered regions. Thus all HOAPS products are restricted to ice-free oceanic conditions. This results in temporally varying sampling density in the polar regions, where the retrieval is only possible during ice-free (summer) months.

The number of DMSP satellite platforms available throughout the years covered by the data record varies between 1 and 5. The first months of the data record are derived from only one satellite, which leads to a greater uncertainty in the mean fields due to the sparser sampling.

The sun synchronous orbit of the DMSP satellites does not allow resolving a detailed diurnal cycle. Hence, systematic biases may occur in regions where a parameter exhibits a strong, non-sinusoidal, diurnal cycle dependency.

HOAPS uses carefully inter-calibrated TBs for the instruments SSM/I and SSMIS aboard 9 different platforms from CM SAF FCDR. Note that the inter-sensor calibration method used to homogenize the SSMIS brightness temperature time series cannot account for an absolute radiometric offset because a true reference is not available. Changes due to orbit drifts have not been corrected, because these are valid measurements and it depends on the parameter if an orbit drift causes an artificial trend in product space or not. Only parameters with a significant diurnal cycle would be influenced by orbital drift.

Although the physical background of systematic errors due to the reflector emission are identified, it is not possible to fully correct for it. The main sources of uncertainty are the correct determination of the reflector emissivity after launch and additionally, in case of the DMSP platform F16, the estimation of the reflector temperature.

The covariance of errors between different channels is not considered because the R-matrix does not only contain instrument noise but also the uncertainty arising from radiative transfer and due to this fact the estimation of such covariance terms is challenging. The estimation of the covariance terms will depend not only on TBs but also on atmospheric conditions and instrument characteristics, here in particular the heating and cooling depending on position relative to Sun/Earth shadow. Thus the R-matrix would ideally be recomputed for every pixel and time. In consequence, associated processing would be computationally very expensive. Also, the covariance of errors between different channels is assumed to be relatively small because the spectral separation is relatively large, with the exception of the vertically and horizontally polarised channels. Deblonde (2002) also assumes within the SSMIS 1D-Var that the instrument and forward model errors are not correlated between channels.

Finally, the near surface air temperature is needed to estimate atmospheric stability. Since it is not possible to measure this parameter directly from space, it is estimated using the mean of two simple bulk approaches (see RD 3).

More details are given in RD 2 and RD 3.

3.3 Gridding Procedures and Data Products

Two gridded data subsets of the HOAPS data record are supplied: a composite product (HOAPS-C) and a monthly averaged product (HOAPS-G). This allows HOAPS to be used for a wide range of applications. Moreover, both data records are available in NetCDF format including extensive metadata.

3.3.1 HOAPS-S

The HOAPS-S data subset contains all parameters in the native SSM/I or SSMIS scan-oriented pixel-level resolution for each individual satellite, providing the basis for the gridded data products HOAPS-G and HOAPS-C. The HOAPS-S products are not disseminated as formal CM SAF products. However, they are available from CM SAF by request to the User Help Desk.

3.3.2 HOAPS-G

HOAPS-G climatological data records contain monthly mean globally gridded data with a spatial resolution of 0.5°. The mean fields are computed from the HOAPS-S data by aggregating all SSM/I and SSMIS pixels that have their centre of the FOV falling in the respective grid box and averaging over the specific time period. The resulting data records consist of multi-satellite averages that include all SSM/I and SSMIS instruments available at the same time. The data fields are supplemented by basic statistical information about standard deviation and number of observations per grid cell as well as the satellites used for each grid cell.

3.3.3 HOAPS-C

HOAPS-C contains 6-hourly globally gridded multi-satellite composite fields of each parameter at a spatial resolution of 0.5°. Each grid cell contains the spatial average of data from one specific satellite that passed this grid box closest to 06:00, 12:00, 18:00, and 24:00 UTC respectively. Hence, each grid cell contains data from only one satellite pass (spatially averaged) and there is no average from two or more satellite passes. This method provides higher spatial consistency on the sub-daily time scale than just averaging all available data to daily mean fields, e.g. the appearance of back and forth moving fronts of fast moving weather systems is minimized. The fields are archived for 00:00 to 06:00 UTC, 06:00

to 12:00 UTC, 12:00 to 18:00 UTC and 18:00 to 24:00 UTC. Time steps in the data files are 00:00 UTC, 06:00 UTC, 12:00 UTC and 18:00 UTC respectively. Note, that there is no product provided per satellite.

4 Outlook

Future tasks will involve the improvement of the 1D-Var to allow the simultaneous retrieval of liquid water path and rain. Also, the retrieval uncertainty will be assessed in more detail. In particular, the validity of uncertainty estimates based on collocated match-ups and from the 1D-Var will be analysed. In order to enhance the temporal sampling observations from other microwave imagers such as AMSR-E will be implemented. These tasks will be part of CDOP-3 and shared between CM SAF and the University of Hamburg.

Moreover, a comprehensive assessment of the long-term stability of satellite-based mean time series is still a not fully resolved issue, which is important for applications regarding local and global trend analyses (e.g., Schröder et al., 2016).

In CDOP-3 it is planned to use the ESA CCI SST as input to HOAPS if the CM SAF requirements on temporal coverage are met.

5 Data format description

CM SAF's climate monitoring HOAPS products are provided as NetCDF (Network Common Data Format) files (http://www.unidata.ucar.edu/software/netcdf/). The data files are created following NetCDF Climate and Forecast (CF) Metadata Convention version 1.6 (http://cf-pcmdi.llnl.gov/) and NetCDF Attribute Convention for Dataset Discovery version 1.3 (http://wiki.esipfed.org/index.php/Attribute_Convention_for_Data_Discovery).

CM SAF recommends the usage of the climate data operators (CDO), available under GNU Public License (GPL) from MPI-M (http://www.mpimet.mpg.de/~cdo), to prepare, process or convert the data for further utilization, e.g. to generate plots from the data.

5.1 Data file contents

A common NetCDF file consists of dimensions, variables, and attributes. These components can be used together to capture the meaning of data and relations among data. All HOAPS product files are built following the same design principles.

Each data file contains the following coordinate variables:

time
>> start of averaging/composite time period
>> [days counted from 1987-01-01]

time_bnds
>> two-dimensional array defining the averaging/composite time period
>> [days counted from 1987-01-01]

latitude
>> geographical latitude of grid-box centre [degree_north]

longitude
>> geographical longitude of grid-box centre [degree_east]

Each data file contains a subset of the following 3-dimensional variables:

hair, wind, evap, late, rain, budg, wvpa
>> parameter grid box mean value, the name depends on the parameter,
>> (see also Table 3 in Appendix A for HOAPS parameter names)

hair_sys, wind_sys, evap_sys, late_sys
>> systematic error information is given for *evaporation-related* parameters

hair_ran, wind_ran, evap_ran, late_ran
>> random error information is given for *evaporation-related* parameters

hair_smp, wind_smp, evap_smp, late_smp
>> sampling error information is given for selected parameters

numo
>> total number of observations counted during the average/composite period
>> (not available for monthly mean freshwater flux product)

satm
>> the satellite instruments used, encoded in a bit mask

numd
>> total number of days with at least one observation counted during the average period (not available for freshwater flux product)
>> (HOAPS-G only)

stdv
>> root mean squared variance (not available for freshwater flux product)
>> (HOAPS-G only)

dtime
>> time elapsed since start of composite period [seconds]
>> (HOAPS-C only)

Each file extracted from the CM SAF database has one record of the dimension (time, lat, lon) with the time dimension as the record dimension. This allows it to concatenate the individual records into an aggregated file. Global attributes are summarized in Table 4 and possible variable attributes in Table 5 (Appendix A).

6 Data ordering via the Web User Interface (WUI)

User services are provided through the CM SAF homepage www.cmsaf.eu. The user service includes information and documentation about the CM SAF and the CM SAF products, information on how to contact the user help desk and allows to search the product catalogue and to order products.

On the main webpage, a detailed description how to use the web 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.

Copyright note:
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6.1 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. After the selection of the product, the desired way of data transfer can be chosen. This is either via a temporary ftp account (the default setting), or by CD/DVD or email. Each order will be confirmed via email, and the user will get another email once the data have been prepared. If the ftp data transfer was selected, this second email will provide the information on how to access the ftp server.

6.2 Contact User Help Desk staff

In case of questions the contact information of the User Help Desk (e-mail address contact.cmsaf@dwd.de, telephone and fax number) are available via the CM SAF main webpage (www.cmsaf.eu) or the main page of the Web User Interface.

6.3 Feedback/User Problem Report

Users of CM SAF products and services are encouraged to provide feedback on the CM SAF product and services to the CM SAF team. Users can either contact the User Help Desk (see chapter 6.2) or use the "User Problem Report" page. A link to the "User Problem Report" is available either from the CM SAF main page (www.cmsaf.eu) or the Web User Interface main page.

6.4 Service Messages / log of changes

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

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8 Appendix A

Table 3: HOAPS code table with mapping to CM SAF product ID's. Note that the netCDF files also contain uncertainty information (systematic, random, sampling), number of valid observations and root mean squared variance.

Acronym	Description	Unit	Par. ID	CM SAF ID	CM SAF CODE
WIND	Wind speed at 10 m height	m/s	0	CM-12911	NSW_HOAPS
HAIR	Near surface specific humidity	g/kg	1	CM-12901	NSH_HOAPS
RAIN	Precipitation	mm/d	2	CM-12611	PRE_HOAPS
WVPA	Vertically integrated water vapour	kg/m**2	3	CM-12701	HTW_HOAPS
TWPA	Vertically integrated total (ice+liquid) water	kg/m**2	4	–	–
LWPA	Vertically integrated liquid water	kg/m**2	6	–	–
ASST	Sea surface temperature	deg C	30	–	–
HSEA	Sea surface saturation specific humidity	g/kg	31	–	–
FNET	Longwave net flux at sea surface	W/m**2	60	–	–
DHUM	Difference in humidity	g/kg	61	–	–
TRCE	Latent heat transfer coefficient (Dalton number)	-	64	–	–
LATE	Latent heat flux at sea surface	W/m**2	65	CM-12811	LHF_HOAPS
HEAT	Sensible heat flux at sea surface	W/m**2	66	–	–
EVAP	Evaporation	mm/d	67	CM-12801	EVA_HOAPS
BUDG	Freshwater flux	mm/d	68	CM-12821	EMP_HOAPS

Table 4: Global NetCDF attributes.

Name	Description
title	data record title, "HOAPS-G" for all files containing averages, "HOAPS-C" for all composite products
summary	short description of HOAPS
Conventions	conventions followed, "CF-1.6" for all files
Metadata_Convention	conventions followed, "Unidata Dataset Discovery v1.3" for all files
id	digital object identifier (DOI)
product_version	data record version: major.minor
creator_name	DWD
creator_url	URL contact information for the creator of the data
creator_email	email contact information for the creator of the data
references	references that describe the data or methods used to produce it
institution	EUMETSAT
project	CM SAF
keywords_vocabulary	GCMD Science Keywords, Version 8.1
keywords	comma-separated keywordsand phrases
standard_name_vocabulary	Standard Name Table (v28, 07 January 2015)
source	original data source, "HOAPS-S" for gridded products
cdm_data_type	data type, "grid" for gridded products
filename	original filename
time_coverage_start	temporal coverage start of the data [ISO8601 date]
time_coverage_end	temporal coverage end of the data [ISO8601 date]
time_coverage_duration	temporal coverage duration of the data [ISO8601 duration]
time_resolution	Temporal resolution of the data [ISO8601 resolution]
geospatial_lat_units	latitude attributes unit
geospatial_lat_resolution	latitude grid resolution
geospatial_lat_min	latitude bounding box minimum
geospatial_lat_max	latitude bounding box maximum
geospatial_lon_units	longitude attributes unit
geospatial_lon_resolution	longitude grid resolution
geospatial_lon_min	longitude bounding box minimum
geospatial_lon_max	longitude bounding box maximum
hoaps_major_version_number	HOAPS major version version
hoaps_minor_version_number	HOAPS minor version version
hoaps_parameter_name	HOAPS parameter name (see Table 3 for the code table)
hoaps_parameter_id	HOAPS parameter ID (see Table 3 for the code table)
platform	comma separated list from GCMD Platform List

platform_vocabulary	GCMD Platforms, Version 8.1
instrument	comma separated list from GCMD Instrument List
instrument_vocabulary	GCMD Instruments, Version 8.1
processed_orbit_node	satellite orbit nodes processed for this mean "ascending, descending" for all files
cmsaf_parameter_id	CM SAF product identifier (see Table 3 for the code table)
cmsaf_parameter_code	CM SAF product name (see Table 3 for the code table)
intercalibration	intercalibration version applied
date_created	date on which the data was created [ISO8601 date]
date_modified	date on which the data was modified [ISO8601 date]
date_metadata_modified	date on which the metadata was modified [ISO8601 date]
history	provides an audit trail for modifications to the original data
ancilliary_variables	a blank separated list of variable names containing the uncertainty estimates and flags to the particular parameter

Table 5: Attributes assigned to variables.

Name	Description
long_name	long descriptive name
standard_name	standard name that references a description of a variable's content in the CF standard name table
units	physical unit [udunits standards]
C_format	format string that should be used for C applications to print values for this variable, applies to the scaled (internal) type and value
FORTRAN_format	format string that should be used for FORTRAN applications to print values for this variable, applies to the scaled (internal) type and value
valid_min	smallest valid value of a variable
valid_max	largest valid value of a variable
scale_factor	The data are to be multiplied by this factor after it is read.
add_offset	This number is to be added to the data after it is read. If scale_factor is present, the data are first scaled before the offset is added.
_FillValue	This number represent missing or undefined data. Missing values are to be filtered before scaling.
cell_methods	method used to derive data that represents cell values
flag_masks	list of bit fields expressing Boolean or enumerated flags
flag_meanings	descriptive words for each flag value
code	eases cdo operation