Satellite Application Facility
on Climate Monitoring

Product User Manual
Vertically Integrated Water Vapour from SSM/I
(CM-127, HTW_SSMI_global_DS)
HOAPS version 3.1

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Version	Implementation	Period	Sensor	Changed Pages/Paragraphs
1	15.12.2008	Jul 1987 – Aug 2006	SSM/I	DMSP F08, F10, F11, F13, F14, F15

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1 Introduction

This CM-SAF Product User Manual provides information on the CM-SAF total column water vapour path (WVPA) data set derived from Special Sensor Microwave/Imager (SSM/I) observations onboard Defense Meteorological Satellite Program (DMSP) platforms F08, F10, F11, F13, F14 and F15 using the algorithm of the Hamburg Ocean-Atmosphere Parameters and Fluxes from Satellite (HOAPS) data set. The manual briefly describes the historical development of CMSAF, the HOAPS data set and the current and upcoming versioning for HOAPS products, the available products including example images; gives basic algorithm descriptions. a brief overview on validation and potential difficulties during scientific interpretation. Additionally, a technical description of the data including information on format as well as on access is provided.

1.1 Organization and products of CM-SAF

EUMETSAT has started the development of a Network of Satellite Application Facilities (SAF) which together with the EUMETSAT central facilities constitute the EUMETSAT Application Ground Segments for MSG and EPS. The SAFs are located in a National Meteorological Service or other approved institutes of an EUMETSAT member state. The scope of the SAF activities is to deliver products, at the level of geophysical parameters, based primarily on the satellite data.

The Satellite Application Facility on Climate Monitoring (CM SAF) targeted its development in the period 1999-2003 on generation and archiving high quality data sets on a continuous basis for the analysis and monitoring of the climate system, its changes and the validation of numerical models (climate and NWP models). The CM SAF started an Initial Operations Phase (IOP) covering the period January 2004 to February 2007. The objectives of the CM SAF IOP were mainly the operational production, control and distribution of products developed in the previous phase, and to carry out research and development for an extension of the product line with new sensors and platforms. The Continuous Development and Operations Phase (CDOP) started in 2007 covering the period March 2007 – February 2012. This CDOP covers - among others - the continuation and further development of the products from the IOP, addition of further GCOS ECV's, but also the provision of long-term data sets with known error characteristics and temporal stability.

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) and the Meteorological Service of Switzerland (MeteoSwiss).

CM-SAF data products are distinguished in operational monitoring products and retrospectively produced data sets. Operational monitoring products are disseminated with high timeliness (within 8 weeks after observation) to support operational climate monitoring application of National Meteorological and Hydrological Services. The timeliness requirement most likely makes this type of product not suitable for monitoring of interannual variability and trends with high confidence. Bias errors due to shift of equator overpass times and orbit height decay as well as instrument caused intersatellite biases are not corrected for in the operational monitoring product. However, the characterisation of relatively strong anomalies on monthly scale should be possible.

Within the retrospectively produced data sets the above described errors are minimised to a level that the data sets can safely be used to analyse variability at longer scales than interannual. CM-SAF aims at the delivery of such data sets for a number of ECVs, as defined by GCOS. One of those data sets is the hereby presented 20-year climatology of WVPA based on SSM/I observations employing the HOAPS algorithm.

A catalogue of available CM-SAF products is available via the CM-SAF webpage, www.cmsaf.eu. Here, detailed informations about product ordering, add-on tools, sample programs and documentation are provided. For some details see section 4 of this manual.

1.2 Historical overview of the HOAPS data set

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 set, which was named the “Hamburg Ocean-Atmosphere Parameters and Fluxes from Satellite (HOAPS)”. This project was part of the special research initiative on Cyclones and the North Atlantic Climate System (SFB512) funded by Deutsche Forschungsgemeinschaft (DFG).

The version 1 of the HOAPS data set was released in 1998 and contained the HOAPS parameters based on non-homogenized radiance time series from the first SSM/I instruments. During the use of this data set in various research projects, it became obvious that systematic differences among the SSM/I instruments exist. Inter-platform homogenisation was identified as the means to overcome the deficiencies of the first HOAPS release. In 2006, the version 2 of the HOAPS data set has finally been released, which incorporated the homogenisation of the time series as described later in this document. Major software re-design and minor updates in some of the retrieval schemes finally led to the latest HOAPS version 3 release, which was in 2007 (Schulz et al., 1998; Jost et al., 2002; Andersson et al., 2008).

In 2007, a memorandum of understanding was signed between MPI-M, UniHH and CM-SAF to ensure the continuous production, elongation and development of the HOAPS data set within CM-SAF’s CDOP. The release of the WVPA data set from SSM/I observations presented in this document is the starting point of CM-SAF’s initiative on development on a selected HOAPS parameter. Neither the homogenisation of the radiance time series, nor the retrieval have been changed. For the current release, an objective gridding method, the kriging, has been applied to allow the production of daily means and the addition of an uncertainty estimate to the mean fields provided. The release is thus called version 3.1 to indicate that it is not a major new version. Future planned extensions of the HOAPS data set may include an updated input data base or changes in homogenisation and/or retrieval schemes and will thus be major new releases, carrying version number 4 and onwards. The release of version 4 is planned at the end of CM-SAF’s CDOP, thus in late 2011. The following table gives an overview over the HOAPS data set versions described above.

Table 1-1: Overview over HOAPS versioning and availability

Version	year	Publisher	Comment	available at
1	1998	MPI-M / UniHH	First release	http://cera-www.dkrz.de/CERA/
2	2006	MPI-M / UniHH	Including homogenisation	http://cera-www.dkrz.de/CERA/
3	2007	MPI-M / UniHH	Major software re-design, minor retrieval updates	http://cera-www.dkrz.de/CERA/
3.1	**2009**	**CMSAF**	**WVPA only, including error estimates**	**http://www.cmsaf.eu**
3.2	2010	CMSAF	HOAPS parameters as marked in Table 1-2, continuation after 2006	http://www.cmsaf.eu
4	2011	CMSAF	Planned	http://www.cmsaf.eu

Due to the fading of SSM/I instruments in the years 2007 and later, the data source for the HOAPS version 4 release will be extended using measurements of the SSMIS and AMSR-E instruments. CM-SAF also aims at providing advanced error an stability estimates for that release. The following table gives an overview on the complete set of parameters, for the current and future releases of the HOAPS data set.

Table 1-2: Overview over HOAPS data set parameters; Columns denote the following: “rev” parameter covered by this document; “past” parameters in previous HOAPS releases; “ctd” parameters that will be provided by CM-SAF in future releases; “pure” parameters directly derived from SSM/I observations; “aux” field derived from auxiliary data source, provided for consistency; “com” fields computed using the auxiliary information.

Parameter	rev	past	ctd	pure	aux	com
Vertically integrated water vapour	X	X	X	X	./.	./.
Vertically integrated liquid water content	./.	X	X	X	./.	./.
Wind speed at 10 m height	./.	X	X	X	./.	./.
Near surface specific humidity	./.	X	X	X	./.	./.
Precipitation	./.	X	X	X	./.	./.
Sea surface temperature	./.	X	X	./.	X	./.
Sea surface saturation specific humidity	./.	X	X	./.	./.	X
Latent heat flux at sea surface	./.	X	X	./.	./.	X
Evaporation	./.	X	X	./.	./.	X
Freshwater flux	./.	X	X	./.	./.	X
Vertically integrated total (ice+liquid) water	./.	X	./.	X	./.	./.
Sensible heat flux at sea surface	./.	X	./.	./.	./.	X
Difference in humidity	./.	X	./.	./.	./.	X
Latent heat transfer coeff. (Dalton number)	./.	X	./.	./.	./.	X
Long wave net flux at sea surface	./.	X	./.	./.	./.	X

1.3 Applicable Documents

Reference	Title	Code
AD.1.	CM-SAF Service Specification Document	SAF/CM/DWD/SeSp/1.3
AD.2.	Validation Report HTW_SSMI_global_DS	SAF/CM/VAL/DRI-1
AD.3.	ATBD HTW_SSMI	SAF/CM/ATBD/HTW_SSM I

1.4 Reference Documents

Reference	Title	Code
RD.1.	CM-SAF Science Plan	SAF/CM/DWD/SCI/3.0
RD.2.	CM-SAF Product Requirements Document	SAF/CM/DWD/PRD/1.2

2 Vertically integrated water vapour from SSM/I

CM-SAF has derived a data set of vertically integrated water vapour from homogenized SSM/I observations. This section provides some details of the retrieval scheme design. It starts with an overview of the product together with information on spatial and temporal resolutions. It is followed by a summary of instrument characteristics, an introduction to the homogenization method applied, the retrieval scheme, and an outline of gridding and averaging procedures. Finally, a discussion of product limitations is provided.

2.1 Product definition

The CM-SAF WVPA data set from SSM/I has global coverage, i.e., within ±180° longitude and ±80° latitude. The product is only defined over the ice-free ocean surface. It is available as daily and monthly averages on a regular latitude/longitude grid with a spatial resolution of $0.5° \times 0.5°$ degrees. The temporal coverage of the data se t ranges from 9th of July 1987 to 31st of August 2006. The product covered by this document is:

Vertically integrated water vapour (WVPA, in kg/m^2) of the atmospheric column (CM-127 according to PRD [RD.2]).

The instantaneous products at pixel scale used to derive the spatiotemporal averaged end products will not be disseminated as formal CM-SAF products. However, they are available from CM-SAF by request to the User Help Desk.

2.2 Instruments, homogenization and retrieval

The Special Sensor Microwave/Imager (SSM/I) is flying aboard the Defense Meteorological Satellite Platforms (DMSP). DMSP satellites are in a near polar sun synchronous orbit at an altitude of approximately 830 km above the Earth with an orbital period of about 101 minutes. The SSM/I instrument is carried aboard DMSP F-08 to F-15, but has failed on F-09 and F-12. Thus, in CM-SAF's current version the WVPA data set utilises data from SSM/I onboard DMSPs F-08, F-10, F-11, F-13, F-14 and F-15. The temporal coverage of each satellite can be found in Figure 2-1. The data set will be extended till 2008 with continued SSM/I observations in a future release (version 3.2). For the next major update (version 4) and further planned extension of the data set, SSMIS as well as AMSR-E measurements will be used.

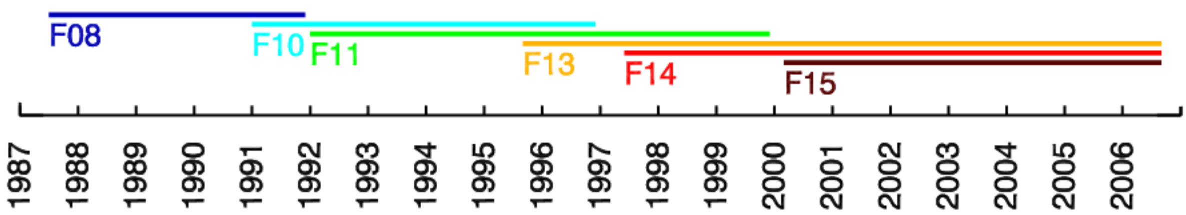

Figure 2-1: Temporal coverage of SSM/I instrument aboard DMSP satellite platforms for the HOAPS processing.

The SSM/I instrument is a conically scanning passive microwave radiometer which operates on a swath width of approx. 1400 km with two reference measurements (hot and cold target temperatures) during each antenna rotation. The instrument has 7 spectral channels located at frequencies of 19, 22, 37 and 85 GHz. All but the 22 GHz channel are measuring in both horizontal and vertical polarization. Given the scan velocity, integration time and antenna lobe pattern, the footprint of the different channels is ranging from approx. 50 km (19 GHz) to 15 km (85 GHz). The scan pattern is rather complex, providing intermittent so-called A-scans (all channels collocated) and B-scans (only the 85 GHz channel). For details see Hollinger et al. (1987) and Wentz (1988).

The DMSPs have a temporal overlap to at least one consecutive satellite, which makes the homogenization of the measured brightness temperatures between different SSM/I instruments possible. Within the HOAPS retrieval algorithm, this homogenization is performed prior to the retrieval. For the homogenization, the SSM/I on the temporally most stable orbiting DMSP has been chosen as a reference instrument, which is the F-11. Based on the overlaps between the DMSPs, ten-day probability density functions (PDFs) of the brightness temperatures in each channel have been calculated. Afterwards, the statistical parameters of the PDFs were matched to derive transfer coefficients for the individual instruments. These coefficients can then be used to homogenize the measurements of different SSM/I instruments. DMSP platforms without a direct temporal overlap to the reference F-11 have been homogenized via intermediate platforms. Details on the homogenization scheme can be found in Andersson (2008).

The retrieval of WVPA for the HOAPS package has been developed by Schlüssel and Emery (1990). It uses the measured brightness temperatures in the 22 GHz and the 37 GHz (vert. pol.) channels. With these two channels, a statistical retrieval is driven which has been derived from a regression analysis of radiative transfer simulations based on approx. 300 atmospheric radiosonde profiles. The retrieval may only be applied for non-precipitating conditions, thus a rain-screening based on threshold criteria is made beforehand. Details on the statistical approach, the retrieval formula and the rain screening can be found in AD.3 and Schlüssel and Emery (1990).

2.3 Gridding procedure

Daily and monthly averages of the WVPA product are computed from the swath-based HOAPS retrievals using a Kriging approach as described in Lindau and Schulz (2004) and in Lindau (2005). The resulting output fields for the global, ice-free oceans are provided on a regularly spaced latitude-longitude grid (dx=dy=0.5 degrees). Additionally, fields of the number of used observations and standard deviations are included in the product. The daily and monthly mean products are merged products of all available SSM/I sensors which is justified by the prior intercalibartion of the individual sensors. The different processing steps are briefly described in the next paragraph.

The method to merge the results from the DMSP platforms into one gridded product is based on the commonly known Kriging technique that does not prescribe a fixed radius in which observations are considered, as performed in ordinary block Kriging. The technique manages the aggregation of additional information step by step, deciding at each stage which observation can contribute a maximum of new, non-redundant information. This depends on the three characteristics of a potentially added observation: (1) its distance to the predicting point, (2) its individual error and (3) its redundancy with the already aggregated observations. Two pieces of information are necessary to run the Kriging procedure. These are: (1) The spatial correlation function that is derived to have an estimate how fast the reliability of an observation is decreasing with increasing distance, and (2) the error of each observation. The error variance of each individual observation is derived by decomposing the total variance at each grid point into an external and an internal part with respect to the considered spatio-temporal scale (see von Storch and Zwiers (1999) for details). From the internal variance, e.g. intra-daily for daily means, the errors are concluded. However, to correctly apply Kriging to compute errors only independent observations may enter the interpolation process. Concerning satellite data, the errors of individual pixels are highly correlated. Thus, the assumption of pixels being independent of each other is invalid. An analysis of this problem revealed that only individual satellite overpasses can be regarded as independent from each other. Hence, the maximum number of independent observations per product grid point and day is two for each satellite. A more detailed description of the approach can be found in Lindau and Schulz (2004) and Lindau (2005).

Figure 2-2 shows an example of the monthly and daily mean WVPA product for April 2004, and 21st April 2004, respectively. Plotted are the mean values, the number of observations, and the random error of daily means as well as the extra daily standard deviation of the monthly means. The latter represents the true variability during the month. The uncertainty of daily estimates is high when only few observations are found or the number of observations is not sufficient to resolve the diurnal variability (see lowest panel on the right column where the typical scan pattern of polar orbiting DMSP is resembled in the daily uncertainty plot). This is not obvious in data sets providing only mean values and/or standard deviations simply computed from all individual pixels.

The exemplary monthly mean plots on the left columns reveal high variability in water vapour in the build-up phase of the Indian Monsoon and over the South Pacific Convergence Zone (SPCZ) as well as medium variability over the Storm Track in the North Atlantic region, In Figure 2-3, zonally integrated values for the monthly mean and standard deviation fields are displayed for the whole time series as Hovmoeller diagrams. It should be noted that the low standard deviation in the Tropics in Figure 2.3 at the beginning of the time series is a sampling issue, as at that time, SSM/I data from only one DMSP satellite were available.

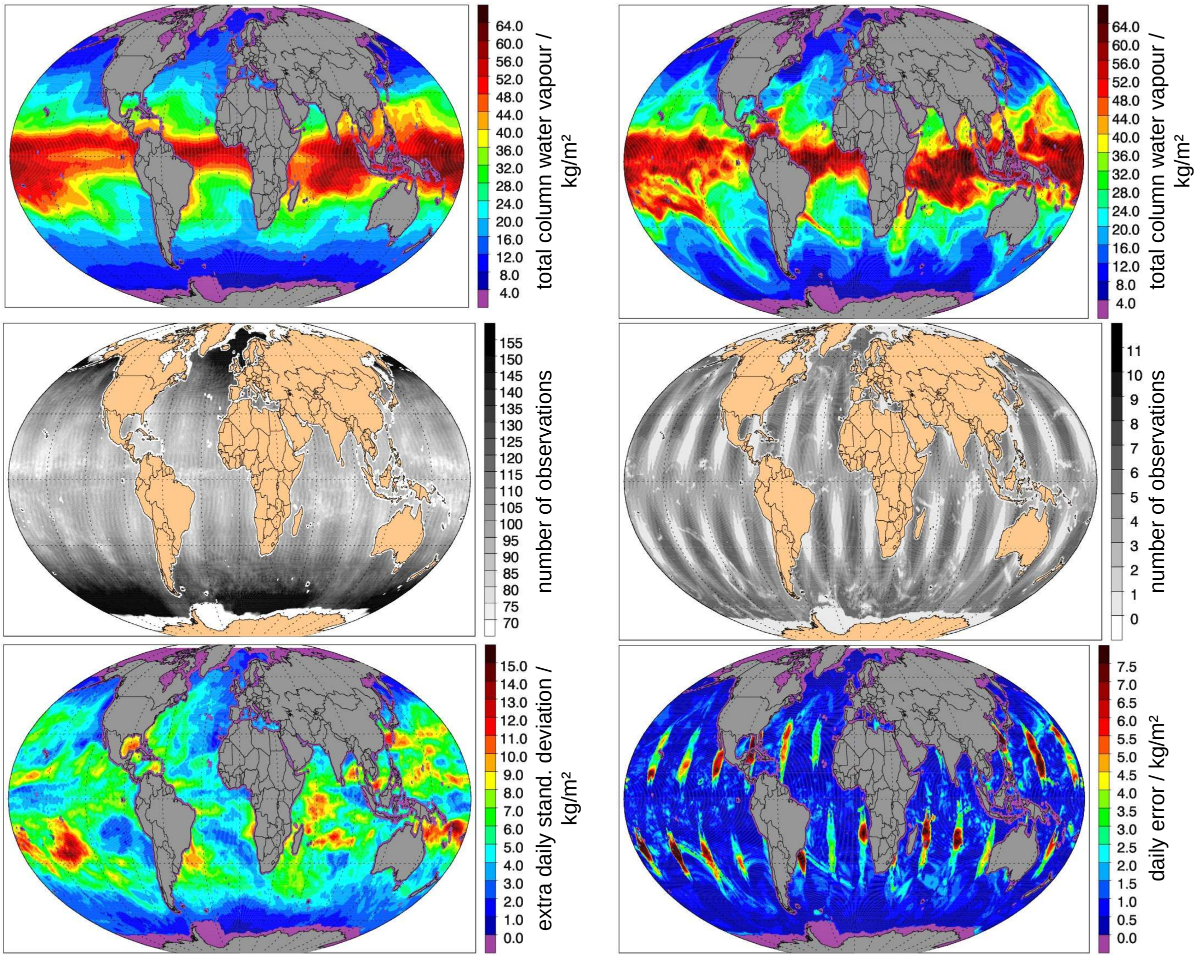

Figure 2-2: Average WVPA (top panels, in kg/m²), number of observations (middle panels, unitless), and uncertainty information (bottom panels, in kg/m²) for a monthly mean product of April 2004 (left column) and a daily mean product for 21st April 2004 (right column).

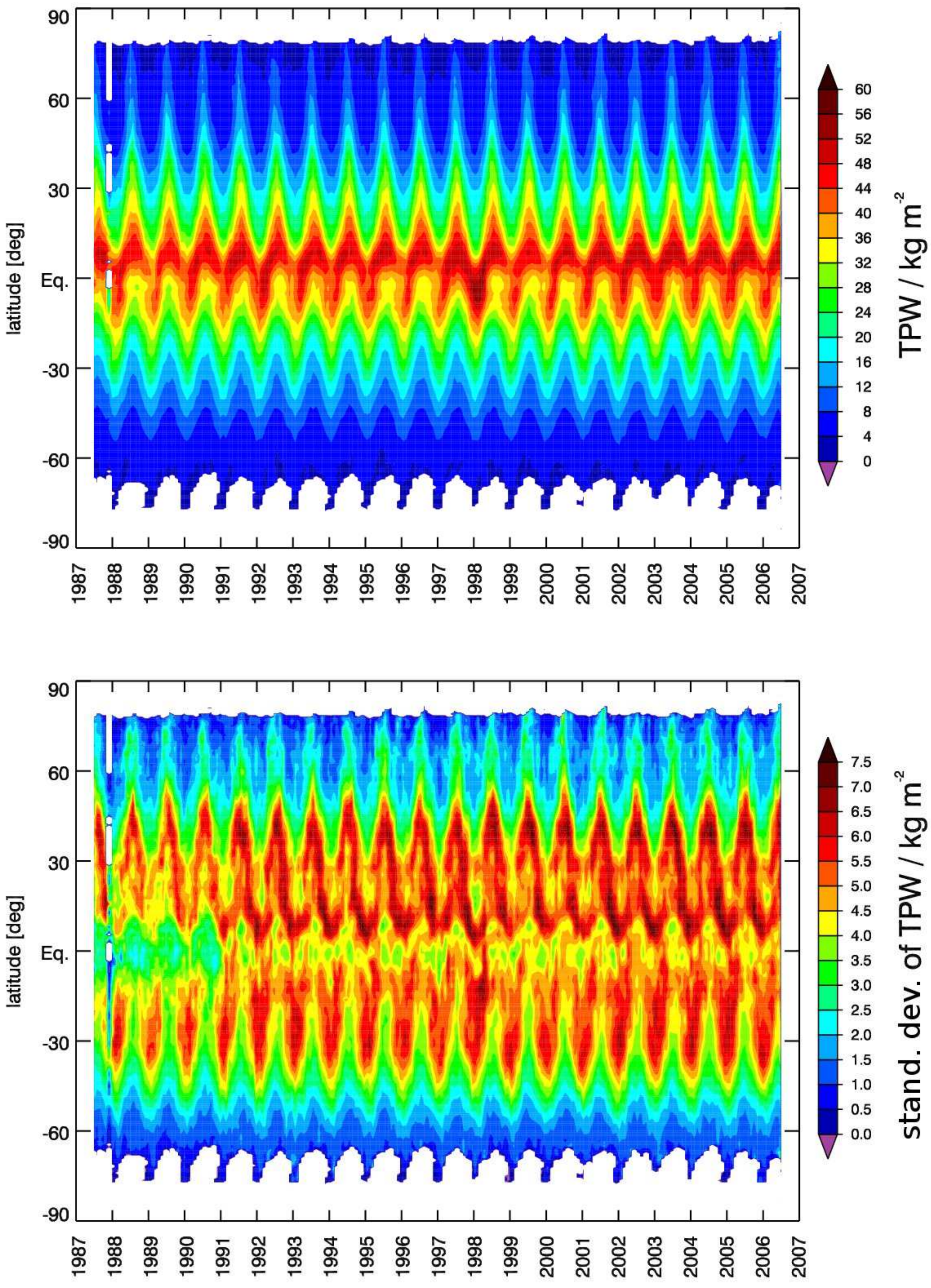

Figure 2-3: Hovmoeller diagram of zonally averaged monthly mean WVPA (upper) and standard deviation hereof (lower panel) for the time series July 1987 – August 2006

Note that the previous versions of HOAPS, i.e. versions 1 to 3 from Hamburg also provide gridded monthly means. Those monthly means have not been produced with a kriging technique, but are the average of all instantaneous retrievals that fall within a target gridcell in the respective month. By this, the daily contributions of the Hamburg HOAPS versions to the monthly mean are not weighted in the same way as in the HOAPS version 3.1 from CM-SAF. As a consequence, minor differences in the monthly mean occur, that are on the order of 0.1 to 0.2 kg/m² in a global averaged sense. The differences occur predominantly at regions with high day to day variability and large gradients in the water vapour fields, i.e. at the extratropical storm tracks.

2.4 Validation

The Service Specification Document (SeSp) [AD.1] lists specific product requirements that are fulfilled in either case. Among other product features a target uncertainty requirement is given in PRD, which is

- 1 kg/m² systematic difference (bias);
- 2 kg/m² variability (rmse);
- 0.26% decadal stability.

The uncertainty of the disseminated data set is assessed against this requirement. The strategy is briefly outlined in this section, an in-depth discussion of the results can be found in the Validation Report [AD.2].
A direct validation of the products against ground-based reference data over the ocean is impossible, as no long time series of accurate ground-based WVPA measurements over the whole time series exist. The global radio sounding network, which could provide a reference measurement as required, is of land-locked nature, though restricted to regions where the WVPA data set from SSM/I is not defined. Nevertheless, a range of validation and intercomparison and validation exercises have been carried out which are described briefly in section 2.4 and in the Validation Report [AD.2].

A thorough validation of the WVPA products themselves against radiosondes is hampered by the land-based nature of radio sounding stations, where the HOAPS product is not defined. Therefore, the validation strategy is as follows:

1. A theoretical assessment of the algorithm accuracy compared to other WVPA retrievals for SSM/I has been carried out in a study by Sohn and Smith (2003). This shows that the HOAPS retrieval is in good agreement with other retrieval schemes, especially an optimum statistical retrieval by Wentz (1995), which has been considered as reference in the mentioned study.

   The results of the above mentioned study have been again checked for the whole time series based on the new CM-SAF product and those derived by RSS. The bias is still found to be in the order of 1 kg/m².

2. Additionally, for a selected year (2004), the CM-SAF WVPA product has been assessed versus the same product from ATOVS observations, which is an operational product from CM-SAF. As the ATOVS product is covering both oceans and land surfaces, it is possible to validate this product with radiosonde observations. The bias found to radiosondes is on the order of 0.5 kg/m². The intercomparison between HOAPS and ATOVS WVPA products shows differences on the order of 1

kg/m². Thus, an indirect assessment of HOAPS WVPA against radiosondes has been performed and yields a good agreement.

3. A third intercomparison is performed to various re-analysis data sets, which represent the best possible assimilation of atmospheric parameters available to date. The comparison to re-analysis shows a good agreement, with systematic differences of less than 1 kg/m² for the newest ERA INTERIM re-analysis for the globally averaged monthly means (variability in terms of rmse is approx. 2 kg/m²). The comparison to daily mean values yields also systematic differences in the order of 1 kg/m², with slightly higher variability (rmse) of 3-4 kg/m².

4. To assess the decadal stability of the data set, trends derived from the CM-SAF and RSS WVPA data sets have been compared. The trends agree well both in their regional patterns and their amplitude. As the difference is less than 0.20 %/decade, the decadal stability request is fulfilled, based on the choice of the RSS WVPA data set as reference.

Based on the argumentation above and the fact that all differences to reference data sets are temporally constant, the quality of the WVPA products from SSM/I can be guaranteed in terms of the specified accuracies in AD.1.

2.5 Limitations

The number of DMSP satellite platforms available throughout the years covered by the WVPA data set varies between 1 and 3 as shown in Figure 2-1. Therefore, the first months of the data set based only on one satellite have greater regions of missing data because the coverage by only one satellite is not sufficient to obtain a global field.

Another limitation is the restriction of the algorithm to ice-free oceanic conditions, as only for this conditions, the emissivity of the lower boundary (ocean surface) may be adequately assessed from SSM/I measurements. Also notice the screening of precipitating pixels prior to the WVPA retrieval as the functional dependence between the SSM/I brightness temperatures in the 22 and 37 GHz channels is only valid for non-precipitating conditions (see AD.3).

The regression algorithm applied within the HOAPS retrieval package has been trained based on forward radiative transfer calculations obtained from a set of radio-soundings. The latitudinal and seasonal variability of this training data base may however be not sufficient to fully represent the extremes of the true atmospheric variability. At the high end the retrieval scheme for SSM/I tend to underestimate WVPA because the 22 GHz channel is directly placed into the centre of the water vapour absorption line leading to a saturation effect at very high water vapour loadings.

In fact, a comparison of WVPA values with other integrated water vapour column retrievals based on GOME and SCIAMACHY as well as the intercomparison to ECMWF's recently published re-analysis ERA INTERIM show that HOAPS yields significantly less retrievals below 4 kg/m², which is compensated by more values between 4-8 kg/m². This can be seen from Figure 2-5 below. Also obvious is the small saturation effect at WVPA larger than 55 kg/m^2.

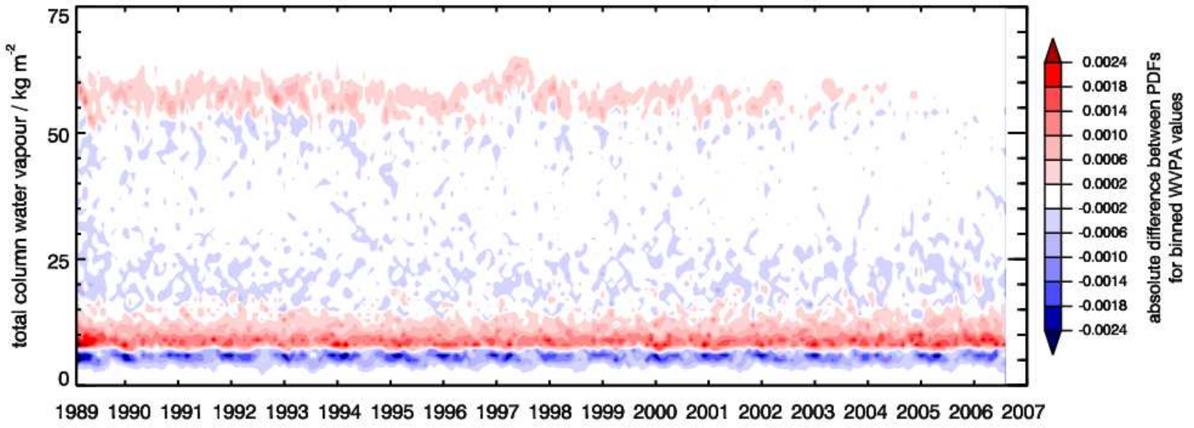

Figure 2-4: Hovmoeller diagram of differences between PDFs of HOAPS-derived water vapour and ECWMF ERA INTERIM water vapour. Bluish colours denote values of the water vapour distribution (y-axis) where HOAPS is moister, reddish colours where HOAPS is dryer than the ECMWF field.

3 Data description

This section describes the filenames and output formats for the total column water vapour product from SSM/I. Data from the available DMSP satellite platforms enter the daily and monthly mean products by applying the Kriging routine. All products are amended by information on the number of observations per grid box and estimates of error and true variances at the different temporal averaging scales.

The temporal resolution of the products is daily and monthly. The spatial coverage is for the global ice-free oceans, with a resolution of 0.5x0.5 degrees (latitude/longitude). The filenames are composed in the following way (1. General composition, 2. Exemplary filename):

1. <Product><Average_type><yyyymmdd>0000<Version><Projection_identifier><Data_index>01GL.nc.gz

2. <HTW><dm><19900101>0000<001><13><00267>01GL.nc.gz

The example file contains daily averages of total column water vapour retrieved from SSM/I observations on 01 January 1990. The products version is 001.
All products are coded in netCDF format which is described at http://www.unidata.ucar.edu/software/netcdf/, following the climate and forecast metadata convention (CF-1.0). Details on this convention can be found at: http://cf-pcmdi.llnl.gov/ .
Further technical details of the products are described in Appendix A.

Sample routines for data access in FORTRAN90 and IDL are provided via the CM-SAF webpage. For data pre-processing and conversion to various graphical packages input format, 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).

4 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 as central and updated document. However, some of the key features and services are briefly described in the following sections.

4.1 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 you selected product type and time period you want to obtain, you can choose your preferred type of data transfer. This is either via a temporary ftp account (the default setting), or by CD/DVD or email. Your order will be confirmed via email, and you will get another email once the data have been prepared. If you selected the ftp data transfer, this second email will give you information on how to access the ftp server.

4.2 Contact User Help Desk staff

You can contact the User Help Desk staff in case you have questions. You find contact information (e-mail address contact.cmsaf@dwd.de, telephone and fax number) on the CM-SAF main webpage (www.cmsaf.eu) or the Web User Interface main page.

4.3 Feedback/User Problem Report

Users of the 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 4.2) 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.

4.4 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.

5 References

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Appendix A Definition of the netCDF file structure

The data in netCDF files is organised in sections as follows:

– *dimension definitions,*

– *variable and specific attribute definitions,*

– *global attribute settings* and

– *data*.

The contents of the *global attributes* group are common to all products. This group contains general information about the product, for example the algorithm and version used to generate the product. Specific information about the variables (e.g. long name, units, missing data values) can be found in the *specific attribute definitions* for every variable.
The *latitude/longitude variables* contain information from which the region covered by the data and the grid can be reconstructed. The *data* group finally contains the products and additional information, i.e. number of observations and uncertainty information.
The following table lists the detailed contents of the variables and attributes in the netCDF files. Note that the grey shaded fields change for daily or monthly mean files.

Table A.1: Metadata group contents.

File section	Identifier	Sub-Identifier	Value	Meaning/Comment
Dimensions	Time		UNLIMITED	
	Lat		320	*number of latitudes*
	Lon		720	*number of longitudes*
Variables	time (double)	long_name	Time	*long name of time variable*
		units	days since 1987-01-01	*unit of time variable*
		calendar	standard	*calendar type used*
	lon (float)	long_name	Longitude	*long name for longitude variable*
		units	degrees_east	*unit of longitude variable*
		standard_name	longitude	*standard long name for longitude variable*
		c_format	%8.3f	*C style format identifier*
		fortran_format	F8.3	*FORTRAN style format identifier*
		valid_min	-180.	*allowed minimum value*
		valid_max	180.	*allowed maximum value*
	lat (float)	long_name	Latitude	*long name for latitude variable*
		units	degrees_north	*unit of latitude variable*
		standard_name	latitude	*standard long name for latitude variable*
		c_format	%8.3f	*C style format identifier*
		fortran_format	F8.3	*FORTRAN style format identifier*
		valid_min	-80.	*allowed minimum value*
		valid_max	80.	*allowed maximum value*
	Wvpa (float)	long_name	Water Vapour Path	*long name for total column water vapour variable*
		units	kg/m**2	*unit of total column water vapour variable*
		c_format	%8.3f	*C style format identifier*
		fortran_format	F8.3	*FORTRAN style format identifier*
		_FillValue	-999.	*missing data value*
		scale_factor	1.	*scaling factor for converting data to physical values*
		add_offset	0.	*offset value for converting data to physical values*
		comment	P.Schluessel, 1990 (IJRS)	*scientific reference for retrieval algorithm*

	numo (float)	long_name	Number of Observations	*long name of number of observations variable*
		units	count	*unit of number of observations variable*
		c_format	%5.0f	*C style format identifier*
		fortran_format	F5.0	*FORTRAN style format identifier*
		_FillValue	-999.	*missing data value*
		scale_factor	1.	*scaling factor for converting data to physical values*
		add_offset	0.	*offset value for converting data to physical values*
	ierr (float)	long_name	kriging uncertainty of daily means / extra daily stand. dev.	*long name for uncertainty variable*
		units	kg/m**2	*unit of uncertainty variable*
		c_format	%8.3f	*C style format identifier*
		fortran_format	F8.3	*FORTRAN style format identifier*
		_FillValue	-999.	*missing data value*
		scale_factor	1.	*scaling factor for converting data to physical values*
		add_offset	0.	*offset value for converting data to physical values*
		comment	see Wackernagel (2003) / see von Storch and Zwiers (1999)	*scientific reference for type of error information*
global attributes	Title		HOAPS-G	*HOAPS gridded*
	Conventions		CF-1.0	*climate and forecast data convention*
	references		http://www.hoaps.org	
	institution		CMSAF at DWD, Offenbach	
	source		satellite observations	
	Major_Version_Number		3	
	Minor_Version_Number		1	
	Parameter		Water Vapour Path	
	Parameter Id		3b	*Parameter identifier within HOAPS parameter list*
	Average_Period		day / month	
	Average_Period_Length		1	
	Average_Origin		day	
	Average_Orbit_Segment		ascending + descending	
	Average_Map_Resolution		30	*units: arc minutes, thus 1/2 degree*
	File_Type		daily mean / monthly mean	

	history	[…]	*time and location of file generation*
Data	**Time**	[…]	*monthly means are assigned to first day of each month*
	Lat	[79.75, …, -79.75]	*latitude ordering from NORTH to SOUTH*
	Lon	[-179.75, …, 179.75]	*longitude ordering from WEST to EAST*
	Wvpa	[…]	*data value matrix*
	numo	[…]	*number of observations value matrix*
	Ierr	[…]	*uncertainty value matrix*

Appendix B Glossary

This section provides a table of acronyms, abbreviations and terms used throughout this document.

AMSR-E	Advanced Microwave Scanning Radiometer - Earth Observing System
ATBD	Algorthm Theroretical Baseline Documentation
ATOVS	Advanced TIROS Operational Vertical Sounder
CDO	Climate Data Operators
CDOP	Continuous Development and Operations Phase
CM-SAF	Satellite Application Facility on Climate Monitoring
DFG	German Research Foundation (Deutsch Forschungsgemeinschaft)
DMSP	Defense Meteorological Satellite Program
DWD	Deutscher Wetterdienst
ECMWF	European Centre for Medium Range Weather Forecasts
ECV	Essential Climate Variable
EPS	European Polar-Orbiting Satellite Program
ERA	ECMWF Re-Analysis
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
FMI	Finnish Meteorological Institute
GCOS	Global Climate Observing System
GOME	Global Ozone Monitoring Experiment
GPL	GNU Public License
HOAPS	Hamburg Ocean Atmosphere Parameters and Fluxes from Satellite
HTW	Total Water Vapour
IDL	Interactive Data Language
IOP	Initial Operations Phase
KNMI	Royal Dutch Meteorological Institute
MPI-M	Max-Planck Institute for Meteorology, Hamburg, Germany
MSG	METEOSAT Second Generation
NWP	Numerical
PDF	Probability Density Function
PRD	Product Requirements Document
RMIB	Royal Meteorological Institute of Belgium
RMSE	Root Mean Square Error
RSS	Remote Sensing Systems
SAF	Satellite Application Facility
SCIAMACCHY	Scanning Imaging Absorption Spectrometer for Atmospheric CHartographY
SMHI	Swedish Meteorological and Hydrological Institute
SPCZ	South Pacific Convergence Zone
SSM/I	Special Sensor Microwave/Imager
SSMIS	Special Sensor Microwave Imager/Sounder
TIROS	Television and Infrared Observation Satellite
UniHH	University of Hamburg, Germany
WUI	Web User Interface
WVPA	Vertically Integrated Water Vapour Path
WWW	World Wide Web