DUE GLOBVAPOUR

Algorithm Theoretical Basis Document
L3 Combined SSM/I + MERIS

Issue 2 Revision 1

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1 Introduction

1.1 Purpose

This document provides the Algorithm Theoretical Basis of the Level 3 combined SSM/I-MERIS total column water vapour product for the ESA DUE GlobVapour project. The algorithm description for SSM/I and MERIS L2 products can be found in the concerning ATBDs ([RD-1a], [RD-1b]).

The methods explained below are developed for the GlobVapour final data set, which is published in summer 2011. Hence, descriptions of prior methods can be find in prior versions of this ATBD.

1.2 Definitions, acronyms and abbreviations

AMSU	Advanced Microwave Sounding Unit
ATBD	Algorithm Theoretical Basis Document
DMSP	Defense Meteorological Satellite Program
DWD	Deutscher Wetterdienst
FCDR	Fundamental Climate Data Record
L1	Level 1
L2	Level 2
L3	Level 3
LST	Local Solar Time
MWR	Microwave Radiometer
NWP SAF	Satellite Application Facility Numerical Weather Prediction
RTM	Radiative Transfer Model
SSM/I	Special Sensor Microwave/Imager
SSMIS	Special Sensor Microwave Imager and Sounder
TCWV	Total Column Water Vapour
WACMOS	Water Cycle Multimission Observation Strategy

1.3 Applicable Documents

[AD-1] DUE GLOBVAPOUR Requirements Baseline Document (RBD), issue 1, revision 0, dated 16 April 2010.

[AD-2] DUE GLOBVAPOUR Technical Specification Document (TSD), issue 1, revision 0, dated 16 April 2010.

[AD-3] DUE GLOBVAPOUR Software Development Plan (SDP), issue 1, revision 0, dated 16 April 2010.

[AD-4] DUE GLOBVAPOUR Summary Report on Existing Algorithm Comparison and Validation Reports (SVR), issue 1, revision 0, dated 29 July 2010.

[AD-5] ESRIN Statement of Work, EOEP-DUEP-EOPS-SW-09-0003, issue 1 rev. 1, 13.05. 2009

[AD-6] DUE GLOBVAPOUR Proposal, issue 1 revision 3, dated 9 July 2009

1.4 Reference Documents

[RD-1a] DUE GLOBVAPOUR Algorithm Theoretical Basis Document (ATBD) for L2 SSMI, issue 1, revision 0, dated 07 October 2010.

[RD-1b] DUE GLOBVAPOUR Algorithm Theoretical Basis Document (ATBD) for L2 MERIS, issue 1, revision 0, dated 28 October 2010.

[RD-2] DUE GLOBVAPOUR Metadata Definition, issue 1, revision 2, dated 07 September 2010

1.5 Structure of the document

Section 2 gives a short overview of algorithms used, illustrated with the processing flow. The algorithm description occurs in section 3, where all theoretical and practical important steps of the algorithm are explained in detail. Assumptions and limitations can be found in section 4. A conclusion is given in section 5.

2 Algorithm overview

There are two different L3 products created from SSM/I and MERIS L2 data, namely global daily composites and monthly means. Since MERIS provides data only during daytime with a fixed equator crossing time at 10:00 LST, the SSM/I products are created from morning overpasses (descending paths) only as well, in order to provide a consistent combined data set. The two L3 data sources, TCWV from SSM/I above the ice-free ocean and MERIS above cloud-free land and sea ice, are prepared separately on two different rectangular grids and merged in the end by oversampling the SSM/I data to the higher MERIS resolution.

The resulting high resolution SSMI+MERIS L3 products are defined on a rectangular (0.05 x 0.05)° grid and stored in NetCDF files that are fully compliant with the NetCDF Climate Forecast convention.A low resolution SSMI+MERIS data set (0.5 x 0.5)° exists also. A detailed description of the output file format can be found in [RD-2].

Figure 1 shows a flow chart of the L3 processor. Detailed information about the L2 retrieval methods for SSM/I and MERIS can be found in the GlobVapour L2 ATBDs ([RD-1a], [RD-1b]).

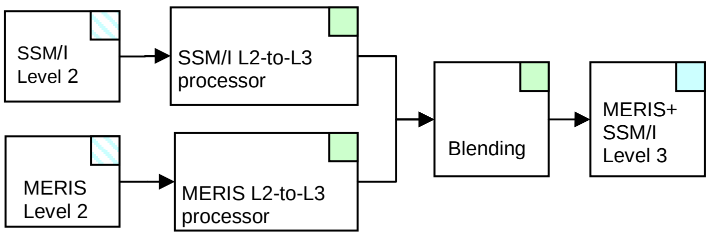

Figure 2-1: Flow chart of the L3 combined SSM/I+MERIS processor. Products are marked blue (blue shaded: instantaneous level 2 products, blue end product) and software development is marked green.

3 Algorithm description

3.1 Theoretical description

The two L3 data sources, TCWV from SSM/I above the ice-free ocean and MERIS above cloud-free land and sea ice, are prepared separately on two different grids.

L2 to L3 processor

The orbital-swath L2 products need to be converted into global-gridded L3 products. Therefore, all products retrieved from the SSM/I instrument were processed through a L2-to-L3 processor developed within GlobVapour project. Accordingly, the data were written on a global rectangular grid with a spatial resolution of $(0.5°)^2$, resulting in 720 x 360 grid boxes. The L3 grid cell indexed (1,1) in the Scientific Data Set is located at the lower left corner of the map and corresponds to a grid box with boundaries of 89.75°S to 89.75°N latitude and 179.75°W to 179.75°E longitude. All L2 grid boxes located in the area of x±0.25° and y±0.25° are centrally arranged in L3 grid box (x,y) on the global grid.

In the GlobVapour project, SSM/I data of two satellites are in use: DMSP F13 (01/1996 – 12/2008) and DMSP F14 (01/1998 - 08/2008). Since MERIS is a daytime only product, the SSM/I data singly contain descending overpasses (morning orbits). Figure 3-1 shows the ascending equator crossing time for various satellites. By adding 12 hours for descending equator crossing times, DMSP F13 and F14 are crossing the equator between 6 am and 8 am local time.

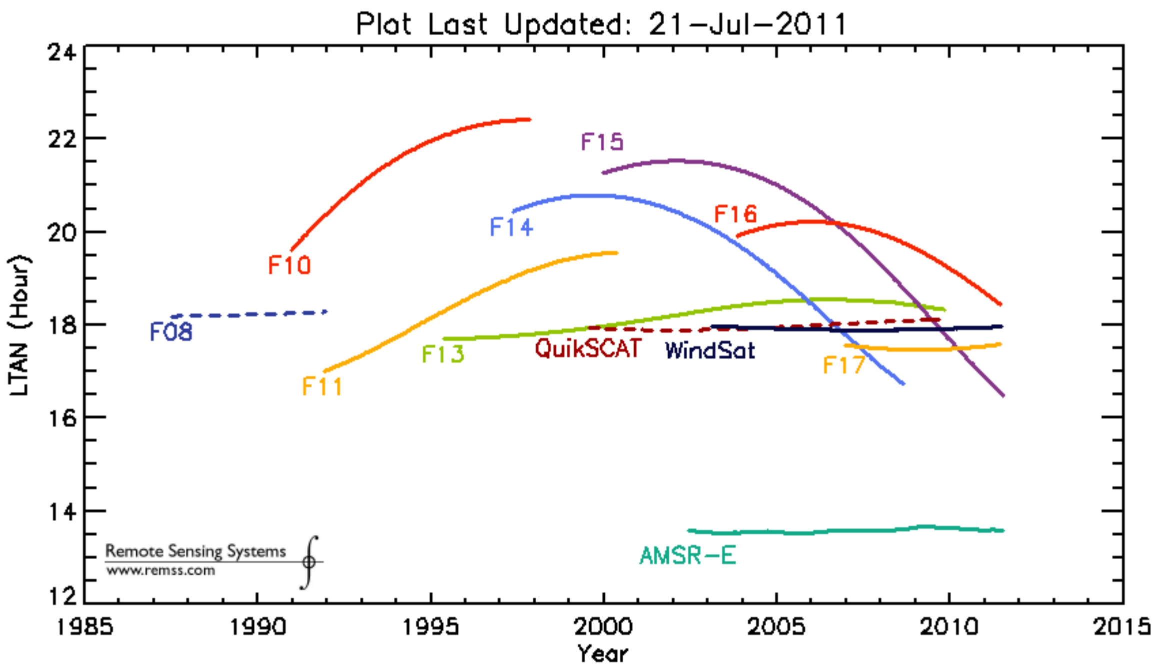

Figure 3-1: Equatorial Crossing Times (Local Solar Time) of the DMSP polar orbiters hosting the SSM/I instruments and the QuikScat platform hosting the SeaWinds scatterometer for the afternoon. Ascending Local Equator Crossing Times: F10, F11, F13, F14, F15, F16, F17, AMSR-E, WindSat / Descending Local Equator Crossing Times: F08, QuikSCAT (www.remss.com).

Two data products have been derived: daily composites and monthly means. For the daily composite the grid boxes will be overwritten chronologically, which implies that no averaging is performed for daily composites. As demonstrated in Figure 3-1, the equator crossing time of the two mentioned satellites has changed over time. Thus, the chronological order of the satellite changes in year 2006, because F14 is crossing earlier.

For the monthly mean, all available data for one month is averaged per grid box. Moreover, the monthly mean is not based on daily mean but is an average of all quality-checked L2 data for the whole month.

Due to the higher spatial resolution of MERIS, the MERIS-only L3 products are calculated on a rectangular (0.05 x 0.05)° grid, resulting in 7200 x 3600 grid boxes. All valid pixels within each grid box are averaged to achieve daily composites, containing all cloud-free observations recorded on the particular day above land, sea ice and sun glint. The latter is used to calculate the bias between MERIS and SSM/I retrievals (see section 3.2). In order to increase the computational efficiency, the monthly means of the MERIS-only L3 product are generated by averaging all valid daily entries for every grid box, extracted from the daily composites.

The two L3 data sources, TCWV from SSM/I above ice-free ocean and MERIS above cloud-free land and sea ice, are simply merged by oversampling the SSM/I data to the higher MERIS resolution of (0.05)°. An addional combined SSM/I+MERIS product with lower resolution (0.5 x 0.5°) is available, too.

The blended daily composites therefore contain

- oversampled, gridded TCWV extracted from SSM/I L2 data over the open ocean,
- gridded TCWV extracted from MERIS L2 data over cloud free land and sea ice,
- gridded TCWV extracted from MERIS L2 data over sun glint, where SSM/I observations are not available.

The blended monthly means contain

- oversampled, gridded TCWV, monthly averaged from SSM/I L2 data over the open ocean,

gridded TCWV, averaged from MERIS daily composites over land and sea ice

Along with the TCWV, each file contains the estimated TCWV error, the number of observations for each grid box and the background knowledge used for the retrieval. The latter is set to a constant value of 20 kg/m^2 in both the daily composites as well as in the monthly means, for all pixels where MERIS was used for the retrieval. The ocean grid boxes contain TCWV as extracted from ERA Interim of the particular day for the daily composites and their monthly average for the monthly means, respectively.

Table 3-1: Variables of the combined SSMI+MERIS data set

tcwv_bg	Background of the TCWV retrieval, unit: kg/m^2
tcwv_res	TCWV retrieval of SSM/I or MERIS, unit: kg/m^2
tcwv_sigma	Standard deviation of the retrieved TCWV, unit: kg/m^2
nobs	Number of observations
sfc_mask	GlobVapour Surface Mask 0: land, 1: ocean, 2: clouds, 3: ssmi_scattering, 4: sea_ice, 5. coast, 6: sun_glint

The SSM/I+MERIS processing scheme is described in detail in the ATBDs for SSM/I L2 [RD-1], MERIS L2 [RD-2], and SSMI+MERIS L3 [RD-3].

3.2 Practical application

L3 output data – end product

The end product (Level 3) undertakes grid-based global data with updated GlobVapour metadata information in NetCDF format following the CF-1.4 standard for daily composites as well as monthly means. Each file provides the following variables: TCWV, TCWV error, quality flag, and Number of Observations. The water vapour product has the unit kg/m^2.

The idea is to use inter-calibrate data of different satellites of the DMSP (see Figure 3-2). The prototype data set contains only descending data (morning orbits) of F13. The test and final data set contain descending data of F13 and F14.

Figure 3-2: Time line of DMSP Satellites. Data of F13 and F14 will be used for GlobVapour.

The bias between MERIS and SSM/I retrievals is hard to assess as the MERIS methodology is applicable only above land and sea ice surfaces, whereas SSM/I measurements allow the retrieval of TCWV above ocean only. A possible way to compare the results of both retrievals is to apply the MERIS retrieval over sun glint areas. Here the direct reflection of the sun at the sea surface provides a strong signal. The bias is therefore estimated for each day from all sun glint contaminated pixels and stored as an extra field of the metadata of the output file. A single bias is calculated for each month, based on all sun glint contaminated pixels of all days. Note that the bias has not been utilised to correct the data.

4 Assumptions and limitations

The SSMI+MERIS data set is a forenoon-only climatology above land and above ocean. There is no correction of the diurnal cycle effect on the retrieved water vapour.

Above ocean, the actual spatial resolution of the L3 products is (0.5 x 0.5)°, while it is (0.05 x 0.05)° above land. In order to provide both data sources within the highly resolved grid, the ocean data is oversampled by a factor of 10.

Neither SSM/I nor MERIS provide reliable estimates of TCWV above ocean in coastal regions. In case of MERIS, this is due to the weak reflectance of the ocean in the near infrared and the resulting uncertainty introduced by the unknown contribution of aerosol scattering and absorption to the signal. In case of SSM/I, the measurements cannot be used in case the relatively large footprint is contaminated by land.

The quality of the MERIS TCWV retrieval is unknown over mountainous and/or ice-covered areas, and is mainly determined by uncertainties in cloud detection.

A further restriction arises from the fact that the MERIS retrieval algorithm relies on measurements in the visible channels. For this reason, the TCWV will only be retrieved from MERIS day time overpasses over land.

A diurnal variation of the atmospheric water vapour is not captured but the differences can be assessed at least over oceans, if you would compare day and night SSM/I products.

Another limitation is that the MERIS level 2 water vapour products will only be generated under clear sky conditions. The filling of cloud gaps is an unresolved issue. Studies on the so called clear sky bias indicate that cloudy areas should not be filled with values from neighbouring clear sky pixels.

Another issue, not dealt within this document, is the homogenisation of the radiance time series. The SSM/I time series relies on existing homogenisations, and MERIS stability is not considered as critical due to the relatively short length of the time series.

5 Conclusions

The combined SSM/I+MERIS TCWV L3 data set provides global daily composites and monthly means of total column water vapour on rectangular grids. Both data streams are processed independently and combined afterwards to fit in one file per day and month, respectively.

By using SSM/I measurements above ocean and the MERIS retrieval above land and sea ice surfaces, the resulting combined data set relies on two highly accurate and well established methods for the retrieval of total column water vapour.