DUE GLOBVAPOUR

Product Validation Report
Combined SSMI + MERIS

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1 Introduction

1.1 Purpose

This document constitutes the Product Validation Report for the GlobVapour combined SSMI+MERIS products, describing the validation and intercomparison of these products for the monthly means of the final phase (2003-2008). Detailed results are presented for two exemplary months of January and August 2008, reflecting the situation for respectively the summer and winter season on the northern hemisphere.

1.2 Definitions, acronyms and abbreviations

AIRS	Atmospheric Infrared Sounder
ARM	Atmospheric Radiation Measurement
ATOVS	Advanced TIROS Operational Vertical Sounder
CDO	Climate Data Operator
CM-SAF	EUMETSAT Satellite Application Facility on Climate Monitoring
GUAN	GCOS Upper Air Network
IAPP	International ATOVS Processing Package
IR	Infrared
MERIS	Medium-Resolution Imaging Spectrometer
MWR	Microwave Radiometer
NIR	Near-Infrared
RMSE	Root Mean Square Error
SSMI	Special Sensor Microwave Imager
TCWV	Total Column Water Vapour
TPW	Total Precipitable Water

1.3 Applicable Documents

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

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

[AD-3] DUE GLOBVAPOUR Product Validation Plan (PVP), issue 1, revision 0, 20 July 2010.

[AD-4] DUE GLOBVAPOUR Validation Data Document (VDD), issue 1, revision 0, 20 July 2010.

1.4 Reference Documents

[RD-1] DUE GLOBVAPOUR Algorithm Theoretical Baseline Document (ATBD) for L3 SSMI+MERIS, issue 3, revision 0, 19 January 2012.

[RD-2] Water Vapour and Temperature from ATOVS, Product User Manual, CM-SAF, issue 1.1, 19 September 2009.

[RD-3] Validation of the water vapour and temperature products from ATOVS, Version 300/310/320 products, CM-SAF, issue 1.2, 29 January 2010.

[RD-4] Sohn, B.J., et al., Dry Bias in Satellite-Derived Clear-Sky Water Vapour and its Contribution to Longwave Cloud Radiative Forcing, J. Climate 19, p. 5570-5580, 19 July 2005.

[RD-5] John, V.O., et al.The Impact of Clear-Sky Only Sampling on HIRS Estimates of Distribution, Variability and Trend in Upper-Tropospheric Humidity, J. Geophys. Res., 2010.

[RD-6] Mieruch, S., et al. 2010: Comparison of monthly means of global total column water vapor retrieved from independent satellite observations. Accepted at J. Geophys. Res.

[RD-7] DUE GLOBVAPOUR Algorithm Theoretical Baseline Document (ATBD) for L2 SSMI, issue 3, revision 0, 19 January 2012.

[RD-8] DUE GLOBVAPOUR Algorithm Theoretical Baseline Document (ATBD) for L2 MERIS, issue 3, revision 0, 19 January 2012.

1.5 Structure of the document

Section 2 gives a concise, exemplary overview of the GlobVapour combined SSM/I+MERIS products. The conducted consistency check of neighbouring pixels is illustrated in section 3. In section 4 the methods, tools and data used for the validation and intercomparison are referenced. The results of the validation and intercomparison for the full final phase (2003-2008) are presented in section 5, with a discussion of the observed values and results at the end of the section. Conclusions are made in section 6.

2 Product Description

Technical specifications of the combined SSM/I+MERIS products are given in [AD-2]. The monthly mean products for the exemplary months July 2007 and January 2008 are shown in Figure 2-1.

As the SSM/I TCWV is only derived from observations in descending orbits, over ice-free sea surface [RD-1], during the Southern Hemispheric winter in July 2007 a large area around the Antarctic Sea is blanked out. In addition, MERIS retrieval over land leaves out cloudy area [RD-1], as well as area with low solar inclination occurring in winter months (which is visible as horizontal cut-off feature over the Northern Hemisphere in January 2008). Furthermore, gaps may appear due to insufficient observations (applied threshold of 10 values per grid box).

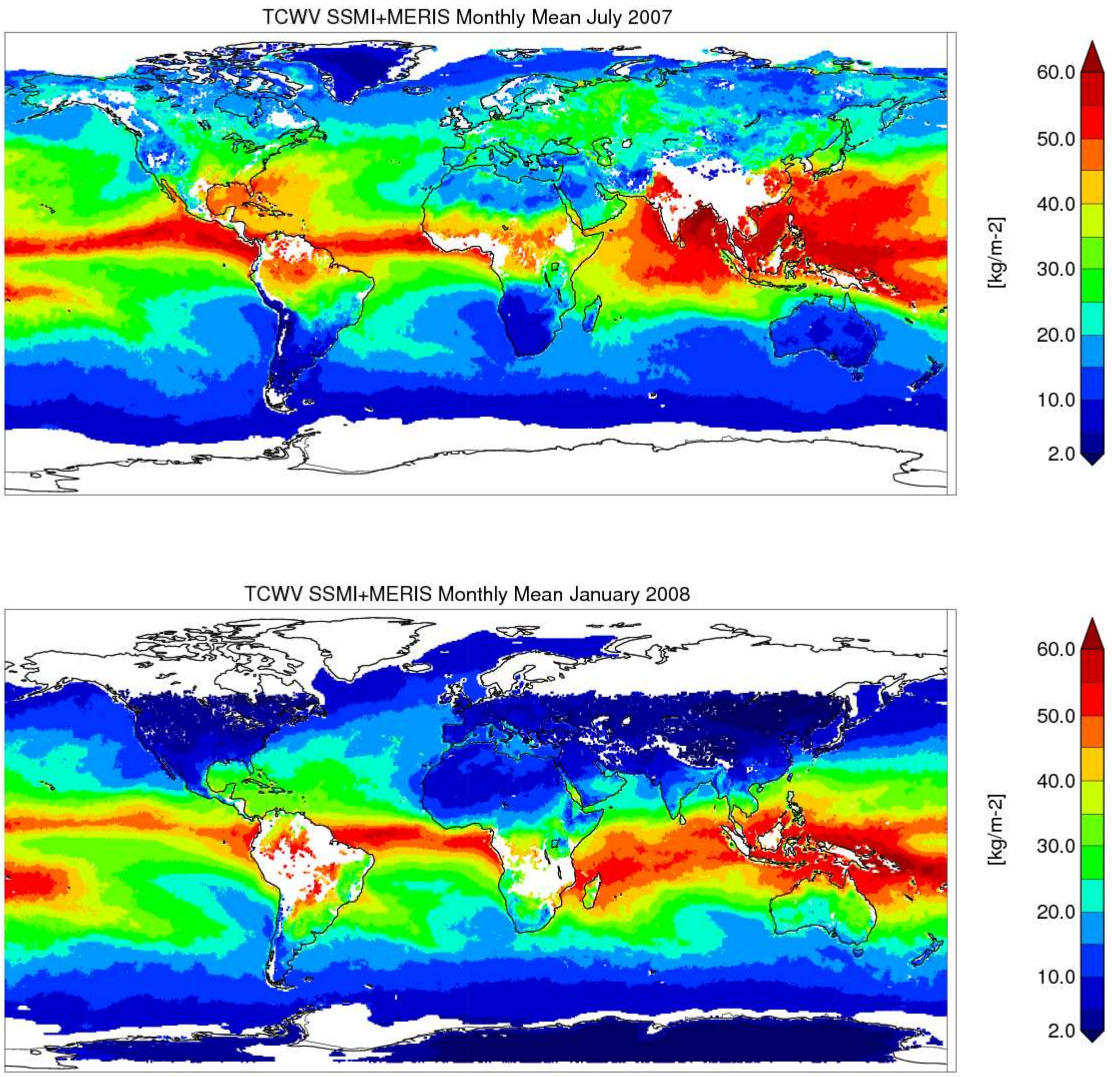


Figure 2-1: Combined SSM/I + MERIS monthly mean TCWV for July 2007 (top) and January 2008 (bottom).

3 Consistency analysis

The SSM/I+MERIS product consists of spatially complementary TCWV products, that is, both TCWV products do not overlap. Therefore, a direct comparison is not possible in order to analyse the consistency between both products. Three approaches are considered to analyse the consistency:

1) Determine the bias in sun glint regions where a reliable retrieval of TCWV from MERIS is possible.
2) Determination of bias and correlation of “neighbouring” SSM/I and MERIS pixels.
3) Visual inspection of regional TCWV SSM/I+MERIS images.

3.1 Analysis of sun glint regions

Figure 3-1 shows bias and RMSD TCWV between SSM/I and MERIS in sun glint regions for July 2007 (GlobVapour test product). Starting at approximately 0.1 in ocean reflectance bias and RMSD approach values of ~1.3 and 5 mm. The monthly average bias between SSM/I and MERIS in sun glint regions will be provided as attribute to the final products.

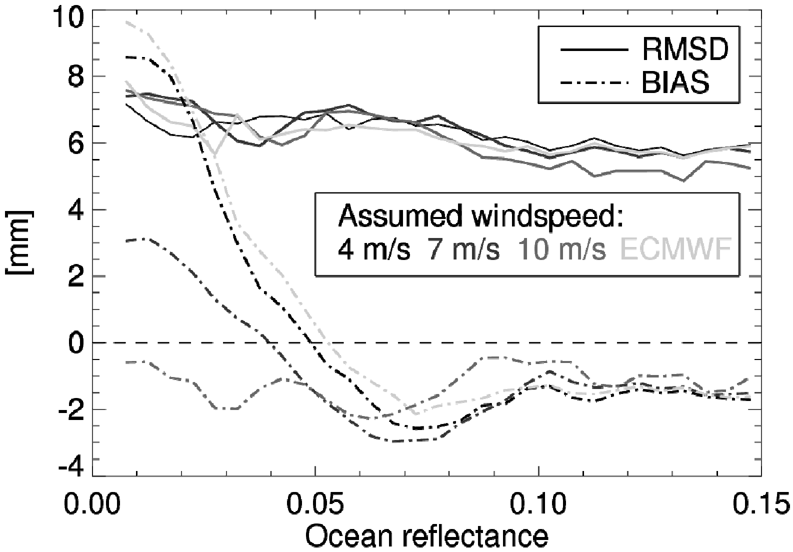


Figure 3-1: Bias and RMSD in TCWV between SSMI and MERIS in sun glint regions for July 2007 (test product).

3.2 Analysis of ‘neighbouring’ regions

The bias and Pearson product-moment correlation coefficient (corr) were also determined between SSM/I and MERIS. The surface flag has been used to identify TCWV products in coastal regions. Then, direct neighbours of SSM/I and MERIS have been identified within a distance of less than 0.7°. In addition, MERIS values were only considered when the altitude is below 50 m. Figure 3-2 gives exemplary collocated SSM/I (red) and MERIS (blue) pixels for July 2007. Bias and correlation are given in Table 3-1. Note that the absolute bias increases with increasing temporal resolution while the correlation does not change significantly.

Table 3-1: Bias and correlation (corr) between neighbouring ocean (SSM/I) and land (MERIS) TCWV values (DC: daily composites, MM: monthly means, Hires: high resolution product).

Resolution	Bias (kg/m^2)	corr
Hires (0.05°)², DC	0.65	0.85
Hires (0.05°)², MM	-2.5	0.88

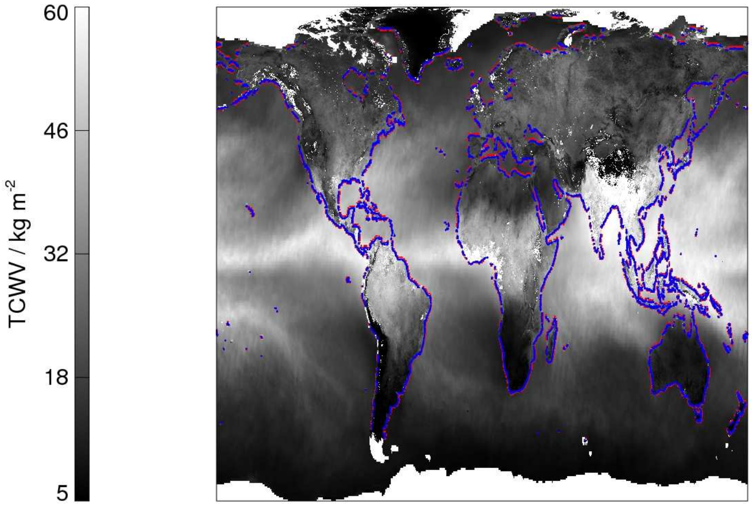


Figure 3-2: Exemplary SSM/I (red) and MERIS (blue) pixels within a distance of 0.7° at maximum but over ocean and over land, respectively. In grey scales TCWV for July 2007 is presented.

3.3 Graphical analysis

Finally, the coastlines of different regions, e.g. Gulf of Mexico, Argentina, and west Europe, have been analysed graphically for daily composites as well as monthly means in July 2007 and January 2008. The regions were chosen, because the coastlines exhibit low topography, e.g. mountain ranges.

The monthly means are displayed in Figure 3-3 and Figure 3-4. Apparently, the neighbouring pixels of SSM/I and MERIS in summer months (in this example July on Northern Hemisphere and January in South Hemisphere) are more consistent than in winter months. The temporal choice for the examples of daily composites (Figure 3-5 and Figure 3-6) was made because the swaths of both instruments (SSM/I and MERIS) coincide. The last mentioned examples present better consistencies in summer months, too.

In summary, the TCWV transforms seamlessly in most of the coastlines with low topography, especially recognisable in monthly means in summer months. But it has to be mentioned that a smooth transition in coastal regions with mountain ranges can not be expected. Again note that biases may occur because SSM/I is an all sky product while MERIS measures only at clear sky.

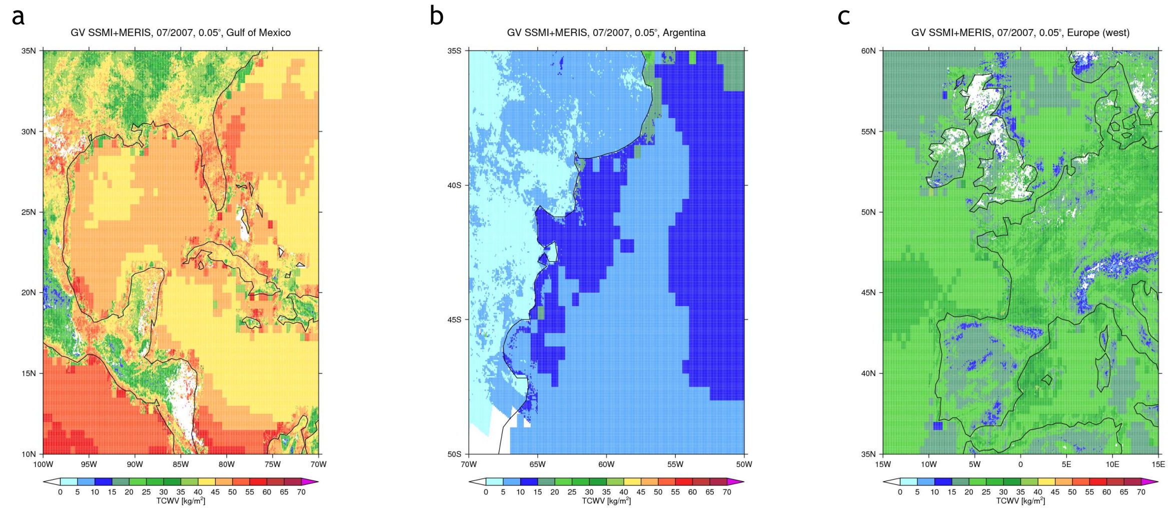


Figure 3-3: SSM/I+MERIS monthly mean TCWV over Gulf of Mexico (a), Argentina (b) and west Europe (c) for July 2007

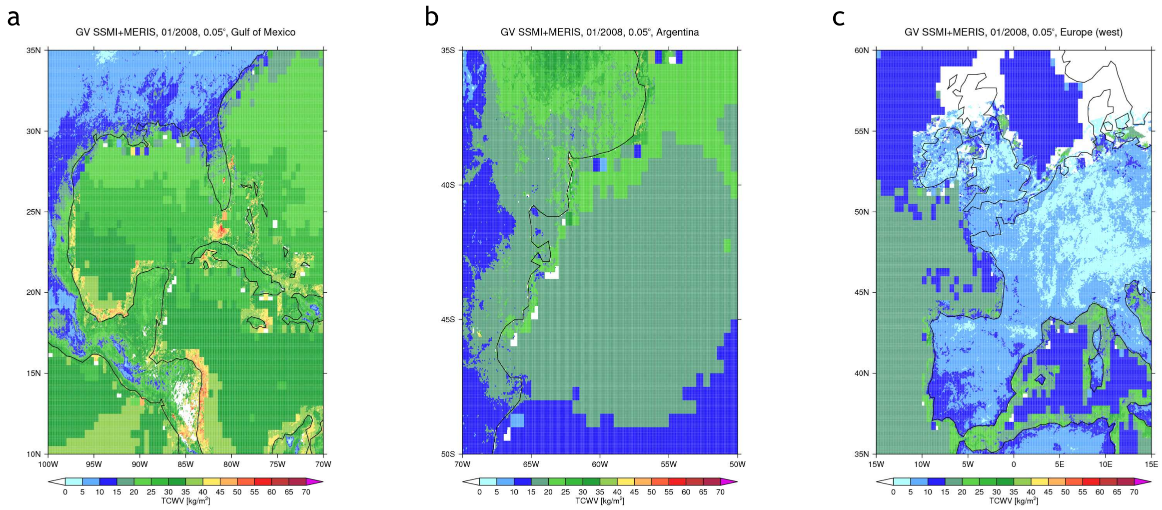


Figure 3-4: SSM/I+MERIS monthly mean TCWV over Gulf of Mexico (a), Argentina (b) and west Europe (c) for January 2008

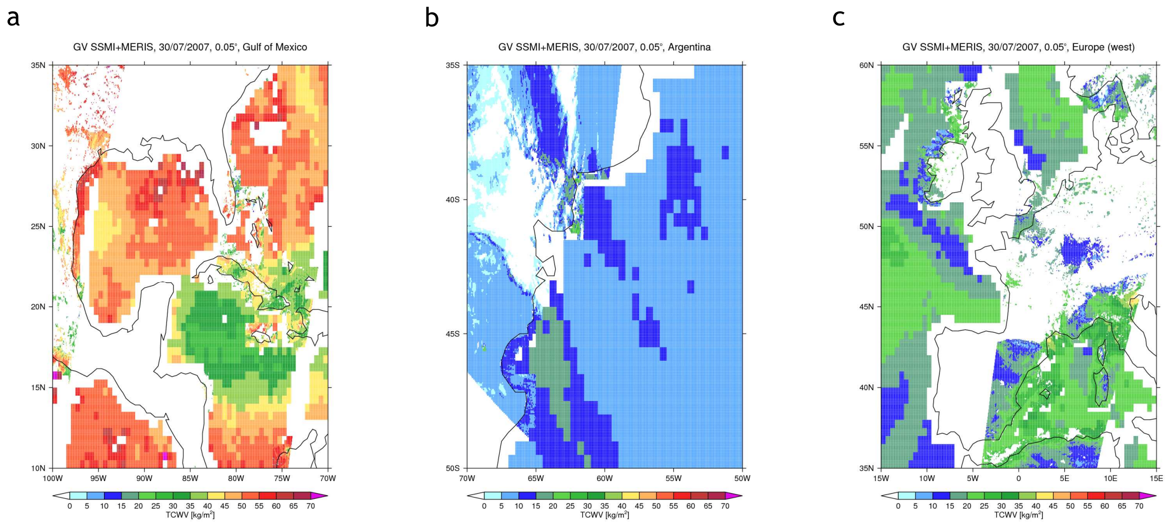


Figure 3-5: SSM/I+MERIS daily composite TCWV over Gulf of Mexico (a), Argentina (b) and west Europe (c) for 30th July 2007

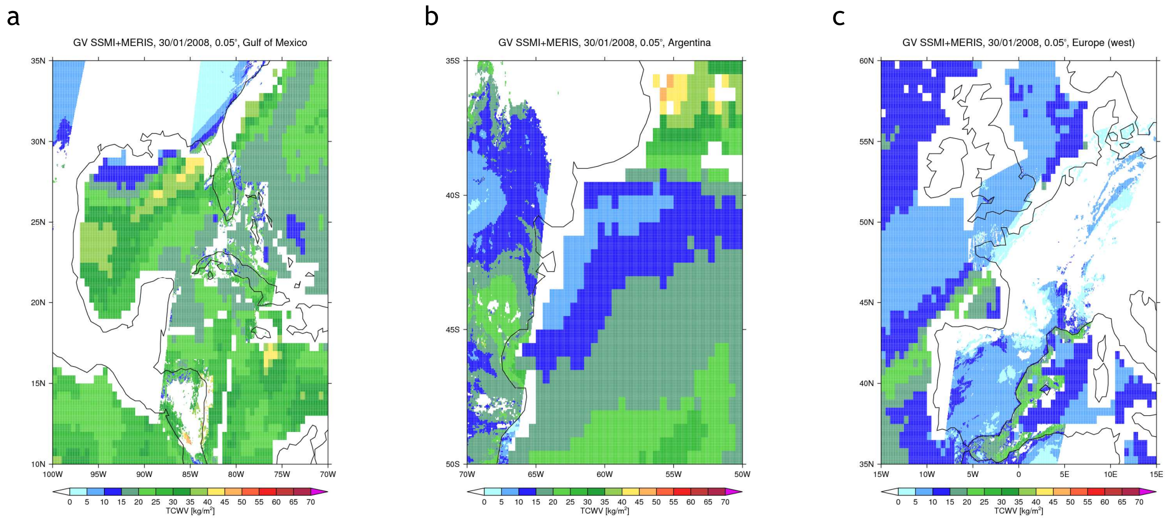


Figure 3-6: SSM/I+MERIS daily composite TCWV over Gulf of Mexico (a), Argentina (b) and west Europe (c) for 30th January 2008

4 Validation Method and Data

The methods and tools used for the validation and intercomparison of the combined SSM/I + MERIS products are described in the GlobVapour Product Validation Plan (PVP) [AD-3]. Further details to the specific techniques used for the processing, sampling and comparison of the Level 3 data, are described in the individual subsections of section 5. The ground based and satellite based data used for the validation and intercomparison are described in the Validation Data Document (VDD) [AD-4].

The validation and intercomparison has been performed for the monthly means on global grid for each pixel. In such a way that positive and negative bias values imply respectively higher and lower humidity of SSM/I + MERIS data.

5 Validation and Intercomparison Results

5.1 Ground based data

<u>*GUAN stations*</u>

Figure 5-1 to Figure 5-4 show the validation results of the GlobVapour combined SSM/I + MERIS products against the radiosonde data from the GUAN network, which includes 165 Stations. A threshold of 30 radiosonde observations per station location per month has been applied to the collocated GUAN and combined SSM/I + MERIS data. Figure 5-1 shows the overall bias as a scaled circle at the station location, where blue and red represent respectively positive and negative values for one exemplary month.

It is noticeable, that the GUAN network contain stations on land the most. Thus, the validation for ocean is not as significant for SSM/I as for MERIS. For a better intercomparision base versus MERIS, a GUAN clearsky product was developed within the GlobVapour project. Unfortunately, the validation results have shown too less observations in the collocated dataset in order to perform significant investigations.

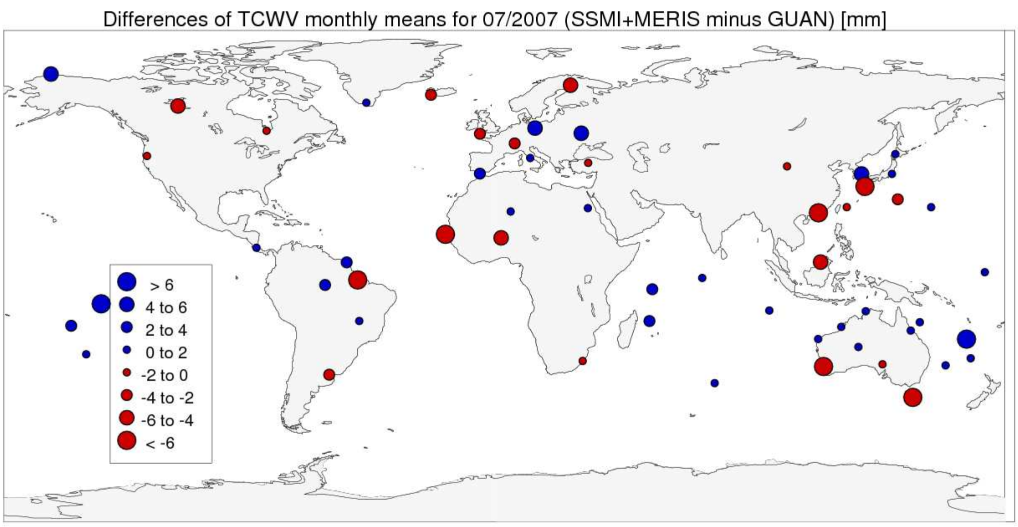


Figure 5-1: Combined SSM/I + MERIS versus GUAN radiosonde monthly mean TCWV global distribution for July 2007.

The graphs in Figure 5-2 show the monthly values of the bias and standard deviation individually for two exemplary years within the years 2003-2008. Figure 5-3 provides a time series of the bias and RMSE for the final data period. Figure 5-4 shows a scatter plot of all valid collocations of the final phase.

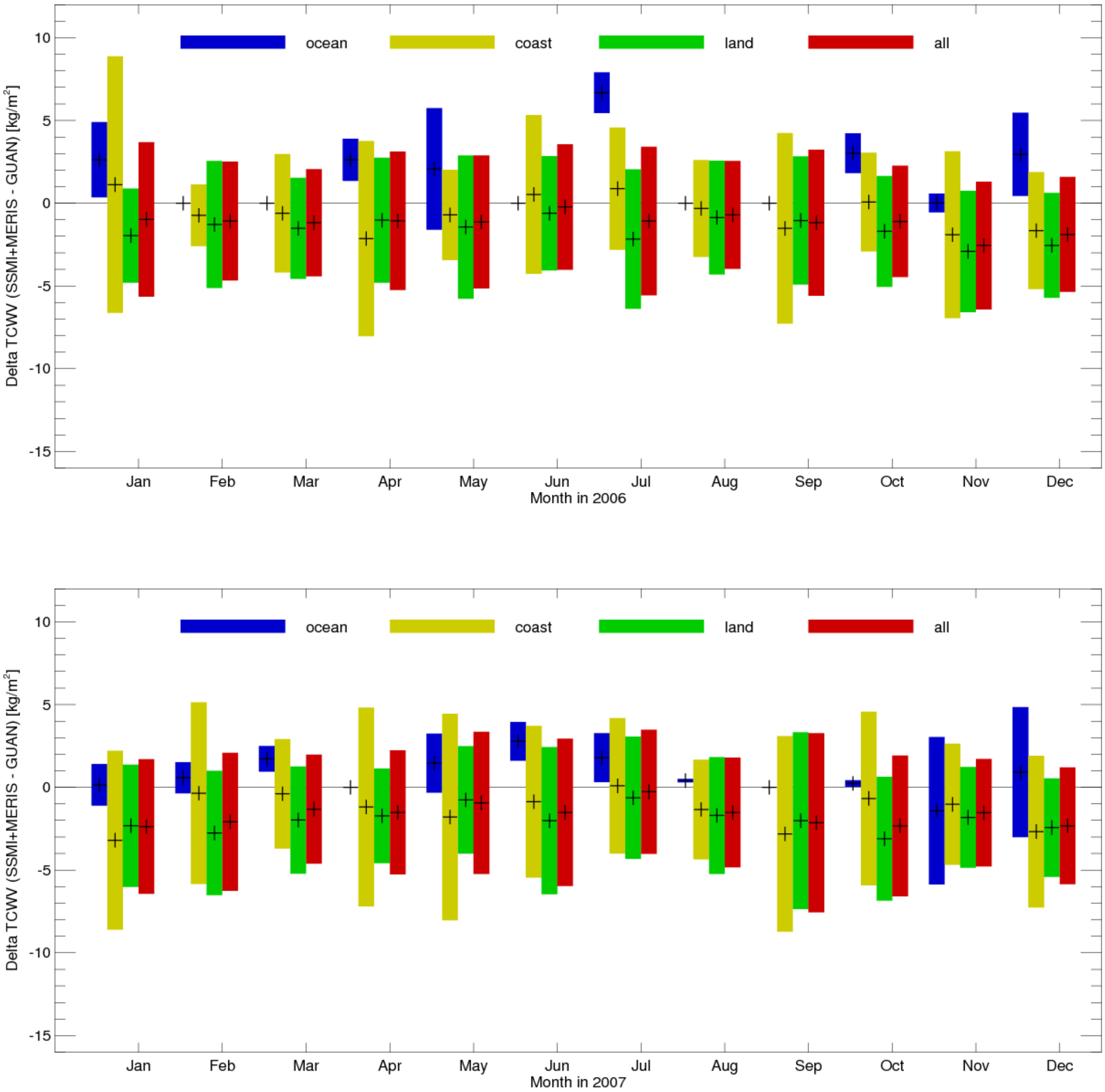
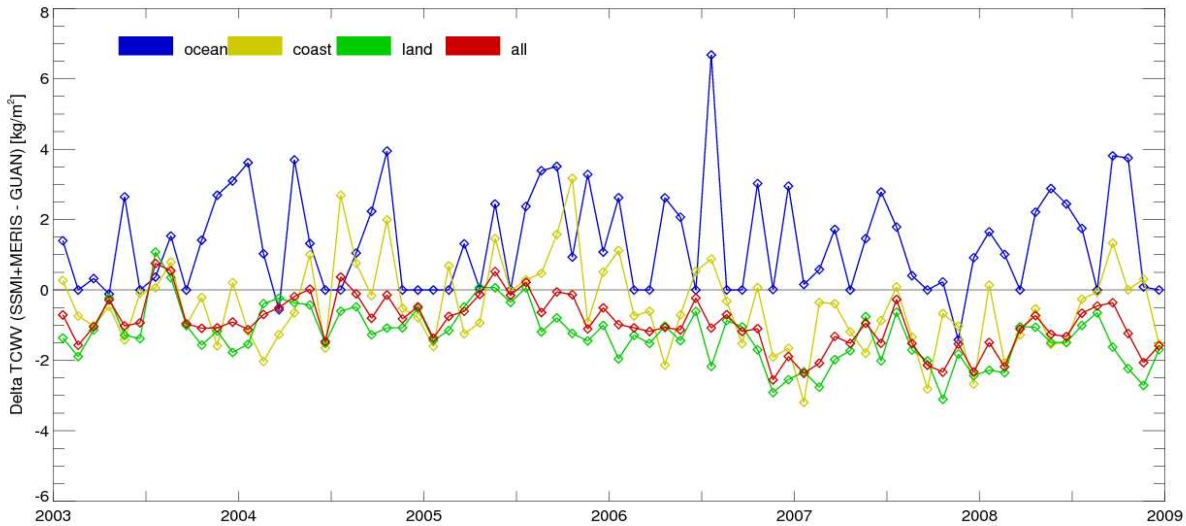


Figure 5-2: Combined SSM/I + MERIS versus GUAN monthly mean TCWV bias and variability for the years 2006 and 2007 within the final time period.



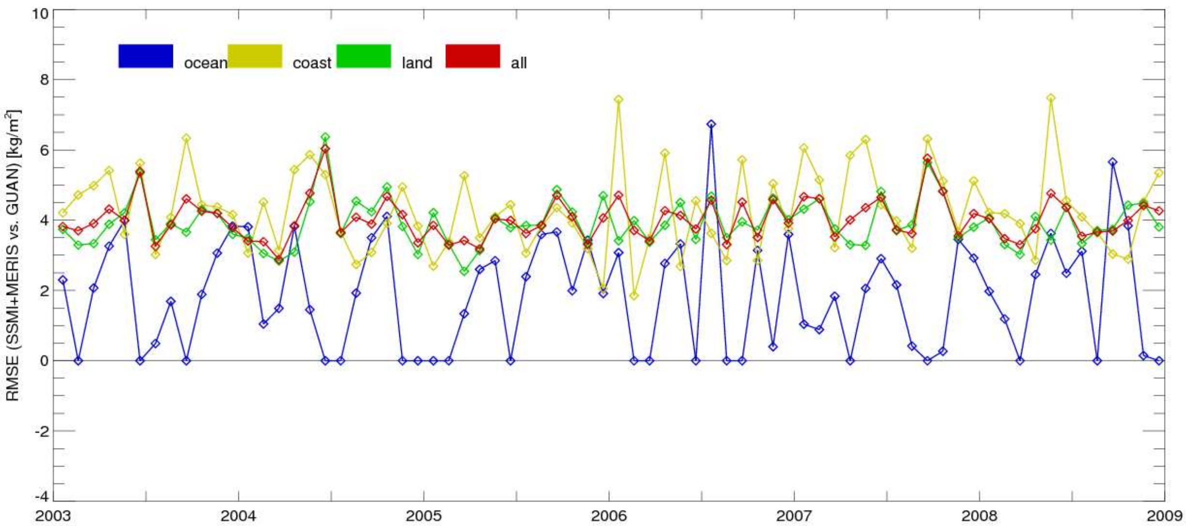


Figure 5-3: Combined SSM/I + MERIS versus GUAN monthly mean TCWV bias (top) and RMSE (bottom) for 2003-2008.

On average for the period 2003-2008 and all stations, the mean bias is **-(0.94 ± 0.72)** kg/m^2, together with a mean RMSE of **(4.03 ± 0.58)** kg/m^2. Here the uncertainty margins result from the (non-weighted) spread (σ_{N-1}) of the four values. Details and average values are discussed in section 5.3.

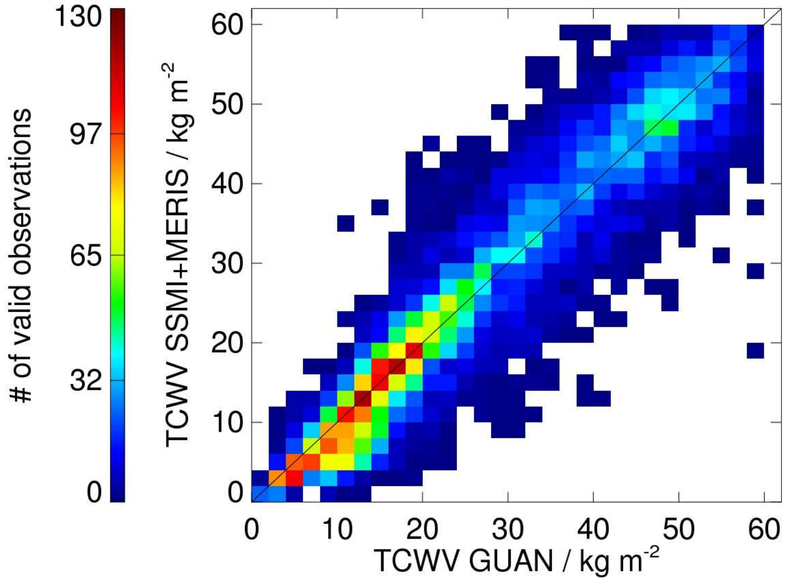


Figure 5-4: Scatterplot of SSM/I+MERIS versus GUAN monthly mean TCWV for 2003-2008. The average bias is given in the text and in the conclusions. The low resolution product has been used (0.5°).

ARM sites

The Radiosonde and Microwave Radiometer (MWR) data from the three ARM sites Barrow, Lamont and Nauru have been used for the validation of the final years 2003-2008. Lamont is located continental and its data are matchable to MERIS data. Nauru is a small island in the pacific and its data can be compared with SSM/I data. The data at coastlines are comparable with data of the station in Barrow, which is located at Alaska's coastline (see figure Figure 5-5).

Figure 5-5: selected stations in the ARM network.

The validation results of the GlobVapour SSM/I+MERIS TCWV MM products against ARM are showed in Table 5-1, Figure 5-6 and Figure 5-7. In the in scatter plots and time series, the bias is shown as a triangle for sea bound observations and as a square for observations over land.

The number of collocated stations is maximal three. A threshold of 15 radiosonde observations per station location per month has been applied to the collocated ARM and combined SSM/I + MERIS data (values below this threshold have not been considered).

Table 5-1: Overall validation results (average number of observations, mean bias and RMSE) for SSMI+MERIS versus ARM site Radiosonde data, from 2003-2008 monthly means.

	Radiosonde			MWR		
	N_obs	Bias (kg/m^2)	RMSE (kg/m^2)	N_obs	Bias (kg/m^2)	RMSE (kg/m^2)
Barrow	14	-2.50	3.35	14	-3.43	4.12
Lamont	55	-2.72	3.90	55	-3.44	4.93
Nauru	70	-0.69	2.43	70	-2.27	2.75

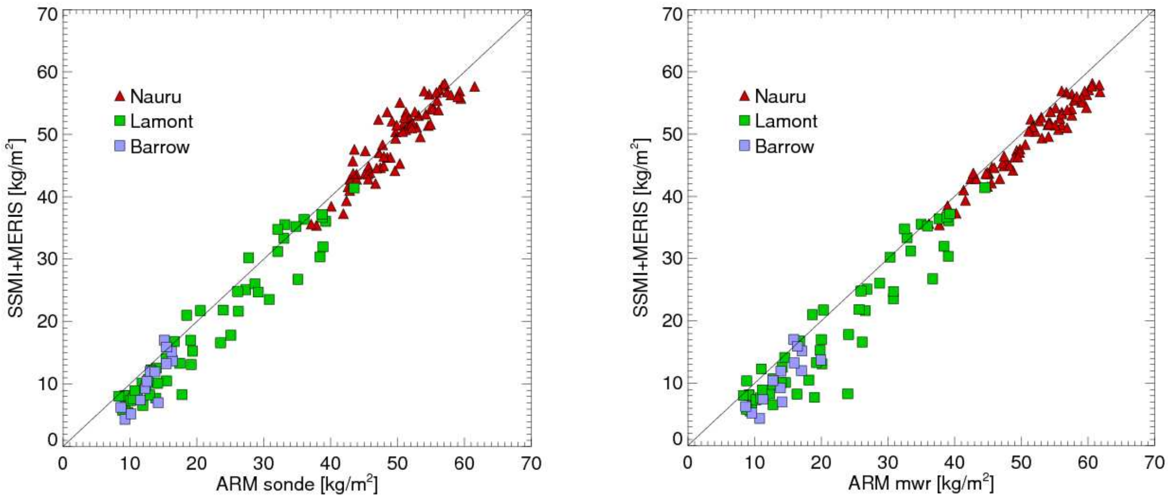


Figure 5-6: Combined SSM/I + MERIS versus ARM Radiosonde (left) and MWR (right) monthly mean TCWV scatter plot of the bias for 2003-2008.

On average for the period 2003-2008 and all three stations, the mean bias is **-(1.97 ± 2.48)** and **-(3.05 ± 2.50)** kg/m^2 for respectively the Radiosonde data and MWR data. Here the uncertainty margins result from the (non-weighted) spread (σ_{N-1}) of the four values. RMSE values are not commented because their significance is considered to be low due to small observation number.

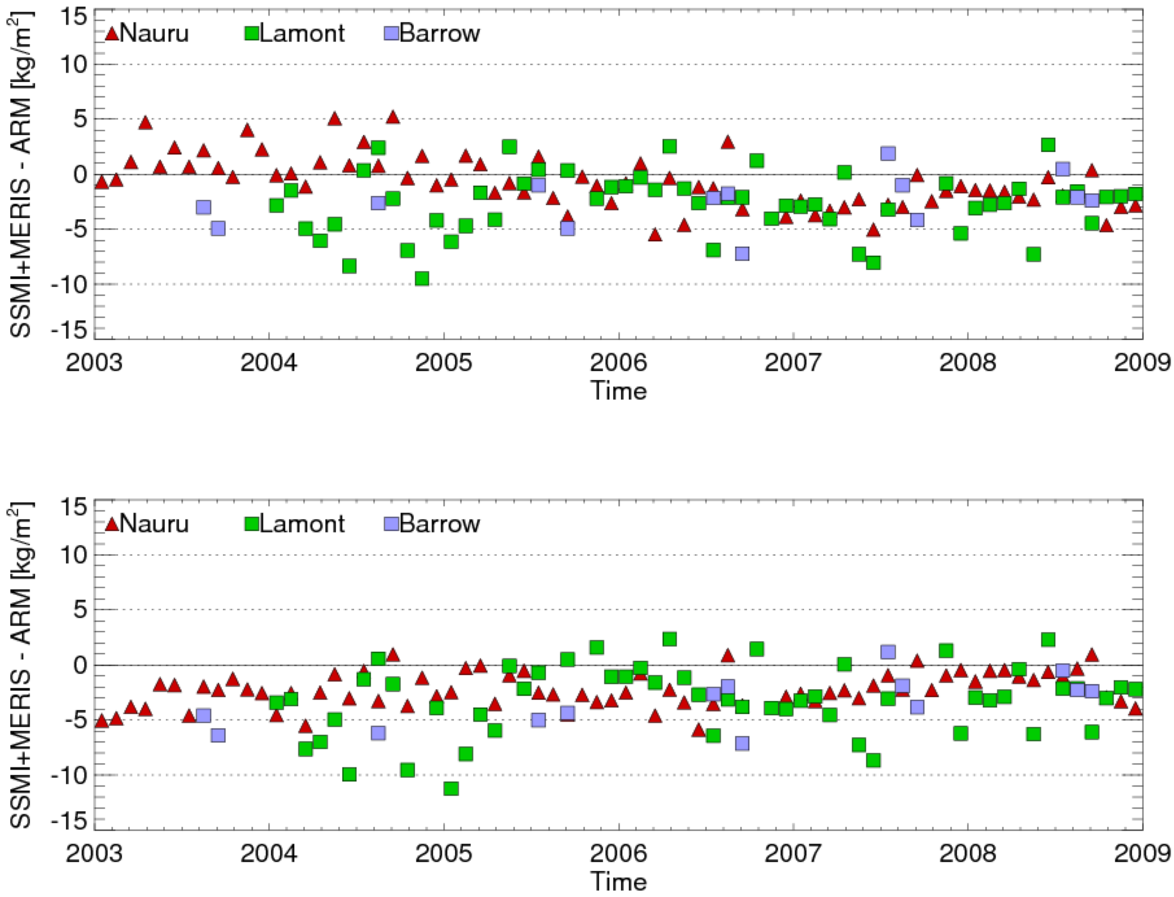


Figure 5-7: Combined SSM/I + MERIS minus ARM Radiosonde (top) and ARM MWR (bottom) monthly mean TCWV time series of the bias for 2003-2008.

5.2 Satellite based data

The GlobVapour final data set has been validated against satellite-based data. Previous GlobVapour validation were completed with various satellite-based sensors, e.g. ATOVS, AIRS, MODIS IR and MODIS NIR. Due to inconsistency duties concerning spatial resolution and technical differences, the final dataset has been validated only versus the sensors AIRS and ATOVS data. The global distribution of the monthly mean for one exemplary month July 2007 is shown in figures per month and per satellite product (AIRS IR and ATOVS). Results for the whole final phase (2003-2008) have been also displayed and discussed in the following.

AIRS

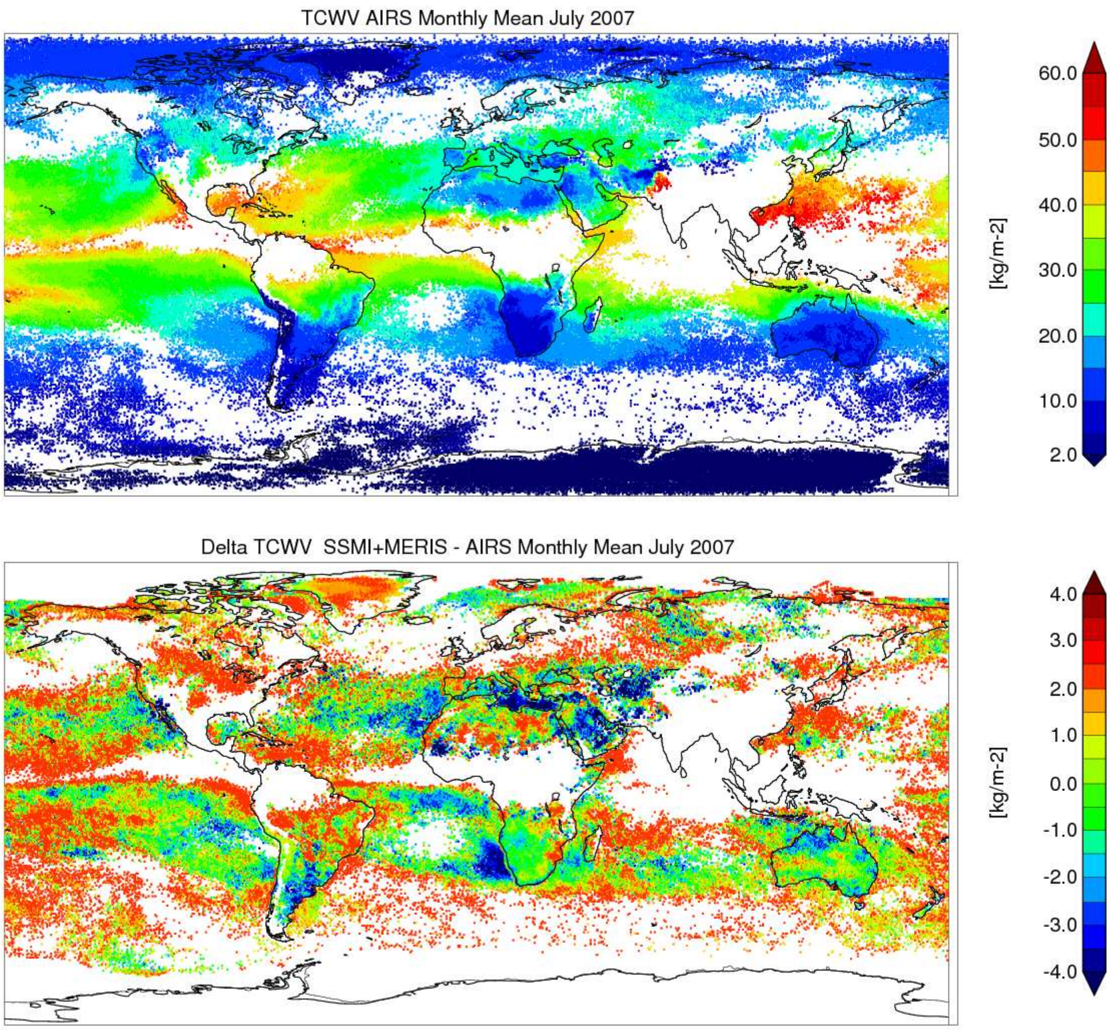


Figure 5-8: AIRS clearsky monthly mean TCWV global distribution for July 2007 (top) and the combined SSM/I + MERIS product versus AIRS clearsky monthly mean TCWV global distribution for July 2007 (bottom).

Only data with a quality flag set to 'Highest Quality' or 'Good Quality' has been used for the processing (data with the third and lowest flag value 'Do Not Use' has been discriminated).

The availability of the downloaded AIRS L2 data (nominally 240 files per day) was resp. 99.32% and 99.94% for the months of January and August 2008, and was only once below 99% for November 2003 in the period 2003-2008.

Figure 5-8 presents the statistics of the global distribution of the associated difference of the monthly mean for one exemplary month (July 2007). All products have been reprocessed with improved data generated during the Final Phase. A generic distance of 150 km to the nearest land mass has been used for identification of the coastal area. A threshold of 10 observations per grid box has been applied (values below this threshold have not been considered). For the difference calculation, the AIRS product has been pixel-wise subtracted from the GlobVapour combined SSM/I + MERIS product, which was down-sampled to adapt spatial resolutions. All products have been normalised to the latitude dependent area of each grid box. The values are given for the collocated subset of valid grids.

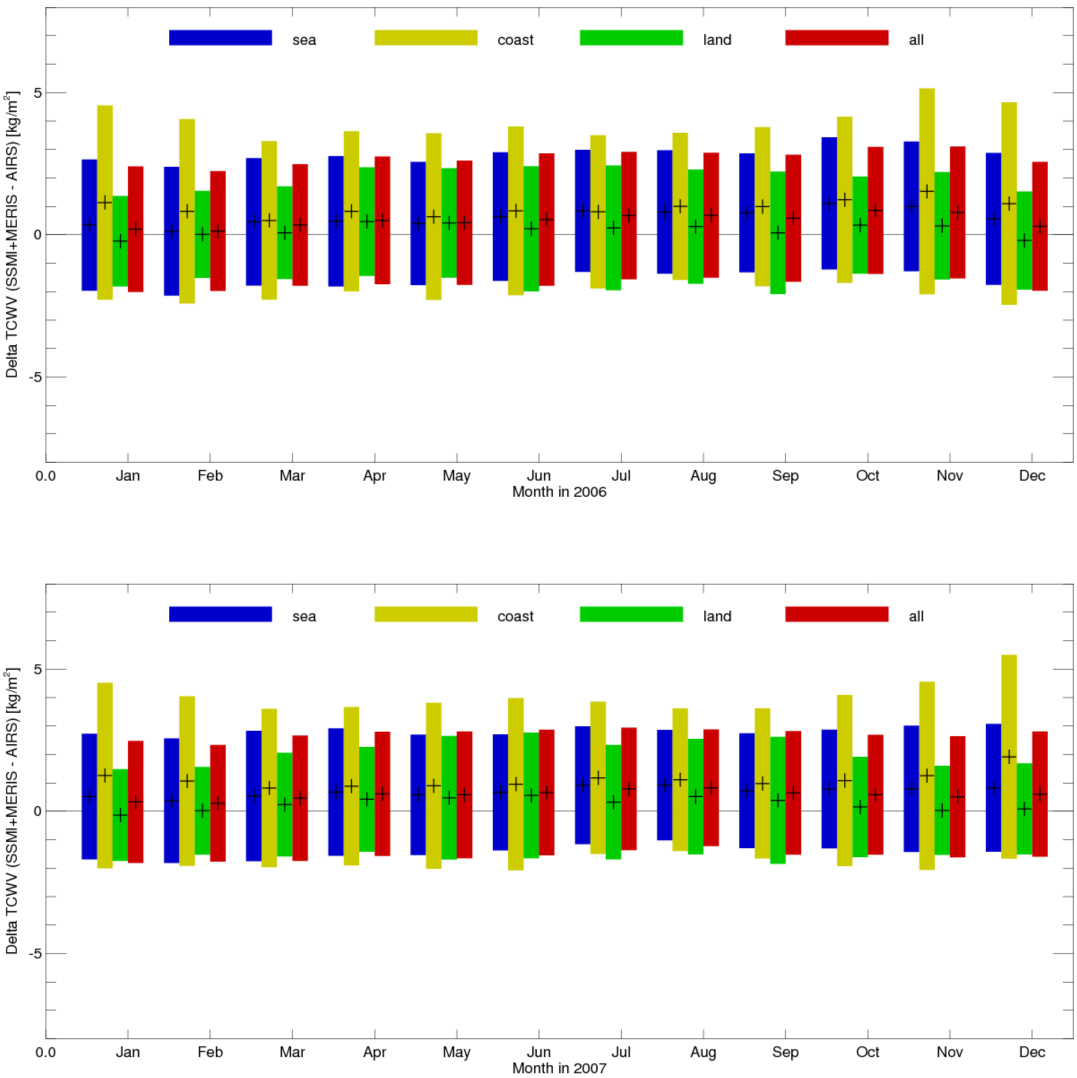


Figure 5-9: Combined SSM/I + MERIS versus AIRS monthly mean TCWV bias with variability for years 2006 and 2007 within the final period of2003-2008.

The graphs in Figure 5-9 show the monthly values of the bias and standard deviation for the years 2003 to 2008. Average values per annum are given for the bias and RMSE in Figure 5-10 differentiated by ocean/sea, coast, land and all.

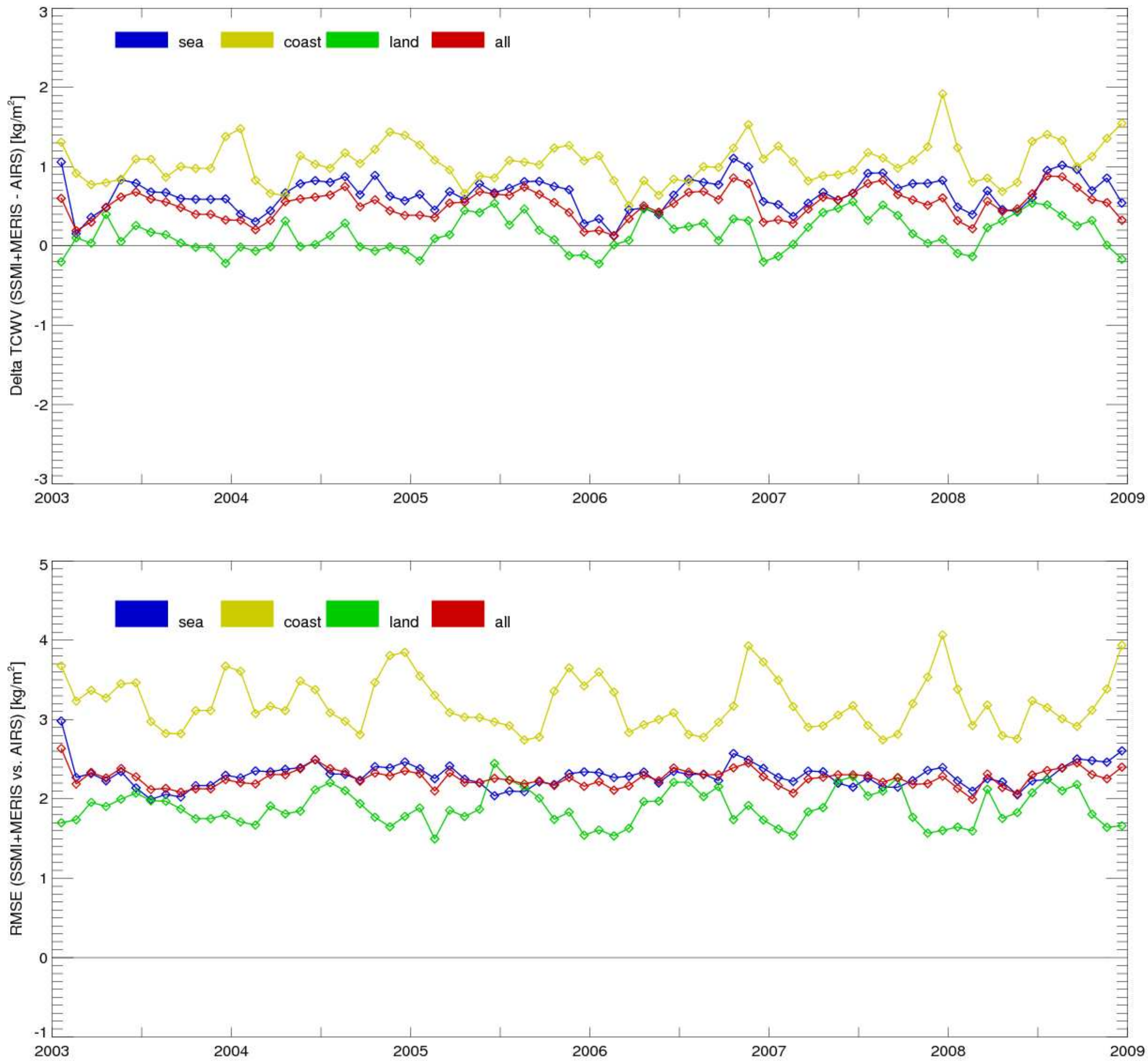


Figure 5-10: Combined SSM/I + MERIS versus AIRS monthly mean TCWV bias (top) and RMSE (bottom) for 2003-2008.

On average for the period 2003-2008, the mean bias is **-(0.52 ± 0.18)** kg/m^2, together with a mean RMSE of **(2.26 ± 0.11)** kg/m^2. Here the uncertainty margins result from the (non-weighted) spread (σ_{N-1}) of the four values. Details and average values are discussed in section 5.3.

ATOVS

For the intercomparison with ATOVS data, the CM SAF L3 products on a global (386 x 162) grid [AD-4], which is a cylindrical equal area projection with (90 km)^2 spatial resolution, have been remapped and re-sampled to a 0.5 squared degree (720x360) grid using the Climate Data Operator (CDO) tool with a nearest-neighbour interpolation function. The data are available for the period of 2004 to 2009 at present. Therefore, the validation against ATOVS data has been investigated only for the time period 2004-2008.

ATOVS data are described in [AD-4] and references therein. Water vapour ATOVS data consist of a Total Column field, as well as water vapour integrated over several layers. The latter are not used for combined SSM/I + MERIS intercomparison.

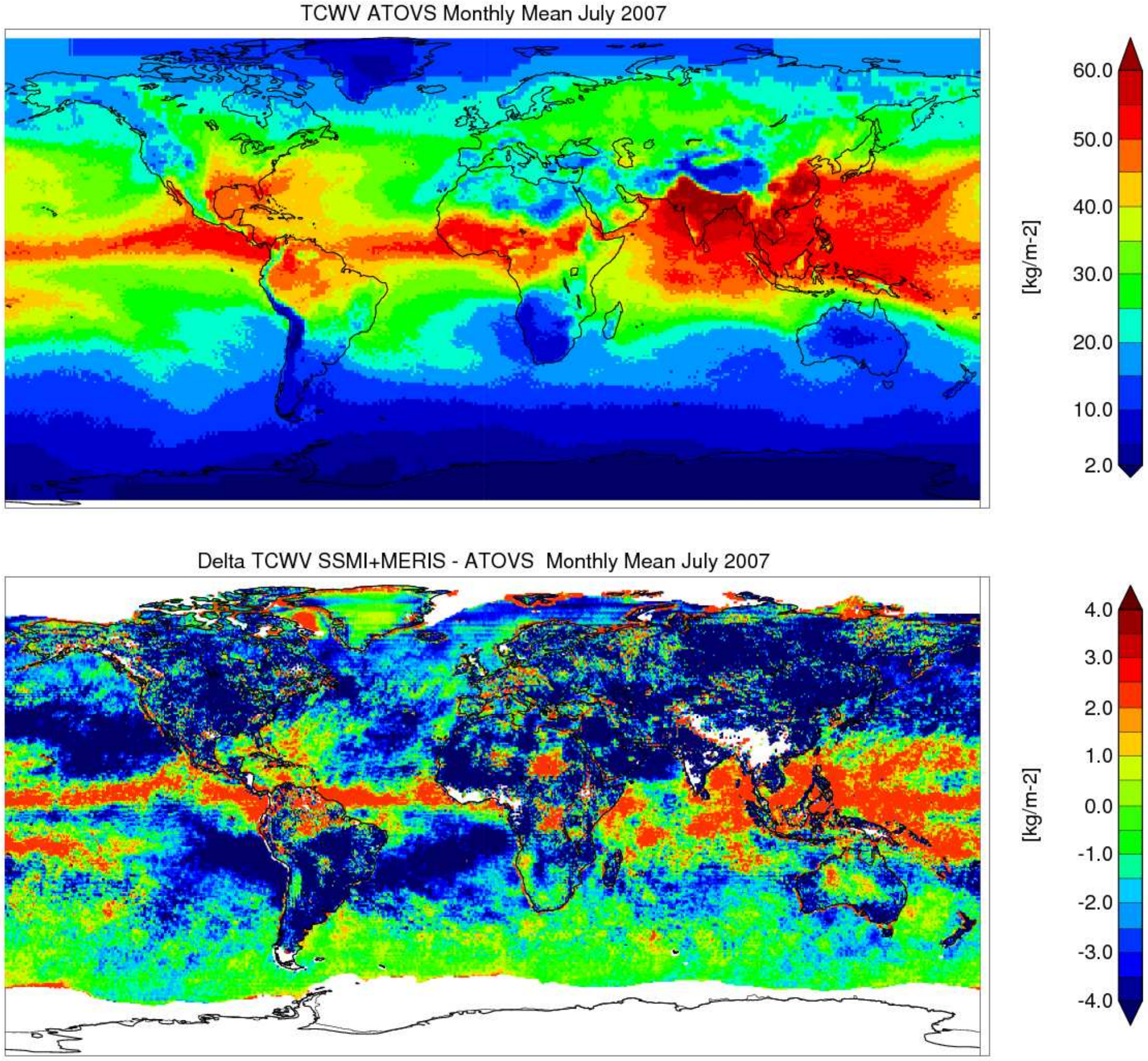
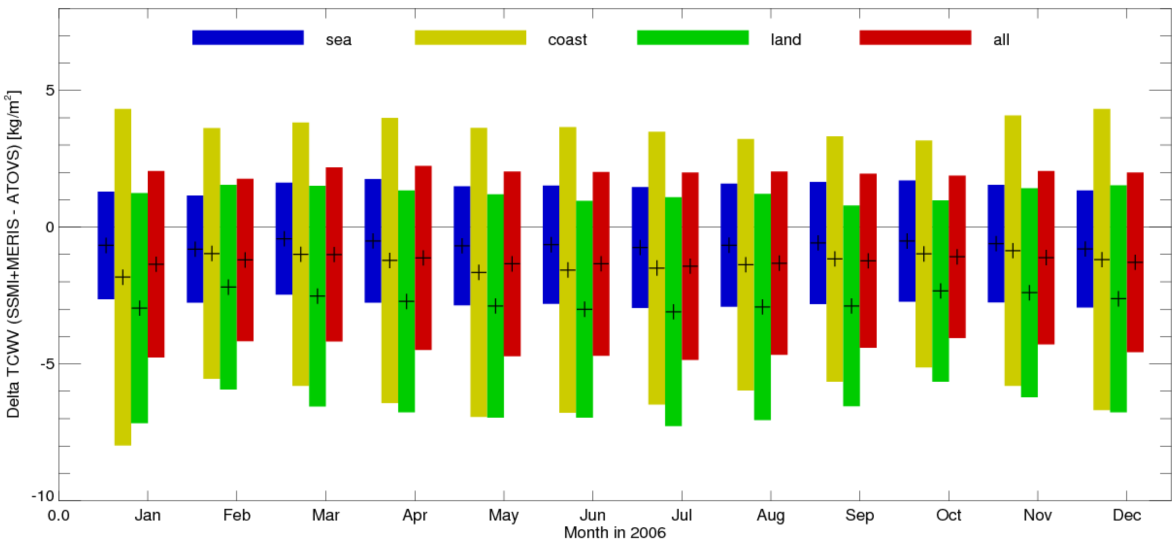


Figure 5-11: ATOVS monthly mean TCWV global distribution (top) and the combined SSM/I + MERIS product versus ATOVS monthly mean TCWV global distribution for July 2007 (bottom).

The CM SAF ATOVS products have no quality flags or masks to be considered. The products have been generated with automatic cloud correction applied by the IAPP package to the HIRS component and an IAPP quality assessment scheme with the following thresholds: no super-adiabaticity, mixing ratio up to 55 g/kg, temperature between 180 and 340 K, TPW up to 90 kg/m^2, surface pressure up to 1050 hPa [RD-2].

A generic distance of 150 km to the nearest land mass has been used for identification of the coastal area. A threshold of 10 observations per grid box has been applied (values below this threshold have not been considered). For the difference calculation, the ATOVS product has been pixel-wise subtracted from the GlobVapour combined SSM/I + MERIS product, which was down-sampled to adapt spatial resolutions. All products have been normalised to the latitude dependent area of each grid box. The values are given for the collocated subset of valid grids.



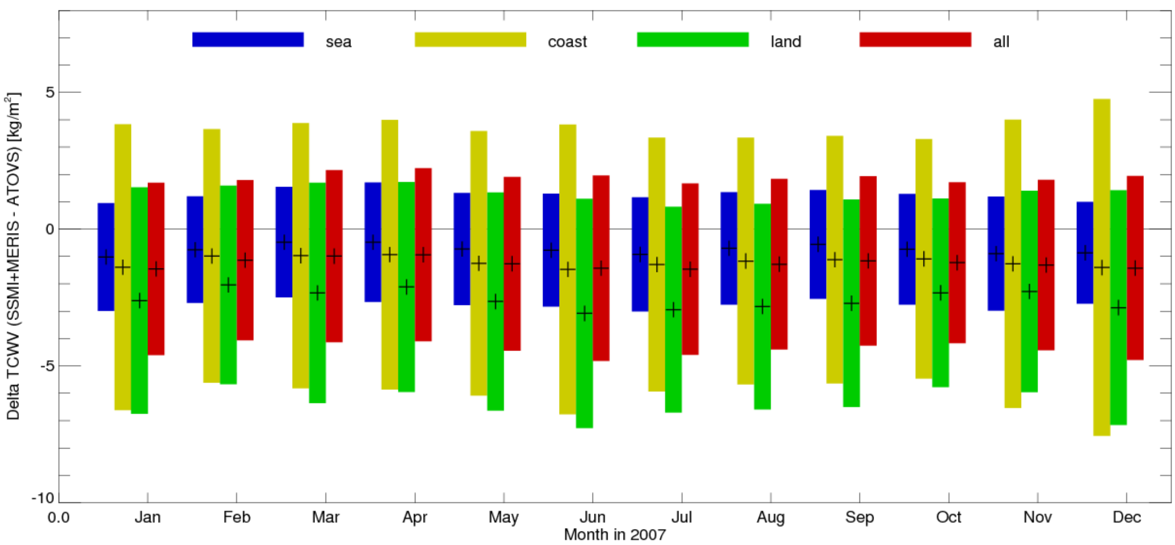


Figure 5-12: Combined SSM/I + MERIS versus ATOVS monthly mean TCWV bias with variability for the years 2006 and 2007 within the final period of 2004-2008.

ATOVS TCWV for July 2007 and the associated difference plot to the combined SSM/I+MERIS product are shown in Figure 5-11, respectively. The plots in Figure 5-12 show the monthly values of the bias with standard deviation for the years 2006 and 2007. Average values per annum for the bias and RMSE are given in Figure 5-13.

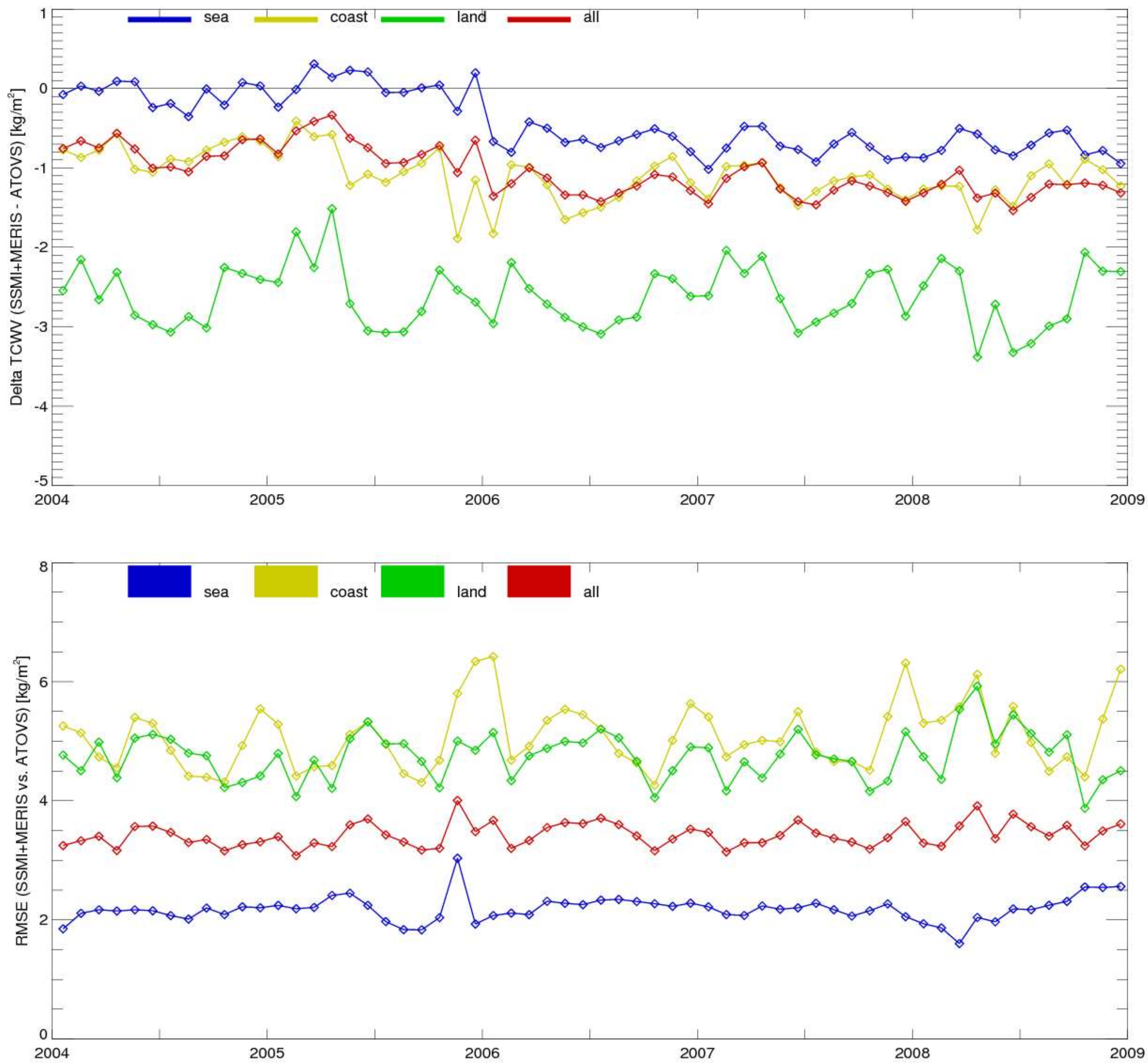


Figure 5-13: Combined SSM/I + MERIS versus ATOVS monthly mean TCWV bias (top) and RMSE (bottom) for 2004-2008.

On average for the period 2004-2008, the mean bias is **-(1.05 ± 0.29)** kg/m^2, together with a mean RMSE of **(3.3 ± 0.20)** kg/m^2. Here the uncertainty margins result from the (non-weighted) spread (σ_{N-1}) of the four values. Details and average values are discussed in section 5.3.

5.3 Discussion

All intercomparisons are based on collocated subsets of valid values on a latitude-corrected rectangular grid, for the final phase (2003-2008). It is recalled that the validation and inter-comparison has been performed in such a way that positive and negative bias values imply respectively larger and smaller SSM/I + MERIS data.

GUAN stations

A mean deviation of **-(0.94 ± 0.72)** kg/m^2 for the Radiosonde data of all GUAN stations is found, together with a mean RMSE of **(4.03 ± 0.58)** kg/m^2.

As shown in Figure 5-2 and Figure 5-3, the annual variability of the observations is significant, with the highest values in the winter months and strong fluctuations for the coastal segment. Values over sea/ocean, where the number of observations is low, should not be considered representative.

Table 5-2 below shows the decomposition of bias and RMSE to surface type, together with the average number of observations per month. Again, the number of GUAN observations over sea/ocean is too low to allow significant statistics. RMSE values are high for both the land and coastal stations, but observations over land show a higher absolute bias.

Table 5-2: Overall mean intercomparison results for SSMI+MERIS versus GUAN for the final phase (2003-2008).

Surface Type	N_obs	Bias (kg/m^2)	RMSE (kg/m^2)
Sea/Ocean	1.7 ± 1.2	+(1.34 ± 1.48)	1.85 ± 1.60
Coast	12.7 ± 2.7	-(0.47 ± 1.20)	4.27 ± 1.19
Land	34.1 ± 5.2	-(1.27 ± 0.80)	3.93 ± 0.66

ARM sites

A mean deviation of **-(1.97 ± 2.48)** and **-(3.05 ± 2.50)** kg/m^2 for respectively the radiosonde and Microwave data of the three ARM sites is found. For all three stations a dry bias is found (both for Raob and MWR), which is lowest for Nauru, a tropical station situated in the pacific, and highest for the land station Lamont in the Southern Great Plains of the USA. The RMSE varies from 1.85 to 4.27 kg/m^2 for the three Stations.

As the radiosonde error and the spatiotemporal mismatching have not been considered it is assumed that the accuracy is better than presented.

AIRS

The observed mean bias of **+(0.52 ± 0.18)** kg/m^2 is well within the technical specifications [AD-2] (bias of 1 0 kg/m^2). With a mean RMSE of **(2.26 ± 0.11)** kg/m^2 the accuracy is within the specification [AD-2] (RMSE of 3.0 kg/m^2).

As shown in Figure 5-9 and Figure 5-10, the annual variability of the data is rather low, in particular over sea, but strong fluctuations over land and coast are observed. A weak seasonal trend can be discerned.

Note that overall between 30 and 32% of the total number of grid boxes contain useful (valid) values.

Table 5-3 shows the decomposition of bias and RMSE to surface type, together with the fraction of the valid grid boxes (those 30 to 32% scaled to 100%) for the final phase.

Table 5-3: Overall mean intercomparison results for SSMI+MERIS versus AIRS for the final phase (2003-2008).

Surface Type	Valid grid fraction (%)	Bias (kg/m^2)	RMSE (kg/m^2)
Sea/Ocean	17.3 ± 2.0	+(0.66 ± 0.21)	2.29 ± 0.15
Coast	2.7 ± 0.7	+(1.05 ± 0.25)	3.20 ± 0.33
Land	9.7 ± 1.4	+(0.16 ± 0.22)	2.26 ± 0.11

Compared to the test products, the final products are validated against AIRS clear sky data. Note that the valid grid fraction has shrinked to a third of all pixel because of the AIRS cloud mask. Due to this reason the biases of the land and ocean parts have the same signs. The land area seems to match best with the AIRS data. Slightly increased absolute values are found for the land mass. The dry bias found for the coastal area is lower in absolute terms than over land and sea, but the RMSE is higher. Obviously, this coastal set represents only a small fraction of the total number of valid grid boxes.

L3 AIRS products processed from L2 (on a 0.5 squared degree grid) and L3 AIRS products downloaded from NASA (on a 1 squared degree grid) have been compared for a consistency check. The observed bias for the four prototype months is -(0.022 ± 0.006) kg/m^2. This value is very low and can be interpreted as confirmation for the applied processing technique.

ATOVS

A negative mean bias of **-(1.05 ± 0.29)** kg/m^2 observed for ATOVS, is not surprising, as at least a dry bias from MERIS due to omitted cloud observations over land (clear-sky only) can be expected. The clear-sky bias in the upper troposphere (200-500 hPa) is discussed in e.g. [RD-4]. According to recent research the clear-sky bias component from HIRS for the upper-tropospheric humidity can be as high as 30% [RD-5]. A clear sky bias was also identified between GOME and SSM/I TCWV products [RD-6].

With an overall mean RMSE of **(3.3 ± 0.20)** kg/m^2 the required accuracy as of the technical specifications [AD-2] (RMSE of 3.0 kg/m^2) is slightly not met.

The annual variability of the overall data (Figure 5-12 and Figure 5-13) is rather low, in particular over sea, but some fluctuations over land and coast are observed. The data jump end of 2005 can be explained, but is only noticeable in the comparison with ATOVS data.

Table 5-4 below shows the decomposition of bias and RMSE to surface type, together with the fraction of the total valid grid boxes (scaled to 100%).

Table 5-4: Overall mean intercomparison results for SSMI+MERIS versus ATOVS for the final phase (2004-2008).

Surface Type	Valid grid fraction (%)	Bias (kg/m^2)	RMSE (kg/m^2)
Sea/Ocean	46.3 ± 1.6	-(0.42 ± 0.37)	2.18 ± 0.21
Coast	8.9 ± 1.3	-(1.09 ± 0.31)	5.07 ± 0.54
Land	18.7 ± 1.5	-(2.62 ± 0.38)	4.75 ± 0.40

The sea/ocean sector displays a fairly low RMSE and a small bias indicating slightly drier SSM/I-MERIS than ATOVS observations. The land area has a larger bias, and higher RMSE values, slightly lower than the coastal area.

Note that the validation of ATOVS data against GUAN radiosondes have shown a bias of +0.35 kg/m^2 and a RMSE of almost 4 kg/m^2 over the period 2004-2009 [RD-3].

6 Conclusions

This report presents extensive validation efforts by utilizing a large variety of "reference" observations. Among the considered data are GUAN radiosonde as well as ARM microwave radiometer and radiosonde observations, AIRS and ATOVS water vapour products.

The following tables show an overview of the overall mean values of bias and RMSE of all validation results.

Table 6-1: Overall mean validation results for SSMI+MERIS versus ground-based data for the final phase.

Sensor-(1.05 ± 0.29)	N_obs	Bias (kg/m^2)	RMSE (kg/m^2)
Raob GUAN	48.8 ± 7.0	-(0.94 ± 0.72)	4.03 ± 0.58
Raob ARM	46	-(1.97 ± 2.48)	3.23
MWR ARM	46	-(3.05 ± 2.50)	3.93

Table 6-2: Overall mean validation results for SSMI+MERIS versus satellite-based data for the final phase.

Sensor	Valid grids (%)	Bias (kg/m^2)	RMSE (kg/m^2)
AIRS (Aqua)	29.7 ± 2.3	+(0.52 ± 0.18)	2.26 ± 0.11
ATOVS	73.7 ± 2.8	-(1.05 ± 0.29)	3.30 ± 0.20

No unique picture of the quality in terms of bias and RMSE of the combined SSM/I+MERIS product can be found. The technical specifications on bias (1 kg/m^2) are met in many cases. However, the bias is generally negative so that it might be concluded that the SSM/I+MERIS product tends to be drier than the compared ground-based and satellite data. Only the bias vs. AIRS is positive. The observed RMSE is smaller than the technical specification of 3 kg/m^2 relative to AIRS, and against ATOVS and AIRS the requirement is within reach. Note that the "reference" data also exhibit differences among another (see e.g. [RD-3, 7]), partly exceeding technical specifications of the GlobVapour products. It seems that this as well as at least some other global water vapour products tend to exhibit RMSE values between 3-4 kg/m^2 when classical approaches as outlined above are applied.

The validation results are not unique, and it is hard to conclude on product quality. This might have several reasons, among them (apart from retrieval uncertainties and uncertainties of the reference data):

- Spatio-temporal mismatches,
- Different cloud screening and associated uncertainties,
- Potentially open calibration issues,
- Potential uncertainties in auxiliary data,

And more. Also, the identification of true reference observations is an open issue.

The presented results clearly underline the need for a sound assessment of at least the quality of satellite products. The activities done within the GlobVapour project can support the GEWEX Data Assessment Panel in its efforts to start addressing such challenging issues in an international context.