EUMETSAT Satellite Application Facility on Climate Monitoring

Validation Report
ATOVS tropospheric humidity and temperature data set

ATOVS edition 1

DOI: 10.5676/EUM_SAF_CM/WVT_ATOVS/V001

Vertically integrated water vapour	**CM-123**
Layered water vapour and temperature	**CM-132**
Specific humidity and temperature at pressure levels	**CM-138**

Reference Number:	**SAF/CM/DWD/VAL/ATOVS**
Issue/Revision Index:	**1.1**
Date:	**07.03.2013**

Document Signature Table

	Name	Function	Signature	Date
Author	Nathalie Courcoux Marc Schröder Maarit Lockhoff	CM SAF scientist		07.03.2013
Editor	Rainer Hollmann	Science Coordinator		07.03.2013
Approval		Steering group		16.04.2013
Release	Martin Werscheck	Project Manager		16.04.2013

Distribution List

Internal Distribution	
Name	**No. Copies**
DWD Archive	1
CM SAF Team	1

External Distribution		
Company	**Name**	**No. Copies**
PUBLIC		1

Document Change Record

Issue/ Revision	Date	DCN No.	Changed Pages/Paragraphs
1.0	12/11/2010	SAF/CM/DWD/VAL/ATOVS/1	First official version.
1.1	07/03/2013	SAF/CM/DWD/VAL/ATOVS/1.1	Implemented the comments from the review board.

Applicable documents

Reference	Title	Code
AD 1	CM SAF Product Requirements Document	SAF/CM/DWD/PRD/2.0

Reference documents

Reference	Title	Code
RD 1	Algorithm Theoretical Basis Document ATOVS data set edition 1	SAF/CM/DWD/ATBD/ATOVS/1.1
RD 2	Product User Manual ATOVS data set edition 1	SAF/CM/DWD/PUM/ATOVS/1.1
RD 3	Product User Manual Water Vapour and Temperature from ATOVS	SAF/CM/DWD/PUM/WVT/2.0
RD 4	Annual Product Quality Assessment Report 2011	SAF/CM/DWD/VAL/OR7/1.1

Table of contents

List of figures

List of tables

1 Executive summary

This CM SAF report provides information on the validation of the CM SAF ATOVS tropospheric humidity and temperature data set derived from ATOVS (Advanced TIROS-N Operational Vertical Sounder) observations. The ATOVS instruments are flying onboard the NOAA (National Oceanic and Atmospheric Agency) satellites, NOAA-15, NOAA-16, NOAA-17, NOAA-18, NOAA-19 and onboard the European Metop satellite. The data set is available for the time period 1999 to 2011.

The CM SAF ATOVS data set offers 13 years (1999-2011) of consistent water vapour and temperature satellite-derived global products. Different parameters generated simultaneously are available: vertically integrated water vapour for the entire atmospheric column, vertically integrated mean water vapour, and mean temperature in 5 layers, specific humidity and temperature on 6 levels.

This report presents an evaluation of:

the vertically integrated water vapour [CM-123, HTW],

the layered water vapour and temperature [CM-132, HLW]

the specific humidity and temperature at pressure levels [CM-138, HSH]

from the CM SAF ATOVS data set against reference radiosonde data (GUAN (GCOS Upper-Air Network)), and other satellite observations with focus on AIRS (Atmospheric InfraRed Sounder). A comparison of the CM SAF ATOVS data set with the CM SAF ATOVS operational products is also presented.

The validation results (bias, RMSE and stability) show a general good agreement with the GUAN (GCOS Upper-Air Network) radiosonde data set (see details below) while some issues are remaining in the validation against the AIRS data (Atmospheric InfraRed Sounder, flying on the NASA Aqua satellite). The comparison with the CM SAF ATOVS operational products exhibits an obvious improvement. The time series of the CM SAF ATOVS data set and of the validation data set are also shown against time to provide a basis to the discussion of the validation results.

The validation against the GUAN radiosondes shows that the precipitable water vapour (TPW) always exhibits a bias within the ± 1 kg m^{-2} range well below the target accuracy. For the HLW products, the maximal bias of the layer mean temperature (for the five layers) is about - 0.8 K (threshold accuracy, 1 K and 1.5 K for the highest layer), however most the data exhibit a bias within the ± 0.5 K range, corresponding to the target accuracy (for the time period between 2001 and 2011; for 1999 and 2000, the data set shows a lower quality for the temperature products). For the HLW layered water vapour products, the difference should be done between the different layers. For the surface closest layer the bias oscillates between -0.3 kg m^{-2} and -1.2 kg m^{-2} (threshold accuracy 1 kg m^{-2}, target accuracy 0.4 kg m^{-2}), for the two middle layers (700-500 hPa (threshold accuracy 0.25 kg m^{-2}, target accuracy 0.1 kg m^{-2}) and 850-700 hPa (threshold accuracy 1 kg m^{-2}, target accuracy 0.4 kg m^{-2})), the bias is most of the time between 0 and 0.5 kg m^{-2}, and for the two highest layers the mean bias is 0.0014 kg m^{-2} for the highest layer (between 300 and 200 hPa (threshold accuracy 0.02 kg m^{-2}, target accuracy 0.01 kg m^{-2})) and 0.0029 kg m^{-2} for the layer between 500 and 300 hPa (threshold accuracy 0.2 kg m^{-2}, target accuracy 0.1 kg m^{-2}). For the HSH products, like for the HLW products, the bias for the temperature products oscillate mostly between -0.5 and 0.5 K and are consequently in the range between the threshold and the target accuracy. For the HSH specific humidity products, for the three lower levels (1000, 850, and 700 hPa), the bias is within the ±0.4 g kg^{-1} range and mostly meets the threshold accuracy, for the 500 hPa level, the bias is between 0 and 0.3 g kg^{-1} (threshold accuracy 0.2 g kg^{-1}, target accuracy 0.05 g kg^{-1}) and for the 200 and 300 hPa levels the mean bias is 0.0032 g kg^{-1} and -0.013 g kg^{-1}, respectively (the threshold accuracy is 0.02 g kg^{-1} for the 200 hPa level, and 0.03 g kg^{-1} for the 300 hPa, and the target accuracy is 0.01 g kg^{-1} for both level). For the decadal stability the results vary depending upon the different products, however, the decadal stability is better than 4 % for most of the products, and consequently the threshold accuracy is meet for most of products.

2 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 sets is pursued. The ultimate aim is to make the resulting data sets 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.

Another essential task of CM SAF is to produce data sets that can serve applications related to the new 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 sets 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 sets also serve the improvement of climate models both at global and regional scale.

As an essential partner in the related international frameworks, in particular WMO SCOPE-CM (Sustained COordinated Processing of Environmental satellite data for Climate Monitoring), the CM SAF - together with the EUMETSAT Central Facility, assumes the role as main implementer of EUMETSAT’s commitments in support to global climate monitoring. This is achieved through:

- Application of highest standards and guidelines as lined out by GCOS for the satellite data processing,
- Processing of satellite data within a true international collaboration benefiting from developments at international level and pollinating the partnership with own ideas and standards,
- Intensive validation and improvement of the CM SAF climate data records,
- Taking a major role in data set assessments performed by research organisations such as WCRP (World Climate Research Program). This role provides the CM SAF with deep contacts to research organizations that form a substantial user group for the CM SAF CDRs,

- Maintaining and providing an operational and sustained infrastructure that can serve the community within the transition of mature CDR products from the research community into operational environments.

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

3 Introduction

The CM SAF ATOVS data set provides global water vapour and temperature products. The products are available as daily and monthly means on a cylindrical equal area projection of 90km×90km. The temporal coverage of the data set ranges from the 1st of January 1999 to the 31st of December 2011.

The products covered by this document are:

- HTW (CM-123): Vertically integrated water vapour (TPW) [kg/m^2]
- HLW (CM-132): Layered products in 5 layers:
    - layered vertically integrated water vapour [kg/m^2]
    - mean temperature [K]
- HSH (CM-138): products at 6 pressure levels:
    - specific humidity [g/kg]
    - temperature [K]

The definition of the pressure levels and layer boundaries is given in Table 1. TPW is integrated from the surface to 100 hPa. Any product is undefined if the corresponding layer or level is not filled with valid observations.

Table 1: Layer and level definitions for the ATOVS products.

HLW layer	1	2	3	4	5	-
Pressure [hPa]	300-200	500-300	700-500	850-700	Surface-850	-
HSH level	1	2	3	4	5	6
Pressure [hPa]	200	300	500	700	850	1000

The CM SAF ATOVS data set is derived from the ATOVS measurements. ATOVS flies since the 13th of May 1998 on NOAA and Metop polar orbiting satellites. So far six platforms carry the sounding instrument system composed of HIRS and AMSU, namely, NOAA-15, NOAA-16, NOAA-17, NOAA-18, NOAA-19, and Metop-A. The AMSU instrument is composed of two separate radiometers, AMSU-A and AMSU-B (which is replaced by MHS on NOAA-18, NOAA-19 and Metop-A). AMSU-A and -B are cross track scanning total power radiometers. AMSU-A channels primarily provide temperature sounding of the atmosphere while AMUS-B channels mainly measure water vapour and liquid precipitation over land and sea. The third ATOVS instrument, HIRS/3 (replaced by HIRS/4 on NOAA-18, and -19, and on Metop-A) is an infrared 20 channel cross track scanning sounder.

The number of available/operational satellites was varying with time. Consequently, different combinations of satellites were used depending on when the different satellites were available/operational; Table 2 gives the details about when which satellite combination was used for the retrieval.

The water vapour and temperature retrieval is done using the IAPP (International ATOVS Processing Package). The IAPP was developed by the University of Wisconsin in Madison and is described in Li et. al. (2000). The IAPP is fed with ATOVS L1d data (intercalibrated with SNO coefficients for the AMUS-B data) and with ECMWF ERA interim data as a priori data. The IAPP output profiles contain 42 levels which are integrated to obtain the CM SAF products described above in this section. Finally, a Kriging routine (Lindau and Schröder, 2010) is applied to the swath based retrievals to compute the daily and monthly means on a global grid in a cylindrical equal area projection of 90 km × 90 km. The Kriging routine also outputs the extra daily standard deviation for the monthly means, the random error for the daily means, and the number of observation per grid point. An example of a TPW daily product is given together with the corresponding standard deviation and number of observation per grid point in Figure 1.

Table 2: The different satellite combinations used to generate the ATOVS products with the corresponding time period for which those combinations were used.

Time period	Satellite used
1999 01 01 – 2000 10 31	NOAA-15
2000 01 11 – 2001 01 31	NOAA-16
2001 02 01 – 2002 10 31	NOAA-15, NOAA-16
2002 11 01 – 2003 09 30	NOAA-15, NOAA-16, NOAA-17
2003 10 01 – 2005 08 31	NOAA-15, NOAA-16
2005 09 01 – 2007 05 31	NOAA-15, NOAA-16, NOAA-18
2007 06 01 – 2009 01 31	NOAA-15, NOAA-16, NOAA18, Metop-A
2009 02 01 – 2009 04 30	NOAA-15, NOAA16, Metop-A
2009 05 01 – 2009 06 30	NOAA-16, Metop-A
2009 07 01 – 2011 12 31	NOAA-16, Metop-A, NOAA-19

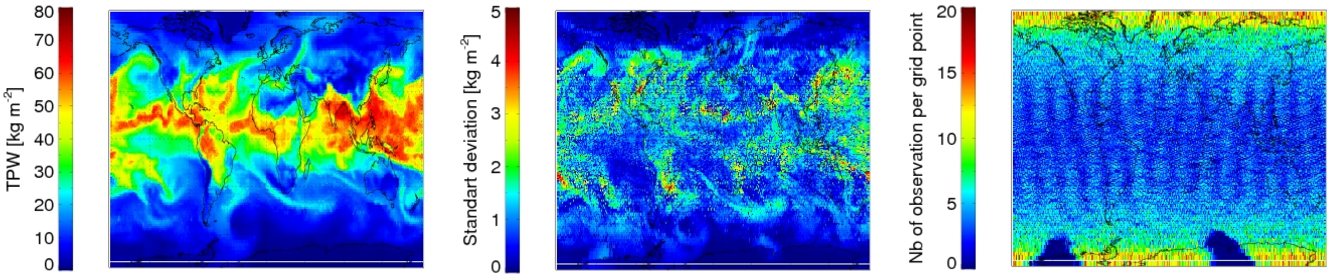


Figure 1: The left panel shows the global total precipitable water vapour (TPW) for the 20th of September 2007, the middle panel the corresponding random error and the right panel the corresponding number of observations per grid point.

The processing chain and the retrieval scheme are described in the Algorithm Theoretical Basis Document for the CM SAF ATOVS tropospheric humidity and temperature data set [RD 1]. Furthermore, details about the retrieval and the IAPP can be found in Li et. al. (2000). Details about the products description and formats can be found in the Product User Manual [RD 2], and the basic accuracy requirements are defined in the Product Requirements Document [AD 1]. The accuracy requirements are given in Table 3 for HTW and HLW and in Table 4 for HSH.

An overview of the datasets used for the validation is given in section 4. The comparisons between the ATOVS tropospheric humidity and temperature data set products and the operational products are shown in section 5 together with a discussion of the results and implications for the individual parameters. The results of the validation are shown and analysed in section 6, together with an analysis of the decadal stability. Finally, a conclusion is given in section 8.

Table 3: Bias threshold and target accuracies requirements for the HTW and HLW products (LPW: Layered Precipitable Water, LT: Layer (mean)Temperature) from the Product Requirements Document [AD 1].

	LPW bias threshold [kg/m^2]	LPW bias target [kg/m^2]	LPW RMSE threshold [kg/m^2]	LPW RMSE target [kg/m^2]	LT bias threshold [K]	LT bias target [K]	LT RMSE threshold [K]	LT RMSE target [K]
TPW	2	1.5	5	3				
L1	0.02	0.01	0.1	0.05	1.5	0.5	3	2
L2	0.2	0.1	0.75	0.5	1.0	0.5	3	2
L3	0.25	0.1	2	1.3	1.0	0.5	3	2
L4	1.0	0.4	2.5	1.5	1.0	0.5	3	2
L5	1.0	0.4	3.0	2.0	1.0	0.5	3	2

Table 4: Similar to Table 3 but for the HSH products (Q: specific humidity, T: Temperature).

	Q bias threshold [g/kg]	Q bias target [g/kg]	Q RMSE threshold [g/kg]	Q RMSE target [g/kg]	T bias threshold [K]	T bias target [K]	T RMSE threshold [K]	T RMSE target [K]
L1	0.02	0.01	0.08	0.03	1.5	0.5	3	2
L2	0.03	0.01	0.5	0.15	1.25	0.5	3	2
L3	0.2	0.05	1.5	0.75	0.75	0.3	3	2
L4	0.3	0.1	1.75	1.25	0.5	0.2	3	2
L5	0.75	0.2	2	1.5	0.5	0.2	3	2
L6	1.0	0.2	2.25	1.5	0.5	0.2	3	2

4 Datasets for validation

The validation of the CM SAF ATOVS data set is done against two different types of data. First, against the GUAN (GCOS Upper-Air Network) radiosonde data, which are also used to validate the CM SAF ATOVS operational products, and against the AIRS (Atmospheric InfraRed Sounder) satellite data. Both data sets are described briefly in the two following sections.

4.1 GUAN

The GUAN (GCOS Upper-Air Network) radiosonde network was established by GCOS (Global Climate Observing System) in order to make available current and historical upper air data for climate change detection and climate monitoring. GUAN provides global radiosonde observations, from homogeneously distributed upper air stations, that meet specific record length, observation continuity requirement, as well as data quality requirements as defined by GCOS. All the GUAN criteria are described in Daan (2002). There are about 160 GUAN stations worldwide.

The validation of the CM SAF ATOVS data set against the GUAN data for the entire time period for which the re-processed data set is available (1999-2011) is presented in sections 6.3, 6.4, and 6.5 for the different products. A comparison of the GUAN validation results for the ATOVS operational products and for the CM SAF ATOVS data set is presented in section 5. This comparison is shown for the time period for which the operational products are available (2004-2011).

4.2 AIRS

AIRS (Atmospheric InfraRed Sounder) is an infrared cross track scanning instrument flying together with an AMUS-A radiometer onboard the NASA Aqua satellite since 2002. The L2 AIRS data set which is used for the validation is the AIRX2RET product (version 5) generated by the NASA GES DISC (Goddard Earth Science Data and Information Service Center, http://daac.gsfc.nasa.gov/) as a part of the AIRS Standard Products. The AIRS Standard Products consist of retrieved estimates of cloud and surface properties, outgoing longwave radiation, profiles of temperature and water vapour, and total column amount of atmospheric minor gases such as ozone, CH_4 and CO. Those products are the results of employing the combined AIRS-IR/AMSU-A-microwave retrieval of the AIRS algorithm (Li, 2008). Since the data retrieval is done using a combination of AIRS-IR data and AMSUA-MW data, the profiles from the AIRS AIRX2RET data set are only used to validate the CM SAF ATOVS water vapour products and not the temperature products. The validation of the CM SAF ATOVS water vapour data set against the AIRS AIRX2RET data is shown in sections 6.3.2 and 6.4.2.

5 Comparison with the ATOVS operational products

CM SAF is providing ATOVS operational products (products CM-122 (HTW), CM-131 (HLW), and CM-137 (HSH), versions 300, 310, and 320) from 2004 until now [RD 3].
The ATOVS tropospheric humidity and temperature data set (products CM-123 (HTW), CM-132 (HLW), and CM-138 (HSH), version 001) is the result of the reprocessing of those operational products but for the entire time period for which ATOVS data are available (1999 - 2011). The aim of this section is to compare the validation against the GUAN radiosonde data for the CM SAF ATOVS operational products (products CM-122 (HTW) and CM-131 (HLW), versions 300, 310, and 320) and for the CM SAF ATOVS data set (products CM-123 (HTW) and CM-132 (HLW), version 001) to demonstrate that the reprocessed data set exhibits increased quality than the operational products, especially in terms of stability. Since the operational products are available since 2004, and the data set is available until 2011, the comparison is done for the time period from January 2004 to December 2011. The results are shown for the HTW products (TPW, Total Precipitable Water) in section 5.1 and for the HLW products in section 5.2 (layered precipitable water and layered mean temperature).

5.1 Total precipitable water vapour (HTW products)

Figure 2 shows that the TPW product from the reprocessed data set exhibits a better quality than the TPW from the operational product. First of all, the jump in the data in the middle of the year 2009 which is visible in the operational product is largely reduced in the reprocessed product. The bias for the reprocessed data set is smoother and smaller than the bias for the operational product. Concerning the bias corrected RMSE, the results are also slightly better for the reprocessed data set than for the operational product.

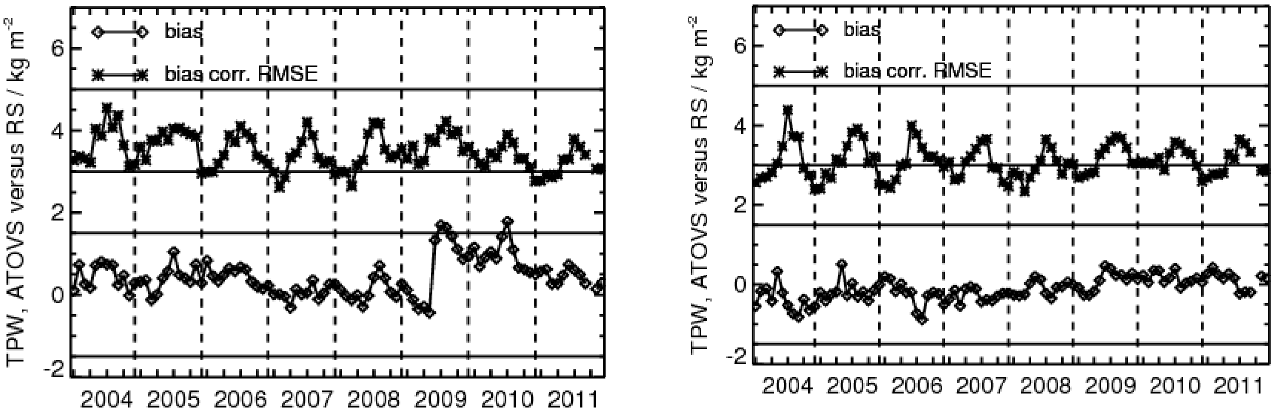


Figure 2: The left and right panels show the bias and the bias corrected RMSE between the total precipitable water from the CM SAF ATOVS operational products, respectively the CM SAF ATOVS tropospheric humidity and temperature data set and the GUAN radiosonde data. The black horizontal lines show the target bias (±1.5 kgm^{-2}) as well as the threshold (5 kgm^{-2}) and target (3 kgm^{-2}) bias corrected RMSE.

5.2 Layered precipitable water vapour and temperature (HLW products)

Figure 3 shows that the jump which is visible in the operational LPW3 and LPW4 products in 2009, is largely reduced in the reprocessed data set, and consequently the LPW3 and LPW4 products exhibit a higher stability in the reprocessed data set. The LPW2 and LPW4 products show a lower bias for the reprocessed data set than for the operational products. For all the layered precipitable water vapour products, the bias corrected RMSEs (Figure 4) show similar features for both the operational products and the reprocessed data set, however, the bias corrected RMSE values are slightly lower for the reprocessed data set.

From the Figure 5, one can see that the LT1 and LT5 products exhibit a lower bias for the reprocessed data set than for the operational products. The LT2 product shows a lower bias for the time period 2004-2008 for the reprocessed data set, for the time period 2009-2011 the LT2 biases are similar for the two data sets. For all the layered mean temperature products, the bias corrected RMSEs show similar features for both the operational products and the reprocessed data set. Table 5 summarises the validation results for the comparison between the operational and reprocessed HTW and HLW products.

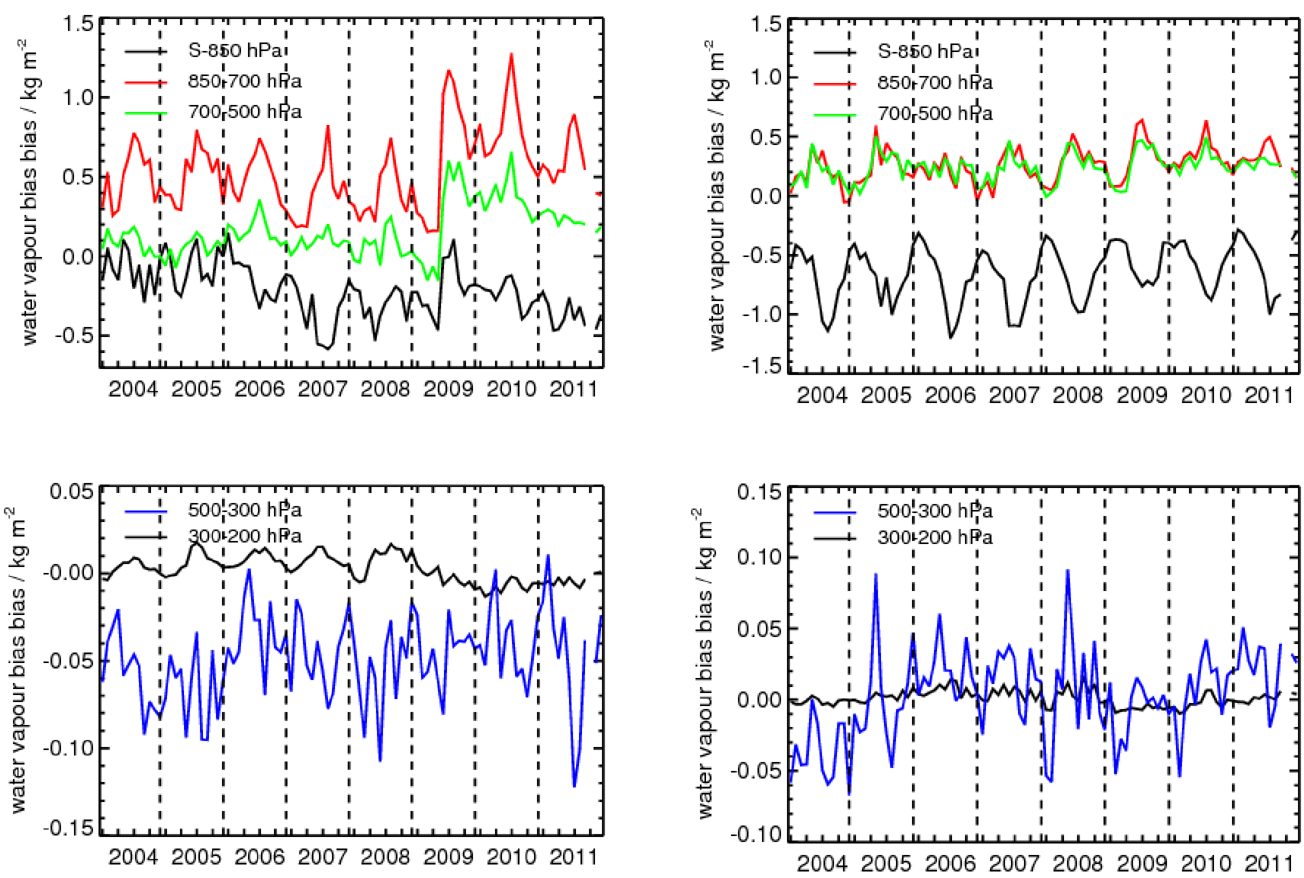
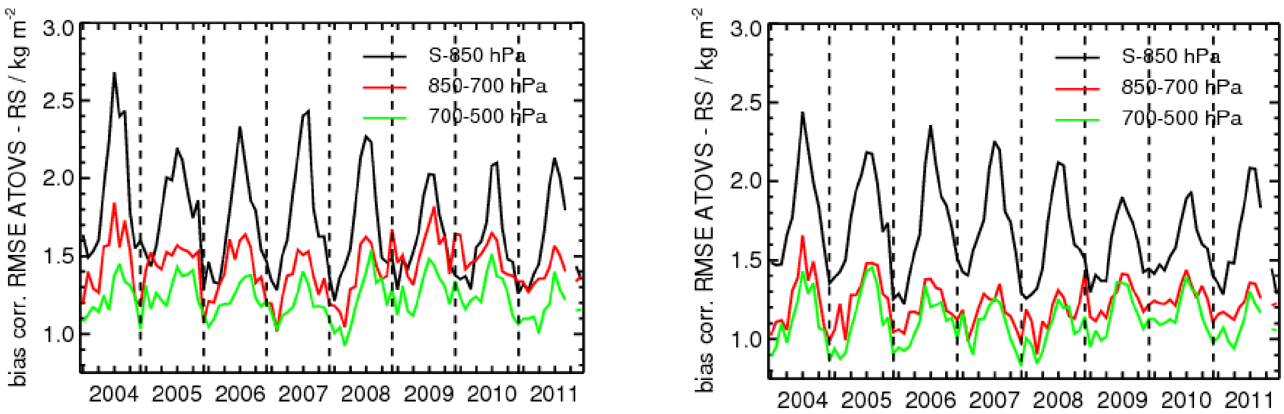


Figure 3: The left panels show the bias between the CM SAF ATOVS operational products and the GUAN radiosonde data for the layered precipitable water vapour products (the three lowermost layers are shown in the upper panel and the 2 uppermost layers are shown in the lower panel), the right panels show the same as the left panels but for the CM SAF ATOVS troposheric humidity and temperature data set.



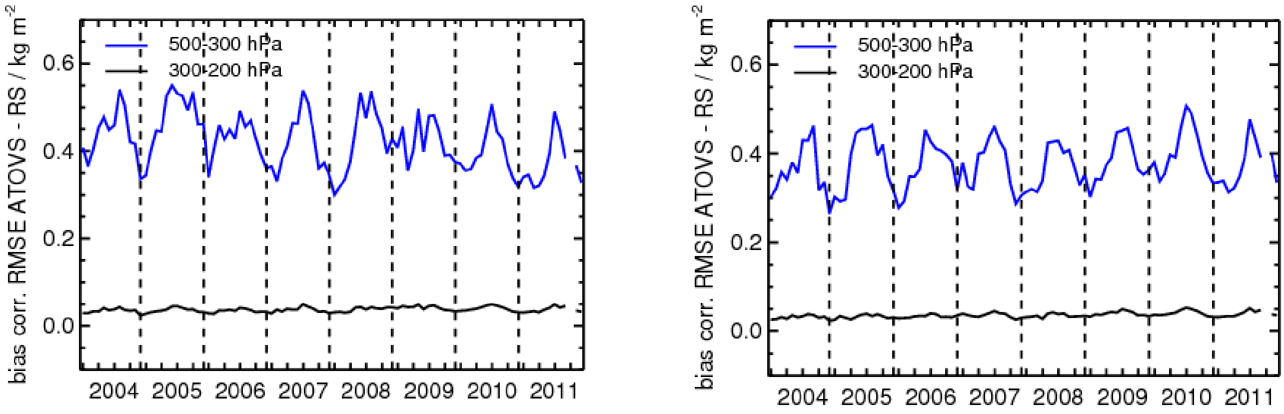


Figure 4: Similar to Figure 3 for the bias corrected RMSE.

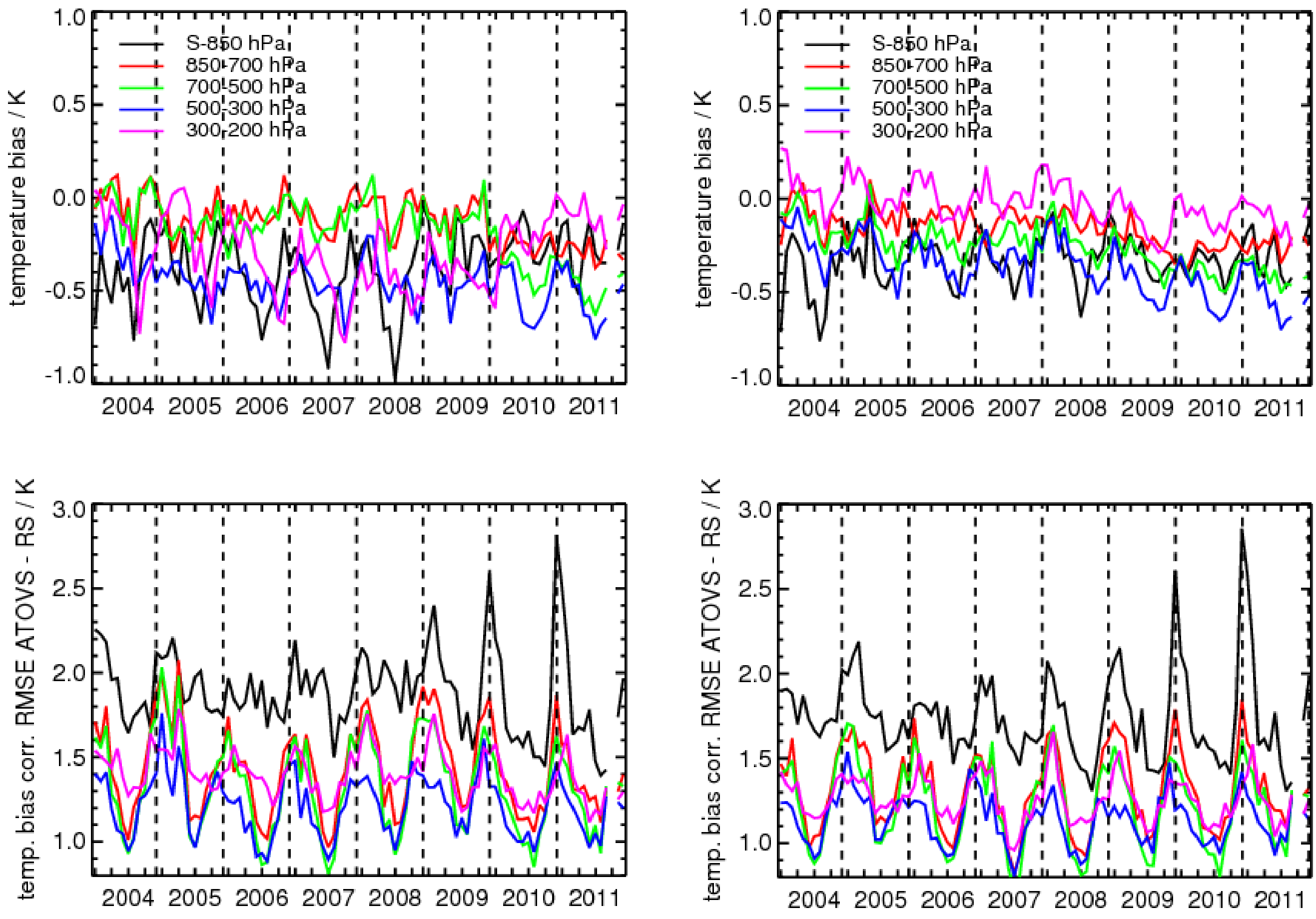


Figure 5: Similar to Figure 3 and Figure 4 but for the temperature products.

To conclude this section the CM SAF ATOVS tropospheric humidity and temperature data set exhibits an increased quality compared to the CM SAF ATOVS operational products. This is particularly true for the HTW TPW product that exhibits a lower bias and a much greater stability for the reprocessed data set than for the operational products.

Table 5: Percentage of months meeting the threshold and target accuracies for the HLW and HTW products for both the operational and reprocessed products (for the time period between 2004 and 2011).

	Ope. bias % in threshold	Ope. bias % in target	Re. bias % in threshold	Re. bias % in target	Ope. RMSE % in threshold	Ope. RMSE % in target	Re. RMSE % in threshold	Re. RMSE % in target
TPW	100	97	100	100	100	15	100	43
LPW1	100	77	100	93	100	100	100	97
LPW2	100	97	100	100	100	87	100	99
LPW3	76	39	53	16	100	67	100	86
LPW4	95	34	100	83	100	60	100	99
LPW5	100	86	91	16	100	77	100	83
LT1	100	84	100	100	100	100	100	100
LT2	100	71	100	78	100	100	100	100
LT3	100	95	100	99	100	99	100	100
LT4	100	100	100	100	100	99	100	100
LT5	100	77	100	88	100	71	100	87

6 Validation of the CM SAF ATOVS products

This chapter presents the validation results of the CM SAF ATOVS tropospheric humidity and temperature data set. First, the methodology used for the evaluation of the data set is described. Then, the time series of the CM SAF ATOVS data set and of the validation data sets are shown. Finally the validation for each product (HTW, HLW, and HSH) against the GUAN radiosonde data and the AIRS data is shown and commented.
The last section of this chapter deals with the evaluation of the products decadal stability.

6.1 Methodology

6.1.1 GUAN

First of all, the GUAN radiosonde data are sampled, integrated and averaged to obtain the water vapour products with the same layer/level definition as the CM SAF data. The nearest CM SAF ATOVS data set pixel is collocated to each of the GUAN stations. For each day, only the stations having at least two radiosonde launches during the day are used. The collocated data are then averaged per day and per month. Finally, the collocated data from the CM SAF daily mean products are also averaged per month and both data are compared.

6.1.2 AIRS

To be able to validate the CM SAF ATOVS data set against the AIRS data, the AIRS swath based data was processed to match the CM SAF ATOVS data set. The AIRS data are integrated to obtain the 5 layers precipitable water vapour (LPW) products and the total precipitable water vapour product (TPW), then the swath based products are converted to grid based products, and finally all the orbits of a day are merged together to obtain a daily and monthly means.

6.2 Time series of the CM SAF ATOVS data set and of the validation data set

This section shows the time series of CM SAF ATOVS data set and of the validation data set (GUAN and AIRS) against time (for the TPW and LPW products). Those time series are shown in order to check the stability of all the data set involved in the validation and to provide a basis to discuss the validation results.

Figure 6 shows that the AIRS data exhibits a good stability over the time, for the TPW and for the LPWs. However, it should be noted for further references that the summer maximum in 2010 is higher than for the other years, and that the winter minimum in 2007 and 2010 are lower than for the other years. Figure 7 shows that the GUAN radiosonde data exhibit a slightly increasing trend in contrast to AIRS. The amplitude of the annual cycle of the GUAN data is greater than for the AIRS data. This can be caused by the dominance of land based measurements in GUAN. The GUAN data set also exhibits a winter minimum in 2007. It is also visible that the two first years (1999 and 2000) show lower means than the rest of the time series.

The time series of the CM SAF ATOVS (Figure 8) data set against time can be decomposed in three periods: the two first years (1999 and 2000) which show a much lower TPW and LPWs as well as a stronger seasonal cycle than the rest of the time series, then the time period between 2001 and 2008 which is very stable and finally the three last years (2009 to 2011) which exhibit a higher TPW, than the rest of the time series (it is also visible for LPW5, LPW4 and LPW3). For the first period, the difference can be caused by a combination of the different facts:

- only one satellite is used to generate the CM SAF ATOVS products,
- a lot of ATOVS data are missing in the database in 1999 and 2000,
- the Kriging method is not applied (because only one satellite is available for this time period and that the Kriging routine requires at least 2 satellites to be applied),
- the SNO based inter-calibration coefficients are not available for this period.

For the period between 2009 and 2011, the difference might be due to the difference in the combination of the satellites used to generate the data. A lot of satellites changes occur at the beginning of 2009 (see Table 2), and basically, early an afternoon overpassing satellite is replaced by a late evening overpassing satellite, that might cause the problem. However, this explanation should be further investigated.

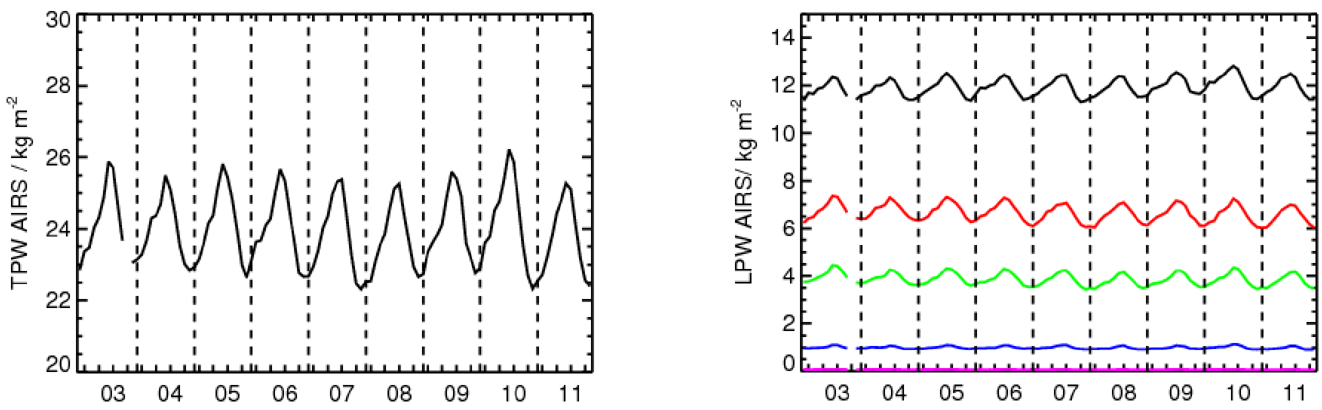


Figure 6: The left panel shows the total precipitable water from AIRS against time, and the right panel shows the layered integrated water vapour from AIRS against time, for the 5 layers

(LPW1 in pink, LPW2 in blue, LPW3 in green, LPW4 in red and LPW5 in black, please refer to table 2.1 for the layers definition).

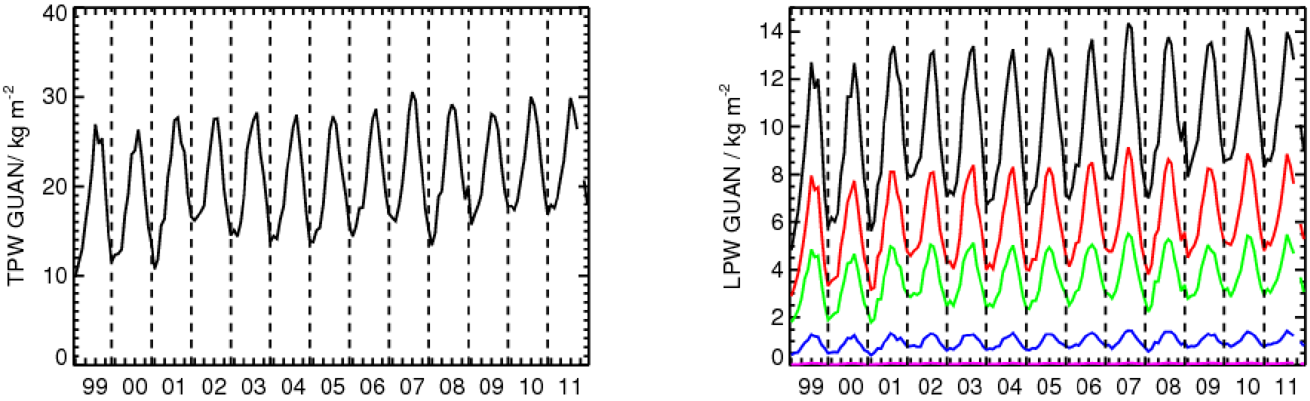


Figure 7: Similar to Figure 6 but for the GUAN radiosonde data set.

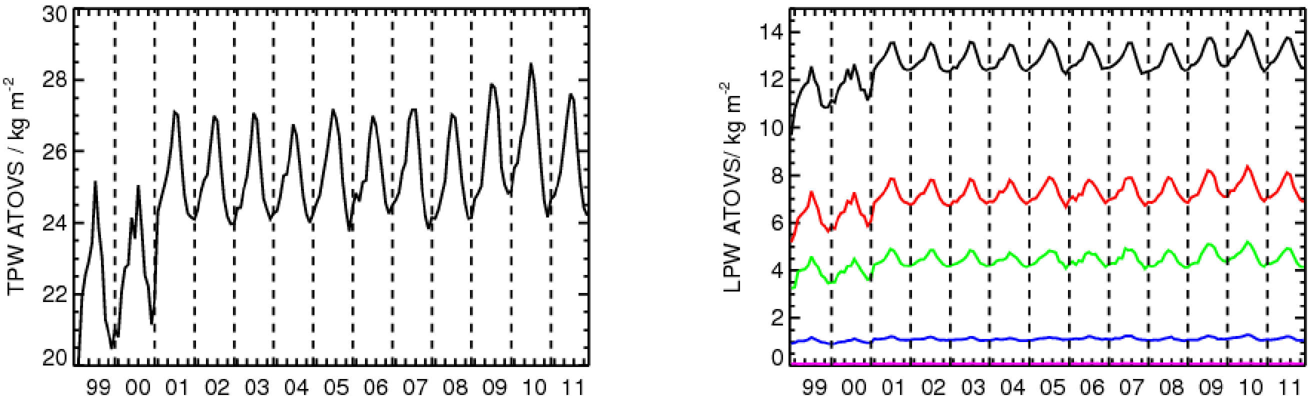


Figure 8: Similar to Figure 6 but for the CM SAF ATOVS data set.

6.3 Validation of total precipitable water vapour (HTW products)

This section describes the validation of the Total Precipitable Water Vapour (TPW), first against the GUAN radiosonde data and then against the AIRS satellite data.

6.3.1 GUAN

Figure 9 shows that the bias of the TPW product against the GUAN radiosonde data always reaches the target accuracy (1.5 kg/m^2), the bias also shows a stable behaviour, especially between 1999 and 2009 From mid 2009 to 2011 the bias gets slightly higher than during the rest of the time period.

The bias corrected RMSE shows maximum values for the two first years of the time series. This is expected since between January 1999 and January 2001 only one satellite was available for the processing, while for the rest of the processing at least two satellites are used for the processing. The rest of the bias corrected RMSE time series shows a good quality, meeting always the threshold accuracy and meeting the target accuracy for more than 40% of the months. Table 6 summarises the validation results of the TPW product against the GUAN radiosonde data.

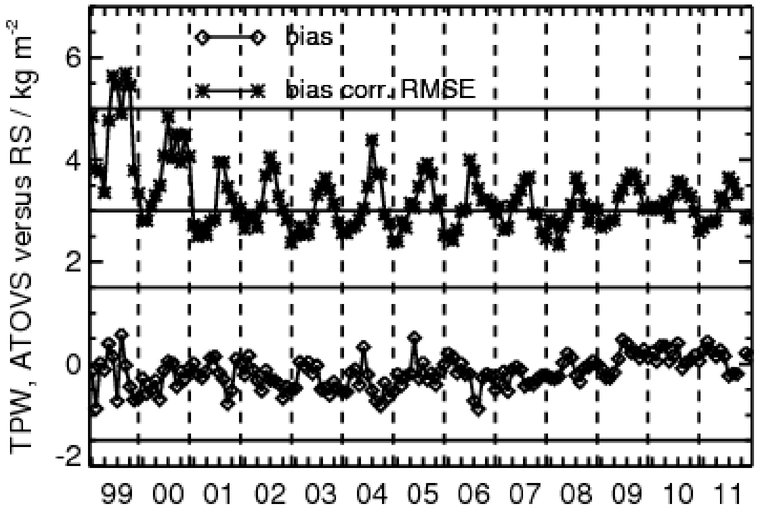


Figure 9: Time series of bias and bias corrected RMSEs between TPW (Total Precipitable Water) products derived from ATOVS and from GUAN radiosonde data, for the time period from January 1999 to December 2011. Black horizontal lines show the target bias (±1.5 kg m^{-2}) as well as the threshold (5 kg m^{-2}) and target (3 kg m^{-2}) bias corrected RMSE.

Table 6: Mean TPW bias and mean TPW bias corrected RMSE with the corresponding the percentage of products meeting the threshold and target accuracies for the validation CM SAF ATOVS – GUAN.

HTW	mean TPW [kg/m^2]	mean bias/RMSE [kg/m^2]	% in threshold	% in target
TPW bias	20.46	-0.16	100	100
TPW RMSE		3.25	97	41

6.3.2 AIRS

Figure 10 shows an obvious increase in bias between the CM SAF ATOVS data set and the AIRS data for the TPW product. The time period for which the validation is done (2003 to 2011) can be split in 3 stable periods. The first period, from 2003 to mid 2006 the TPW product meets almost always the target accuracy. The second period between mid 2006 and beginning/mid 2009 where the TPW product is above the target accuracy but still meets the threshold accuracy, and finally the third period from mid 2009 to 2011 where the TPW products doesn't meet the threshold accuracy any more. On the other hand the bias corrected RMSE for TPW always meet the target accuracy with the exception of one month in 2009. Table 7 summarises the validation results of the TPW product against the AIRS data and Figure 11 shows the spatial mean TPW bias for the time period 2003 - 2011. Figure 11 obviously shows that the bias is dominated by regions of strong precipitation and frequent cloud occurrence. Both, the AIRS and ATOVS retrievals, apply cloud clearing. However, differences in these approaches can also explain the bias.

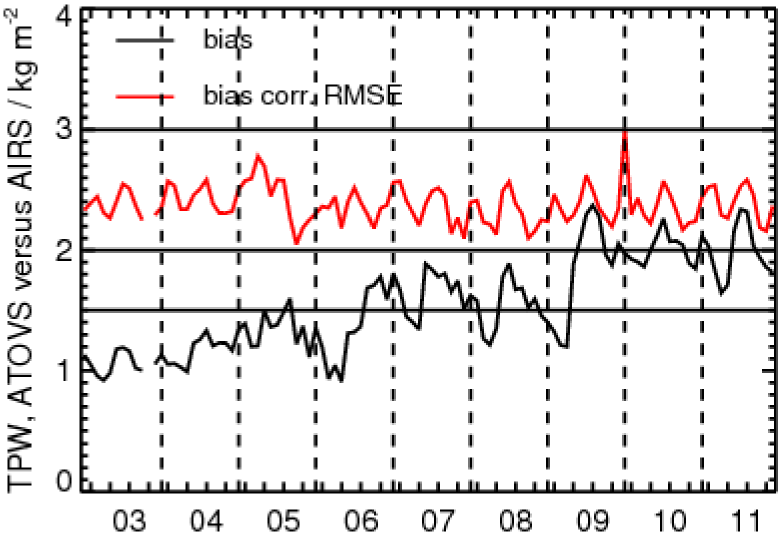


Figure 10: Similar to Figure 9 but for the validation against AIRS.

Table 7: Similar to Table 6 but for the validation against AIRS.

HTW	mean Bias/RMSE [kg/m^2]	% in threshold	% in target
TPW bias	1.53	85	49
TPW RMSE	2.38	100	99

The increased bias in AIRS comparison relative to the GUAN comparisons has also been found in DUE GlobVapour PVR (2012) where GUAN and AIRS data has been compared to SSM/I+MERIS total column water vapour products.

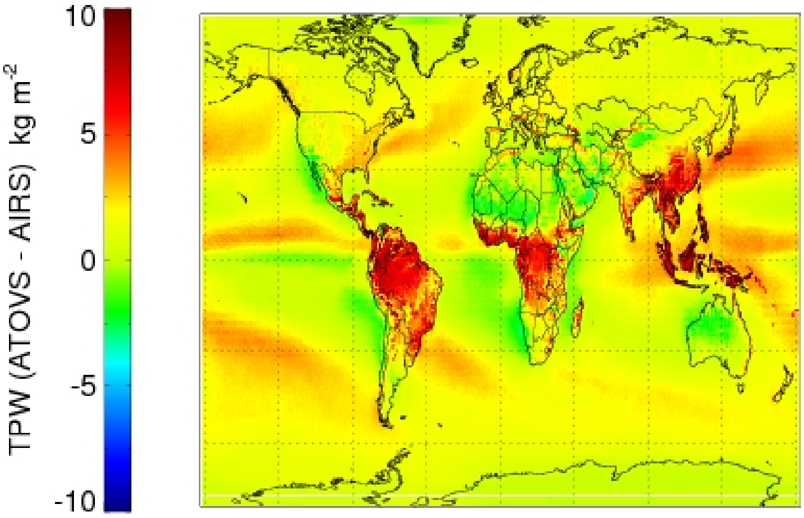


Figure 11: Mean TPW bias (ATOVS-AIRS) for the time period 2003 – 2011.

The steep increasing bias between the CM SAF ATOVS data set and AIRS in spring 2009 shown in Figure 10, is due to the NOAA-15 satellite data being removed from the retrieval in May 2009. Figure 12 and Figure 13 explain this phenomenon. Figure 12 shows the bias between the CM SAF products derived from each satellite separately (for that particular exercise the Kriging routine is not applied to the CM SAF data) and the AIRS data. Figure 12 obviously shows that the bias for the data derived from the NOAA-15 satellite is much lower than the bias for the data derived from any of the other satellites. Consequently, when NOAA-15 is removed from the retrieval in May 2009, the bias immediately gets larger. This might be explained by the fact that the retrieval software, the IAPP, was developed and tuned at a time when NOAA-15 was the only available satellite (Li et. al. (2000)). Figure 13 is similar to Figure 10 but for that figure, data from the NOAA-15 satellite were removed from the retrieval from June 2008 on, the consequence is that the steep bias increase is then visible in spring 2008 instead of spring 2009. Figure 13 proves that the bias increase visible in Figure 10 is reproducible by removing from the retrieval the data originating from the NOAA-15 satellite. This phenomena also explains the increasing bias visible in May 2009 between the ATOVS CM SAF data set and the GUAN radiosondes (Figure 2, right panel), and also partly the steep increasing bias between the CM SAF operational products and the GUAN radiosondes (Figure 2, left panel).

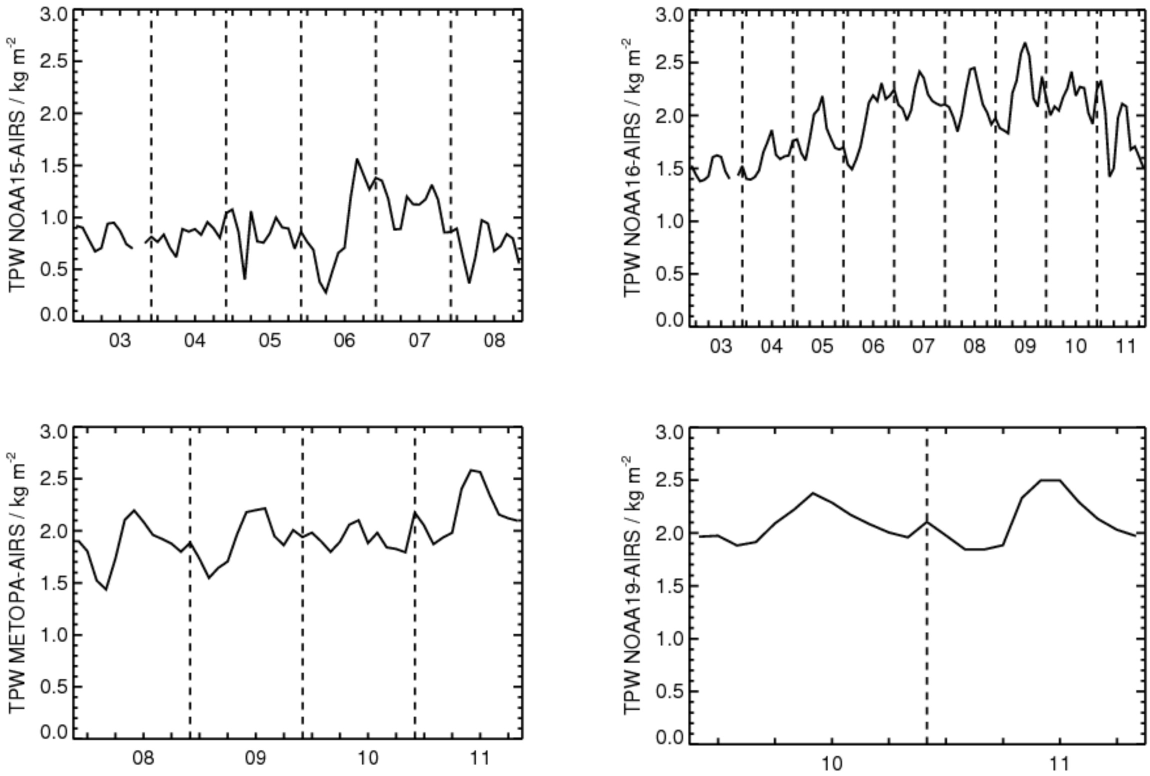


Figure 12: Bias between the CM SAF ATOVS data set derived from each satellite separately (upper left panel: NOAA-15, upper right panel: NOAA-16, lower left panel Metop-A, and upper right panel: NOAA-19) and the AIRS data.

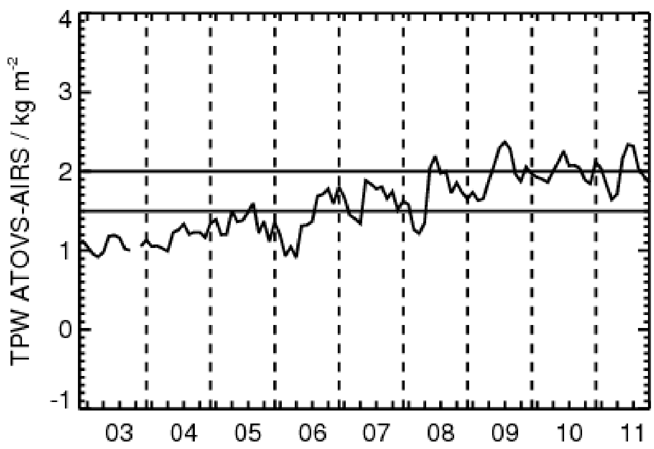


Figure 13: Similar to Figure 10, but with the data originating from the NOAA-15 satellite being removed from the retrieval from June 2008 on.

6.4 Validation of the layered products (HLW products)

6.4.1 GUAN

This section shows the validation results for the HLW products, namely, the 5 layered integrated water vapour products and the 5 layered mean temperature, first against the GUAN radiosonde data set and then against the AIRS data.

The left panels of Figure 14 and the Table 8 summarize the bias between the 5 layered integrated water vapour products (hereafter LPW products) and the GUAN radiosonde data. They show that the LPW1, LPW2, and LPW4 products meet the threshold accuracy for at least 99% of the months. Furthermore, the LPW1 and LPW2 products also meet the target accuracy for 94% and 98% of the months, respectively. The LPW5 product meets the threshold accuracy for 93% of the months while the LPW3 products show a degraded bias with only 59% of the months meeting the threshold accuracy. Furthermore, the LPW products are showing a good stability (especially LPW1, LPW2, and LPW5). The bias corrected RMSE (see Figure 14, right panel and Table 9) shows a good accuracy for all layers with more than 99% of the months meeting the threshold accuracy. Furthermore, the LPW1, LPW2, and LPW4 products meet the target accuracy for more than 90% of the months.

Figure 15, left panel, and Table 8 show the bias between the CM SAF ATOVS layered mean temperature products and the GUAN radiosonde data. The two first years of the data set show a suspiciously lower accuracy compared to the rest of the data set and this is due to missing ATOVS data in the archive. However, 100% of the products meet the threshold accuracy and the LT1, LT3, and LT4 products even meet the target accuracy for more than 90% of the months. The LT2 and LT5 products meet the target accuracy for more than 80% of the months. Except for LT5, all products show a decreasing trend. For the bias corrected RMSE (see Figure 15, right panel and Table 9), the two first years also exhibit a degraded accuracy and this is because only one satellite is used to generate the data set for that period. However, the products meet the threshold accuracy for more than 98% of the months, and the LT1-4 products meet the target accuracy for more than 90% of the months.

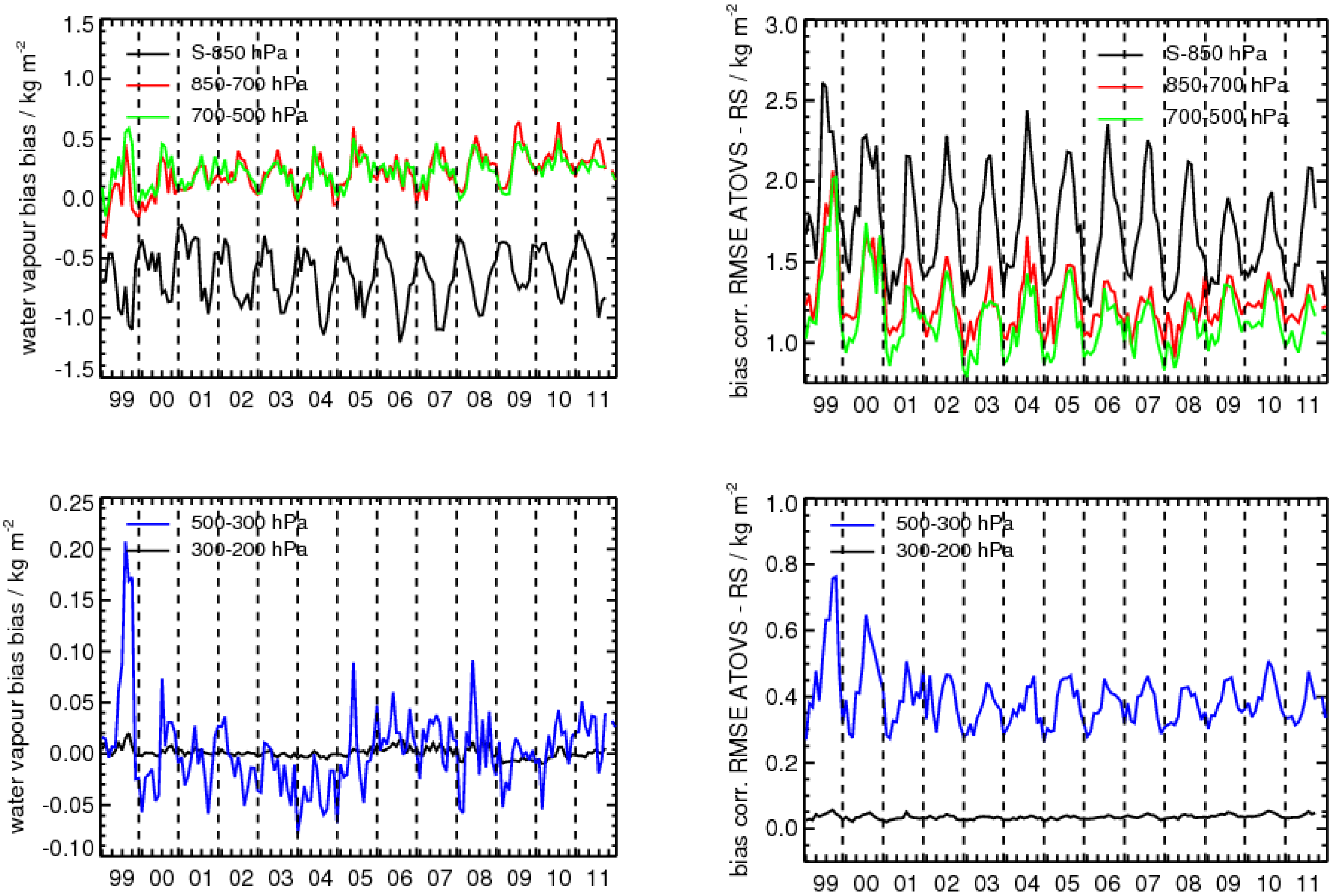


Figure 14: The left panels show the time series of bias (left panel) and bias corrected RMSE (right panel) between the 5 LPW (Layered Precipitable Water) products derived from the ATOVS and from GUAN radiosondes data for the time period from January 1999 to December 2011 (the entire time period for which the CM SAF ATOVS tropospheric humidity and temperature data set is available). The upper panels show data for the three lowermost layers and the lower panels shows data for the two uppermost layers.

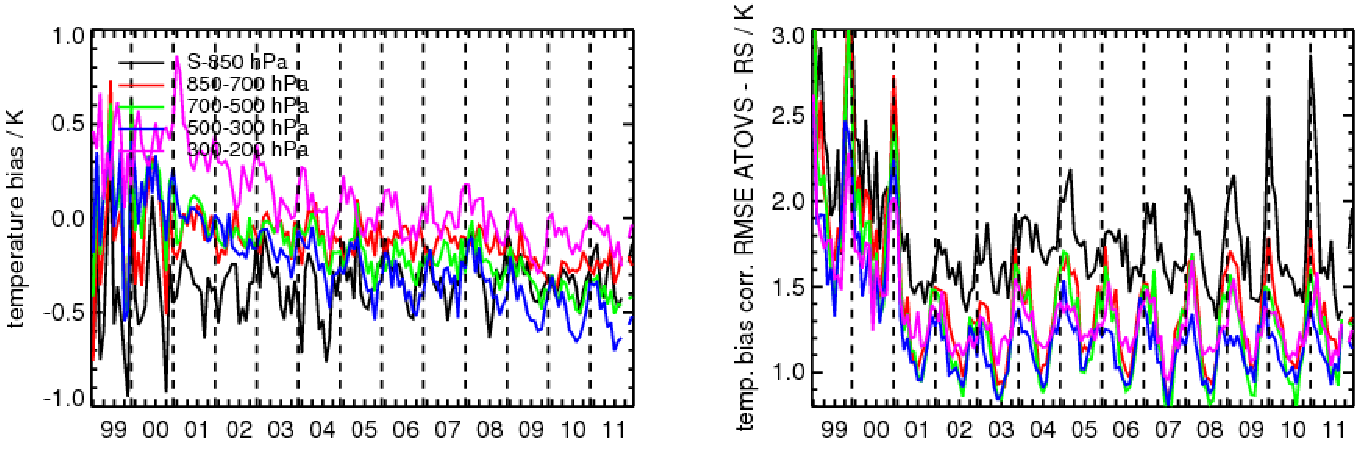


Figure 15: Similar to Figure 14Figure 15 but for the temperature products.

Table 8: Mean bias and percentage of products meeting the bias threshold and target accuracies for the validation against GUAN (CM SAF ATOVS - GUAN) of the HLW products (LPW: Layered integrated water vapour products, LT: Layered mean temperature products, for the layer definition, see Table 1).

HLW	LPW				LT			
bias	mean HLW [kg/m^2]	mean bias [kg/m^2]	% in threshold	% in target	mean HLW [K]	mean bias [K]	% in threshold	% in target
L1	0.065	0.0014	99	94	223.5	0.11	100	94
L2	0.97	0.0029	99	98	242.0	-0.23	100	86
L3	3.88	0.22	59	20	262.6	-0.16	100	97
L4	6.22	0.21	100	88	274.4	-0.13	100	98
L5	9.30	-0.64	93	16	281.2	-035	100	82

Table 9: Similar to Table 8Table 8 but for the bias corrected RMSE.

HLW	LPW			LT		
RMSE	mean RMSE [kg/m^2]	% in threshold	% in target	mean RMSE [K]	% in threshold	% in target
L1	0.035	100	97	1.34	100	98
L2	0.39	99	93	1.24	100	95
L3	1.15	99	80	1.34	99	93
L4	1.25	100	92	1.44	99	90
L5	1.72	100	79	1.8	98	80

6.4.2 AIRS

Figure 16 and Table 10 present the results of the validation of the HLW water vapour products against the AIRS data. The left panels of Figure 16 shows that the LPW3 and LPW4 products show similar features as the ones exhibited by the TPW product. The quality ranges from fully within the threshold requirement (LWP1, LWP2) to fully outside the threshold requirement (LPW3). The discussion about the validation results for the TPW product against the AIRS data (section 6.3.2) is also be relevant for the LPW products. The bias corrected RMSE meet the threshold and the target accuracy for all the products and for all layers. There are discontinuities in the bias corrected RMSE in mid 2005 and mid 2009, for LPW4 and LPW3 products. Those discontinuities correspond to changes in the satellite constellation used to generate the data set (from mid 2005 to mid 2009 at least three satellites are used to generate the data set, and even four satellites are used between mid 2007 and the beginning of 2009, while before mid 2005 and from beginning of 2009 on, only 2 satellites are used).

Table 10: Similar to Table 8 and Table 9 but for the validation against AIRS.

HLW	bias			RMSE		
	mean bias [kg/m^2]	% in threshold	% in target	mean RMSE [kg/m^2]	% in threshold	% in target
L1	0.011	98	43	0.016	100	100
L2	0.15	100	7	0.23	100	100
L3	0.64	0	0	0.82	100	100
L4	0.71	86	6	1.07	100	100
L5	1.03	50	0	1.24	100	100

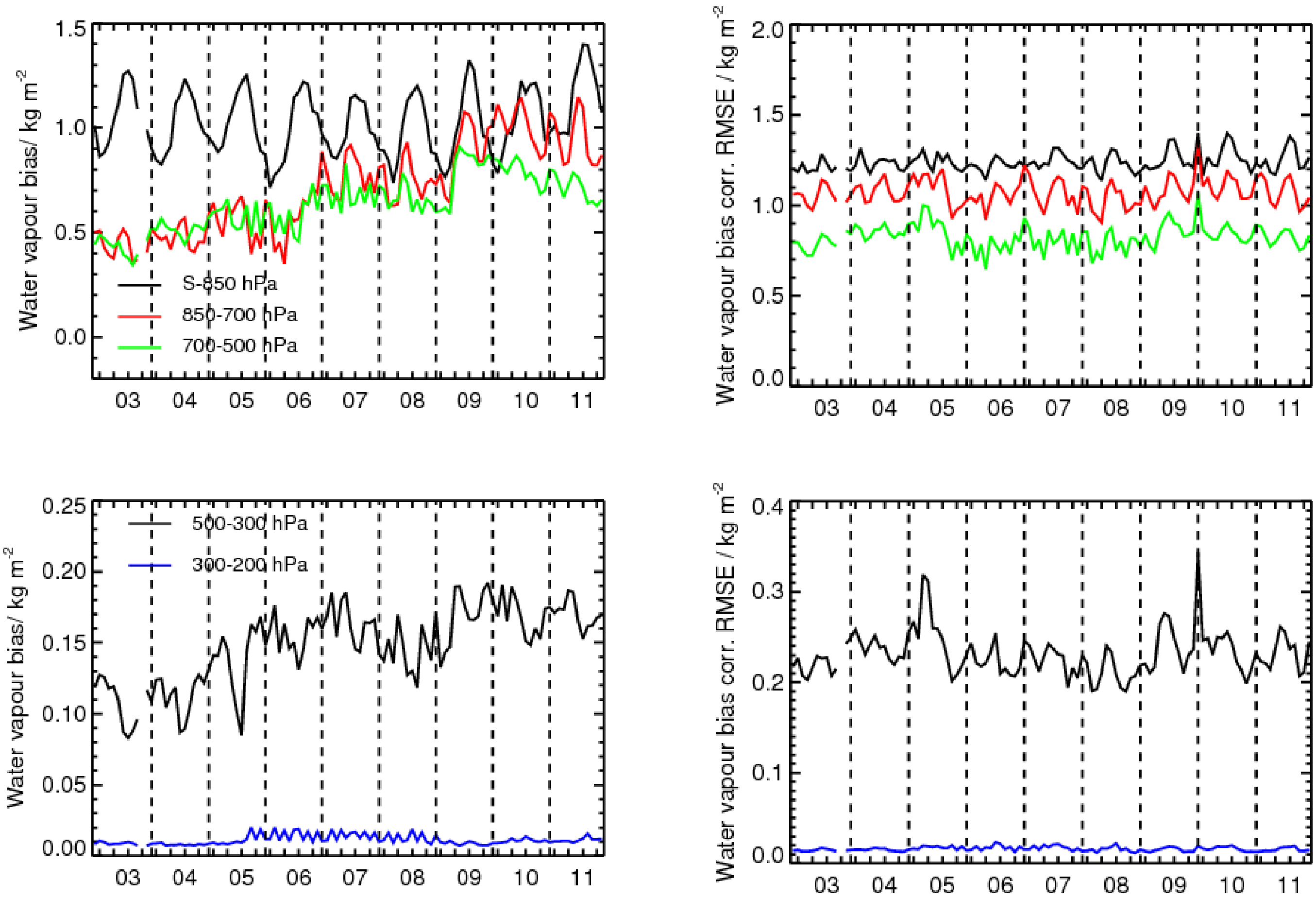


Figure 16: Similar to Figure 14 but for the validation against AIRS.

6.5 Validation of the level products (HSH products)

This section shows the results of the validation against the GUAN radiosonde data of the HSH products, namely, the specific humidity and temperature products at six pressure levels. Figure 17 and Table 11 summarize the bias between the GUAN radiosonde data and the CM SAF ATOVS data set for the specific humidity products. All products show a good stability (even if the bias for the Q6 product is really noisy) and meet the threshold accuracy for more than 90% of the months. Concerning the bias corrected RMSE (Figure 17, right panels and Table 12) the Q6 product shows a decreasing trend, otherwise, all the other products show a good RMSE stability against the GUAN radiosonde data set and all the products meets the threshold accuracy for all the levels. The Q2, Q3, Q4 and Q5 products even meet the target accuracy for more than 97% of the months.

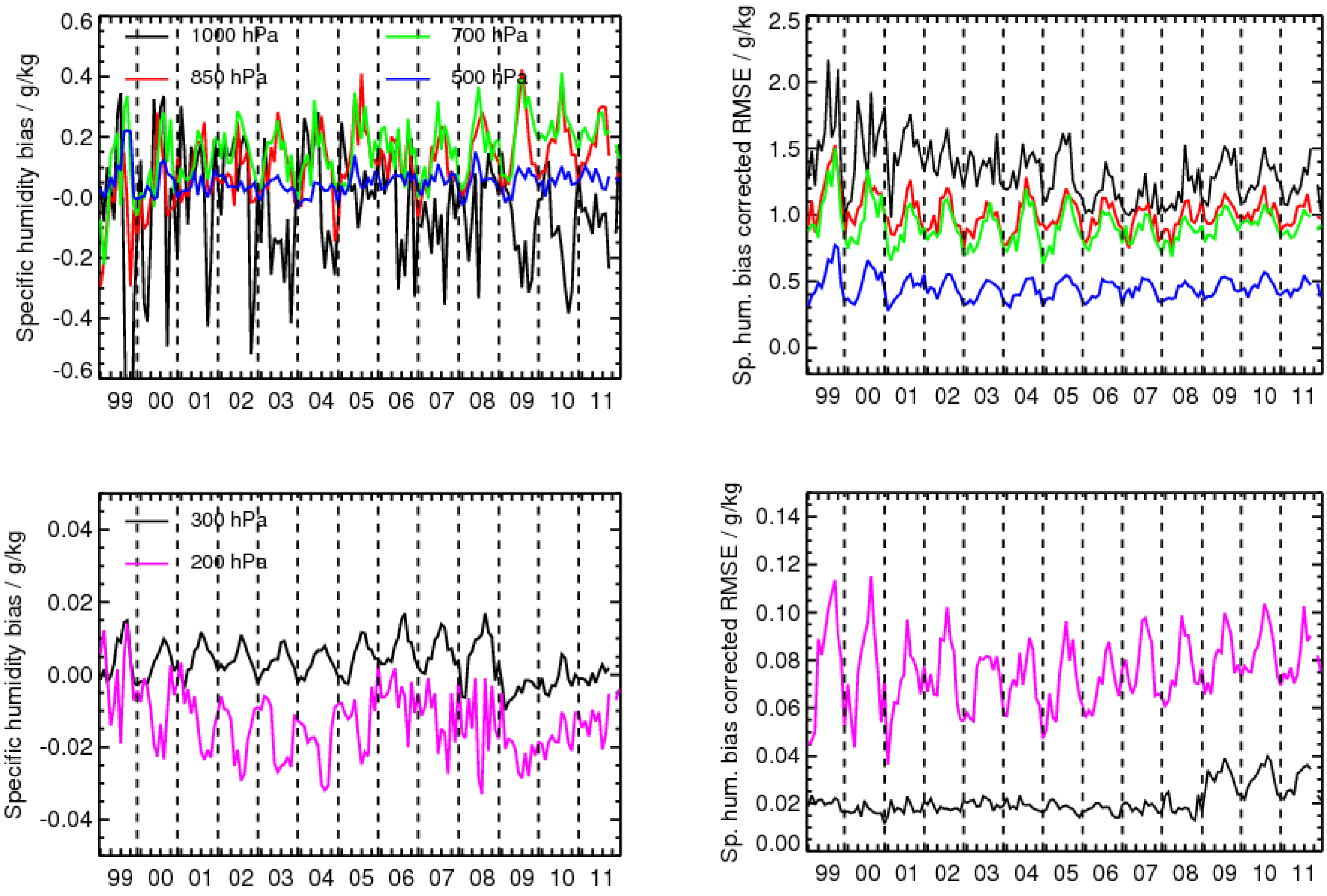


Figure 17: Time series of bias (left panel) and bias corrected RMSEs (right panel) between the specific humidity products on six levels derived from ATOVS and from GUAN radiosonde data for the time period from January 1999 to December 2011 (the entire time period for which the CM SAF ATOVS data set is available). The upper panels show data for the four lowermost layers and the lower panels shows data for the two uppermost layers.

Figure 18 and Table 11 deals with the bias against the GUAN radiosonde data for temperature products. The T1, T2, and T3 products always meet the threshold accuracy while the T4, T5 and T6 products meet the threshold accuracy for >90% of the month respectively. All the products meet the threshold accuracy for more than 97% of the months, the T2, T3, and T4 products even meet the bias corrected RMSE target accuracy for more than 90% of the months.

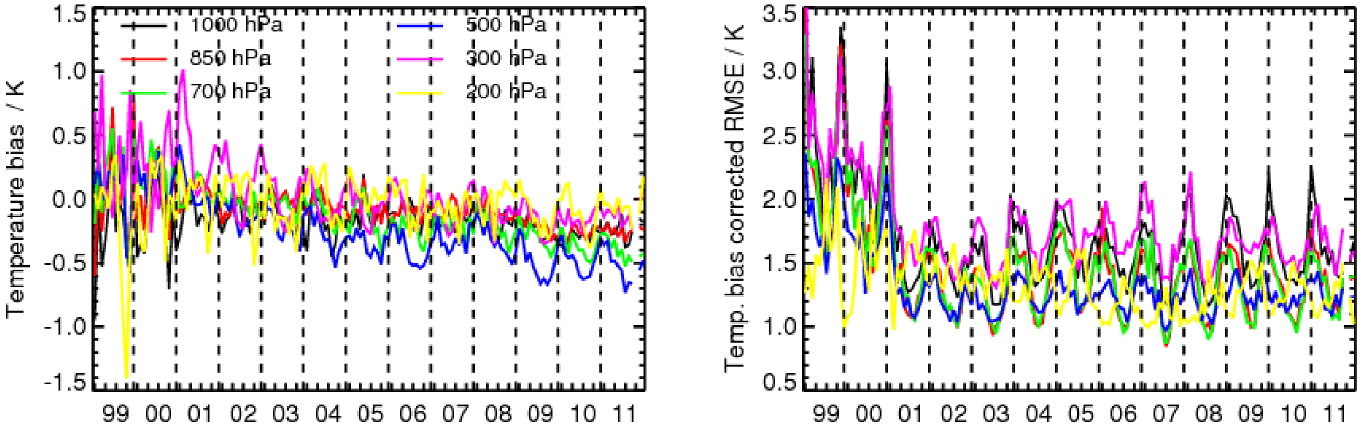


Figure 18: Similar to Figure 17 but for the temperature products.

Table 11: Similar to Table 8 but for the HSH products.

HSH	Q				T			
bias	Mean HSH [g/kg]	Mean bias [g/kg]	% in threshold	% in target	Mean HSH [K]	mean [K]	% in threshold	% in target
L1	0.027	0.0032	100	89	219.1	0.026	100	94
L2	0.11	-0.013	97	38	229.5	-0.25	100	84
L3	1.02	0.05	98	53	254.6	-0.13	100	73
L4	2.97	0.15	94	29	270.4	-0.076	98	71
L5	5.36	0.11	100	78	278.2	-0.17	97	57
L6	9.48	-0.046	99	73	287.5	0.029	88	53

Table 12: Similar to Table 9 but for the HSH products.

HSH	Q			T		
RMSE	mean RMSE [g/kg]	% in threshold	% in target	mean RMSE [K]	% in threshold	% in target
L1	0.021	100	88	1.80	99	83
L2	0.076	100	100	1.32	100	97
L3	0.45	100	99	1.45	99	92
L4	0.92	100	97	1.46	99	92
L5	1.01	100	99	1.70	97	83
L6	1.32	100	81	1.81	99	74

6.6 Decadal stability

The decadal stability for the CM SAF ATOVS data set is calculated relative to the GUAN radiosonde data set. For the water vapour products, the decadal stability is calculated using the relative bias, while for the temperature products the decadal stability is calculated using the absolute bias. The decadal stabilities for the CM SAF ATOVS data set products are given in Table 13 and Table 14.

Table 13: Decadal stability for the HTW and HLW products together with the value for the decadal stability threshold and target accuracies.

product	decadal stability [%]	decadal stability threshold [%]	decadal stability target [%]	product	decadal stability [K]	decadal stability threshold [K]	decadal stability target [K]
TPW	1.9	4	1				
LPW1	-5.2	4	1	LT1	-0.48	0.5	0.08
LPW2	0.46	4	1	LT2	-0.53	0.5	0.08
LPW3	1.6	4	1	LT3	-0.40	0.5	0.08
LPW4	3.8	4	1	LT4	-0.17	0.5	0.08
LPW5	1.8	4	1	LT5	0.075	0.5	0.08

Table 14: Similar to Table 13 but for the HSH products.

Product	Decadal stability [%]	decadal stability threshold [%]	decadal stability target [%]	Product	Decadal stability [K]	decadal stability threshold [K]	decadal stability target [K]
Q1	-10.5	4	1	T1	-0.42	0.5	0.08
Q2	-4.1	4	1	T2	-0.55	0.5	0.08
Q3	0.18	4	1	T3	-0.47	0.5	0.08
Q4	3.8	4	1	T4	-0.27	0.5	0.08
Q5	3.0	4	1	T5	-0.074	0.5	0.08
Q6	-0.23	4	1	T6	0.031	0.5	0.08

All the water vapour products meet the threshold accuracy in term of decadal stability except the LPW1 and Q1 products. The Q2 product is slightly above the threshold accuracy. On this other hand the LPW2, Q3 and Q6 products meet the target accuracy.

All the temperature products meet the threshold accuracy in term of decadal stability except the LT2 and T2 products. The LT5, T5, and T6 meet even the target accuracy.

To summarise, the CM SAF ATOVS data set shows a good stability.

7 Inter-comparison of Metop water vapour products

This section describes the intercomparison of total precipitable water vapour products (TPW) retrieved from different instrument flying onboard the Metop-A satellite. The different data sets used for the intercomparison are:

- Instantaneous CM SAF ATOVS HTW products (using only Metop-A measurements, and none of the measurements collected by the NOAA satellites),
- GOME 2 products (processed by the DLR in cooperation with the MPI-C within the ESA DUE GlobVapour project (www.globvapour.info),
- IASI (processed by the DWD within the ESA DUE GlobVapour project using the retrieval method described in Schwaerz (2004), see Stengel et al. (2012) for IASI inter-comparison results).

For consistency reasons, the level 2 to level 3 conversion for GOME 2 and IASI data was done similarly to the conversion of the ATOVS data: first, GOME 2 and IASI swaths were averaged onto the global 90 km × 90 km cylindrical equal area grid. In a second step, these gridded swaths were used to calculate daily means, which were then, in a third step, used for the calculation of the monthly mean. This intercomparison covers two months, namely October 2007 and December 2008.

Because all the three instruments are onboard Metop-A, no temporal sampling problem between the instruments might appear. An important difference between the products, however, is the fact that ATOVS shows allsky TPW (except for heavy rain) whereas both GOME 2 and IASI provide TPW only for clear-sky cases.

Measures of bias, RMS and correlation have been calculated for the two months considered within this intercomparison. Regional maps as well as spatial averages are provided.

Figure 19 shows global monthly mean TPW for the month of October 2007 for the three different data sets. ATOVS shows good agreement with the other datasets with respect to the overall global distribution of TPW. All three data sets depict an area of high TPW values along the ITCZ, especially over the continents and warm pool and decreasing TPW towards higher latitudes. However, there are some features of the ATOVS TPW that deviate from the other datasets which can be observed from the bias maps plotted in Figure 19 (right panels). The most prominent deviations can be observed over land. ATOVS exhibits larger TPW compared to GOME 2 over central Africa, South-East Asia and also in parts of South America. The opposite is true when compared to IASI. The latter shows the highest TPW values over land which results in a negative bias (>-10 kg/m²) compared to the two other data sets. As especially high mountain areas are affected, it seems that IASI estimates may suffer from an orography related problem.

Over the ocean the bias is generally lower. ATOVS exhibits over most of the ocean larger TPW compared to GOME 2 and IASI. This is most likely caused by the differences in sampling in clear and all sky conditions and leads to a clear sky bias. Underestimations are evident at ITCZ position and off the west coast of Southern America and Africa.

Figure 20 shows the associated bias histograms. The histograms exhibit closer agreement between ATOVS and IASI as well as GOME 2 than between IASI and GOME 2.

The overall statistics are summarized in Table 15. The bias is generally low and ranges between 0.01 kg m^{-2} (for GOME 2 versus IASI) and 1.2 kg m^{-2} (for ATOVS versus IASI). Biases are found to be slightly higher for the month of December 2008. The same is true for the RMS which is the lowest for ATOVS versus GOME 2 (~3.6 kg m^{-2}) and the highest for GOME 2 versus IASI (~5.2 kg m^{-2}).

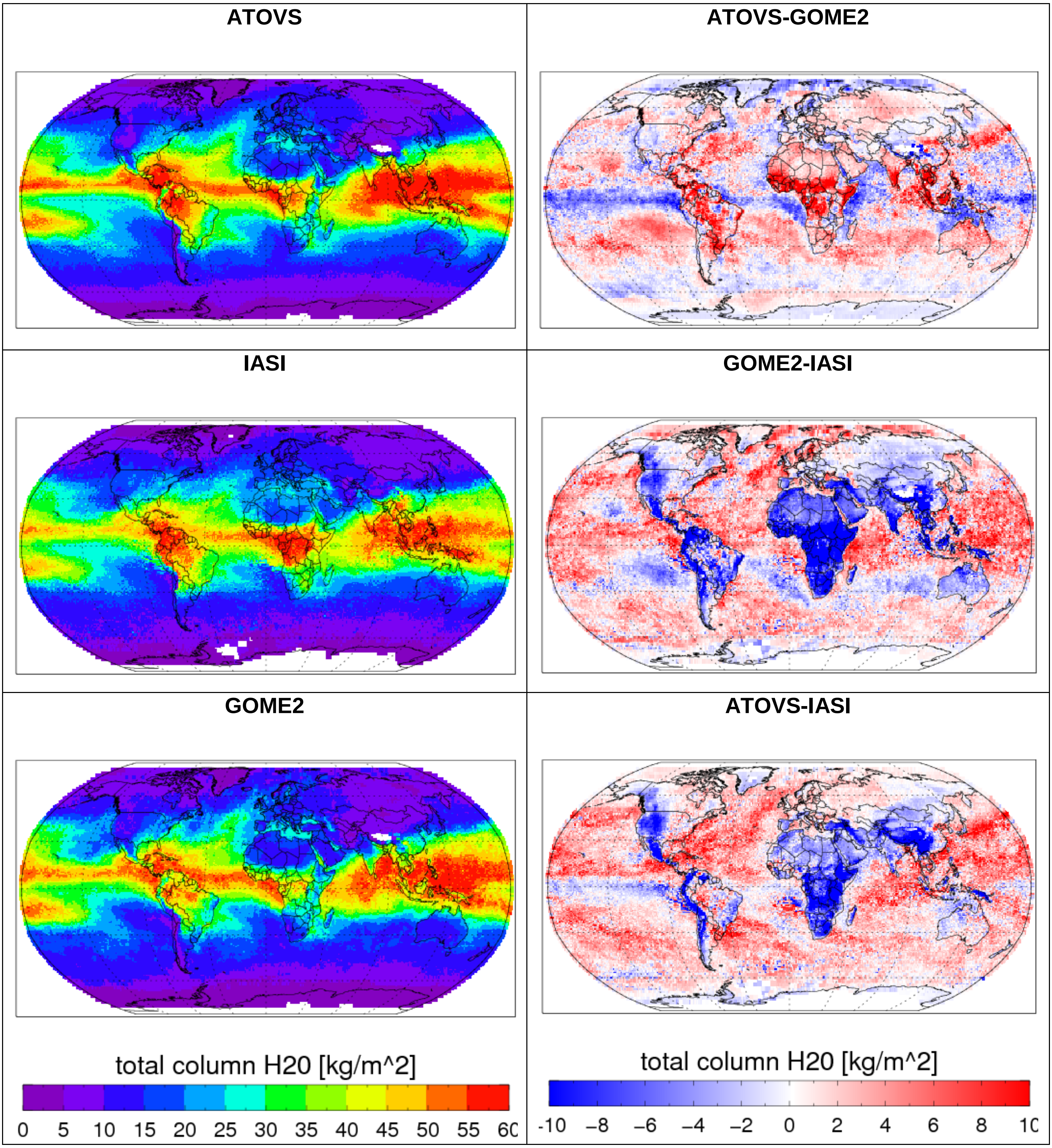


Figure 19: The left panel shows TPW monthly mean for different instruments: ATOVS (top), GOME 2 (bottom) and IASI (middle). The right panel shows the TPW bias differences between the different instruments, ATOVS – GOME 2 (top), ATOVS - IASI (bottom) and GOME 2 - IASI (middle). Both panels show data for October 2007.

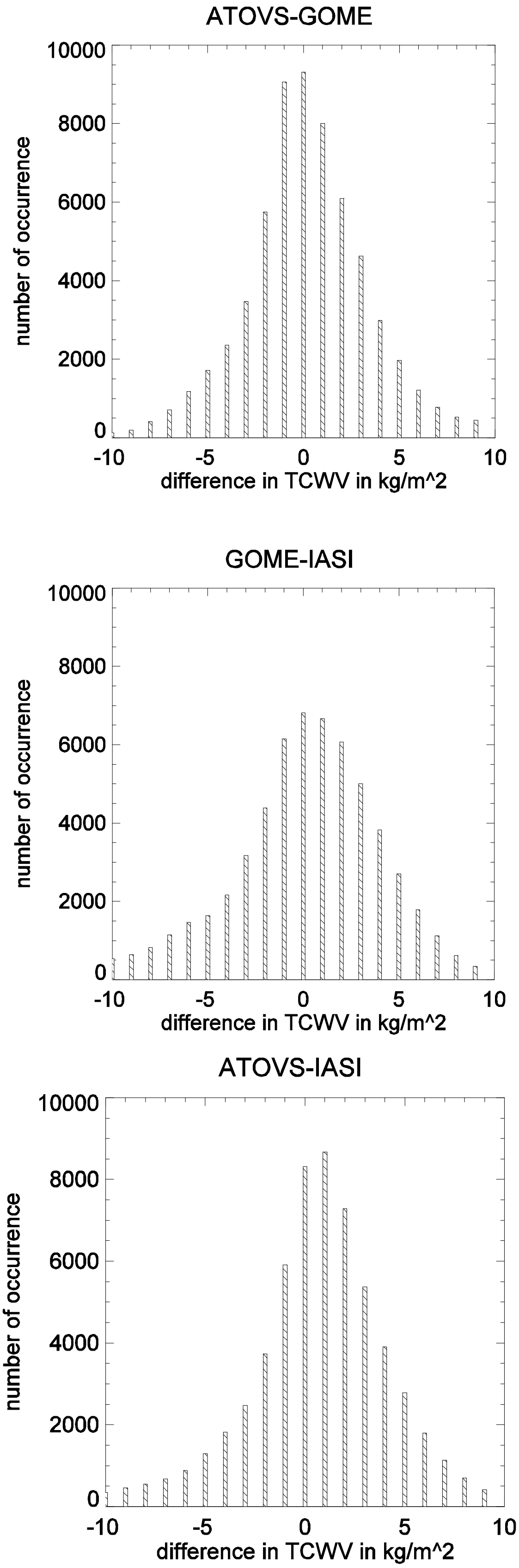


Figure 20: Histograms of the bias for ATOVS - GOME 2 (top), ATOVS - IASI (bottom) and GOME 2 - IASI (middle) for the month of October 2007.

Table 15: Bias, RMS and correlation (CORR) for the three pairs of data set (ATOVS - IASI, ATOVS - GOME 2 and GOME 2 - IASI for October 2007 and December 2008.

	BIAS [kg m^{-2}]		RMS [kg m^{-2}]		CORR	
	OCT 2007	DEC 2008	OCT 2007	DEC 2008	OCT 2007	DEC 2008
ATOVS - GOME2	0.86	1.1	3.6	3.77	0.98	0.97
ATOVS - IASI	0.83	1.2	4.58	4.65	0.96	0.96
GOME2 - IASI	0.01	0.13	5.2	5.26	0.94	0.94

8 Conclusion

The CM SAF ATOVS data set has been validated against the GUAN radiosonde data set and against other satellite data with focus on AIRS observations. Furthermore, the CM SAF ATOVS data set has been compared to the CM SAF ATOVS operational products and intercompared to other Metop-based water vapour observations, namely from GOME 2, IASI and GRAS. The validation of the CM SAF ATOVS data set against the GUAN radiosonde data set shows a general good agreement. However, a small jump is still present in the comparison results against GUAN and AIRS, however, explanations have been given to justify this jump. Overall, the CM SAF ATOVS products meet the threshold requirements in the majority of cases and often even reach target accuracy.

9 References

Daan Harald (2002), Guide to the GCOS surface and upper air networks: GSN and GUAN, Version 1.1, GCOS-73, WMO/TD No. 1106.

ESA DUE GLOBVAPOUR Product Validation Report (PVR) for SSM/I+MERIS, issue 3, revision 1, dated 21 August 2012, available online at www.globvapour.info.

John, V. O., G. Holl, S. A. Buehler, B. Candy, R. W. Saunders, and D. E. Parker (2012), Understanding inter-satellite biases of microwave humidity sounders using global simultaneous nadir overpasses, Journal of Geophysical Research, 117(D2), D02305, doi:10.1029/2011JD016349

Li, J. (2008), Readme Document for the AIRS Level-2 Version 005 Standard Products, NASA GES DISC.

Li, J., W. W. Wolf, W. P. Menzel, W. Zhang, H.-L. Huang, and T. H. Achtor (2000), Global sounding of the atmosphere from ATOVS Measurements: the algorithm and validation, Journal of applied meteorology, vol. 39, pp 1248-1268.

Lindau, R. and M. Schröder (2010), Algorithm Theoretical Basis Document Objective analysis (Kriging) for water vapour products (2010), CM SAF document, Ref: SAF/CM/DWD/ATBD/KRIGING/1.1.

Schwaerz M. (2004), Joint temperature, humidity, ozone, and sea surface temperature retrieval from Infrared Atmospheric Sounding Interferometer data, Scientific report 21, IGAM, Institute of Physics, University of Graz, Austria.

Stengel, M. et al (2012), The ESA DUE GlobVapour IASI assessment. GEWEX Newsletter, May 2012.

10 Glossary

AD	Applicable Documents
AIRS	Atmospheric InfraRed Sounder
AMSU	Advanced Microwave Sounding Unit
AMSU-A	Advanced Microwave Sounding Unit-A
AMSU-B	Advanced Microwave Sounding Unit-B
ATOVS	Advanced TIROS-N Operational Vertical Sounder
AVHRR	Advanced Very High Resolution Radiometer
CDR	Climate Data Record
CM SAF	Climate Monitoring Satellite Application Facility
DUE	Data User Element
DWD	Deutscher Wetterdienst
ECMWF	European Center for Medium-range Weather Forecast
ECV	Essential Climate Variable
ERA	ECMWF ReAnalysis
ESA	European Space Agency
EUMETSAT	EUropean organisation for the exploitation of METeorological SATellites
FCDR	Fundamental Climate Data Record
FMI	Finnish Meteorological Institute
GCOS	Global Climate Observing System
GES DISC	Goddard Earth Science Data and Information Service Center
GOME	Global Ozone Monitoring Experiment
GUAN	GCOS Upper-Air Network
HIRS	High-resolution InfraRed Sounder
HOAPS	Hamburg Ocean Atmosphere Parameters and Fluxes from Satellite Data
IAPP	International ATOVS Processing Package
IASI	Infrared Atmospheric Sounding Interferometer
IR	InfraRed
ITCZ	InterTropical Convergence Zone
KNMI	Koninklijk Nederlands Meteorologisch Instituut
LPW	Layered Water Vapour
LT	Layered Temperature
LTAN	Local Time Ascending Node
MERIS	MEdium Resolution Imaging Spectrometer
Metop	METeorological Operational satellite
MHS	Microwave Humidity Sounder
MPI-C	Max Planck Institute for Chemistry
NASA	National Aeronautics and Space Administration
NMHS	National Meteorological and Hydrological Service
NOAA	National Oceanic and Atmospheric Agency
NWP	Numerical Weather Prediction
PVR	Product Validation Report
RD	Reference Documents
RMIB	Royal Meteorological Institute of Belgium
RMS	Root Mean Square
RMSE	Root Mean Square Error
SAF	Satellite Application Facility

SCOPE-CM	Sustained COordinated Processing of Environmental satellite data for Climate Monitoring
SMHI	Swedish Meteorological and Hydrological Institute
SNO	Simultaneous Nadir Overpass
SSM/I	Special Sensor Microwave/Imager
TCWV	Total Column Water Vapour
TIROS	Television Infrared Observation Satellites
TPW	Total Precipitable Water
WCRP	World Climate Research Program
WMO	World Meteorological Organisation