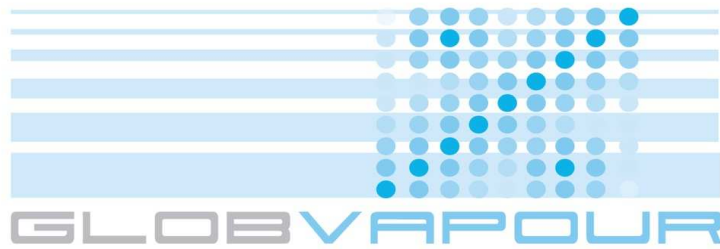




## DUE GLOBVAPOUR

### Requirements Baseline Document





Issue 1 Revision 1

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## 1. Introduction

### 1.1 Purpose

This document compiles the baseline requirements for different applications for the atmospheric water vapour products developed in GlobVapour from user inputs. This will be the basis to derive the Technical Specifications of the GlobVapour products and to assess how well the products produced in the GlobVapour project meet these requirements.

### 1.2 Definitions, acronyms and abbreviations

AATSR	Advanced Along Track Scanning Radiometer
AIRS	Atmospheric Infrared Sounder
AMSR	Advanced Microwave Scanning Radiometer
AMSU-A,B	Advanced Microwave Sounding Unit-A and -B
AOPC	Atmospheric Observation Panel for Climate
ATSR	Along-Track Scanning Radiometer
EPS	European Polar System
GCM	Global Climate Model
GCM-MOM	GlobVapour Consultation Meeting - Minutes of Meeting
GCOS	Global Climate Observing System
GHG	Greenhouse Gas
GPS	Global Positioning System
GOES	Geostationary Operational Environmental Satellite
HIRS	High resolution Infrared Sounder
IASI	Infrared Atmospheric Sounding Interferometer
MERIS	MEdium Resolution Imaging Spectrometer
MHS	Microwave Humidity Sounder
MTSAT	Meteorological Satellite
MSG	Meteosat Second Generation
SEVIRI	Spinning Enhanced Visible and Infrared Imager
SSM/I	Special Sensor Microwave/Imager
SSMIS	Special Sensor Microwave Imager Sounder

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STSE	Support To Science Element
TCWV	Total Column Water Vapour
UKMO	United Kingdom Meteorological Office
WACMOS	Water Cycle Multi-Mission Observation Strategy
WMO	World Meteorological Organisation

### 1.3 Applicable Documents

- [AD-1] ESRIN Statement of Work. EOEP-DUEP-EOPS-SW-09-0003, issue 1 revision 1, dated 13 May 2009
- [AD-2] ECSS-E-ST-40C Part 1B; Space Engineering - Software; 6 March 2009  
<http://www.ecss.nl/>
- [AD-3] DUE GLOBVAPOUR Proposal, issue 1 revision 3, dated 9 July 2009
- [AD-4] DUE GLOBVAPOUR Clarification Note, issue 1, revision 1, dated 29 October 2009

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- [R-14] SoG, 2008: Statement of guidance for global numerical weather prediction, WMO, J. Eyre, 9 December 2008.
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## 1.5 Structure of the document

This document summarises the importance of water vapour for climate and NWP and the status of measurements in section 2, the activities relevant to the requirements process in section 3 and in

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section 4 the requirements for water vapour (profiles and total column) are given. Finally, section 5 gives a brief summary.

## 2. Relevance of water vapour measurements and their status



Water vapour is a key climate variable. In the lower troposphere, condensation of water vapour into precipitation provides latent heating which dominates the structure of tropospheric diabatic heating (Trenberth and Stepaniak, 2003a,b). Water vapour is also the most important gaseous source of infrared opacity in the atmosphere, accounting for about 60% of the natural greenhouse effect for clear skies (Kiehl and Trenberth, 1997), and provides the largest positive feedback in model projections of climate change (Held and Soden, 2000).

In the stratosphere, there are potentially important radiative impacts due to anthropogenic sources of water vapour, such as from methane oxidation. In the troposphere, the radiative forcing due to direct anthropogenic sources of water vapour (mainly from irrigation) is negligible. Rather, it is the response of tropospheric water vapour to warming itself - the water vapour feedback - that matters for climate change. In GCMs, water vapour alone provides the largest positive radiative feedback, it roughly doubles the warming in response to forcing (such as from greenhouse gas increases). There are also possible stratospheric water vapour feedback effects due to tropical tropopause temperature changes and/or changes in deep convection.

The radiative effect of absorption by water vapour is roughly proportional to the logarithm of its concentration, so it is the fractional change in water vapour concentration, not the absolute change that governs its strength as a feedback mechanism. Randall et al. (2007) stated in the IPCC Fourth Assessment Report that calculations with GCMs suggest that water vapour remains at an approximately constant fraction of its saturated value (close to unchanged relative humidity (RH)) under global-scale warming. Under such a response, for uniform warming, the largest fractional change in water vapour, and thus the largest contribution to the feedback, occurs in the upper troposphere. In addition, GCMs find enhanced warming in the tropical upper troposphere, due to changes in the lapse rate. This further enhances moisture changes in this region, but also introduces a partially offsetting radiative response from the temperature increase, and the net effect of the combined water vapour/lapse rate feedback is to amplify the warming in response to forcing by around 50%. The close link between these processes means that water vapour and lapse rate feedbacks are commonly considered together. The strength of the combined feedback is found to be robust across GCMs, despite significant inter-model differences, for example, in the mean climatology of water vapour.

For NWP models the water vapour information is assimilated directly from the satellite radiances (infrared and microwave) in channels affected by water vapour absorption. This is achieved by 4D variational analysis utilising a fast radiative transfer model as the observation operator. Currently infrared radiances from IASI, AIRS, HIRS, SEVIRI, GOES-Imager and MTSAT-Imager and microwave radiances from AMSU-A, AMSU-B, MHS, SSM/I, SSMI(S) and AMSR-E are all used in global NWP centres to complement the radiosonde measurements network. GPS total zenith delay is also used to define the total column water vapour at GPS sites and the MERIS total column water vapour is beginning to be used over land during the day. The impact of the water vapour measurements improves the water vapour analyses but it has been harder to demonstrate improvements to the forecasts by improving the water vapour field especially for low level water vapour analysis changes. This is because the models are often tuned to their own water vapour climatology and modifying the low level water vapour can often lead to changes in the model spin up which have detrimental effects on the forecasts.

The global network of radiosonde measurements provides the longest record of water vapour measurements in the atmosphere, dating back to the mid-1940s. However, early radiosonde sensors suffered from significant measurement biases, particularly for the upper troposphere, and changes in instrumentation with time often lead to artificial discontinuities in the data record (e.g., see Elliott et al., 2002). Consequently, most of the analysis of radiosonde humidity has focused on trends for altitudes below 500 hPa and is restricted to those stations and periods for which stable instrumentation and reliable moisture soundings are available.

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Satellite observations provide near-global coverage and thus represent an important source of information over the oceans, and over land where radiosonde observations are scarce, and in the upper troposphere and stratosphere, where radiosonde sensors are unable to measure or at best unreliable.

Difficulties in observing water vapour in the upper troposphere have long hampered both observational and modelling studies, and significant limitations remain in coverage and reliability of observational humidity data sets (Trenberth et al., 2007). To reduce the impact of these problems, in recent years there has been increased emphasis on the use of satellite data (such as 6.3 to 6.7  $\mu\text{m}$  infrared radiance measurements and 183 GHz measurements in the microwave region) for inferring variations or trends in humidity, and on direct simulation of satellite radiances in models as a basis for model evaluation. An area of concern for infrared based products is that they cannot infer the tropospheric water vapour in cloudy areas whereas the microwave products can. Various studies (e.g. Mieruch et al., 2010 and Xavier et al., 2010) have shown this can lead to a dry bias for the infrared products. All satellite measurements of lower tropospheric water vapour over land are challenging but developments using products based on visible and near infrared radiance (e.g. MERIS) are showing promise.



### 3. Requirements analysis

The requirements for water vapour profiles for global NWP and climate modelling were collated starting with the Global Climate Observing System (GCOS) (for climate) and WMO (for NWP) user requirements as a baseline (both on WMO UR, 2010). The consolidated set of user requirements include: requirements in terms of horizontal and vertical resolution, temporal sampling, and accuracy of the product. In addition the dissemination timeliness requirements were defined. Other requirements on long term stability are of high importance for climate monitoring applications. Within the GCOS framework a list of Essential Climate Variables (ECVs) were defined. Among atmospheric ECVs total column water vapour as well as tropospheric and lower stratospheric water vapour profiles are recommended for priority analysis. It is stated in GCOS (2006) taking into account Ohring et al. (2005) that in-situ and satellite observations are vital to achieve an integrated observing system for ECVs in general and more specific, that water vapour observations will largely depend upon satellite observations. The updated GCOS implementation plan GCOS (2010) continues to highlight the importance of water vapour profiles and the role of the GCOS Reference Upper Air Network (GRUAN) to 'calibrate' all the satellite sensors. The Global Satellite-based Inter-Calibration System, GSICS will also help to improve the calibration of the satellite sensors. It is emphasised in all user requirement documents that the validation of the satellite products is of utmost importance.

GCOS have postulated their requirements for satellite observations suitable for climate variability and trend analysis. WMO also published user requirements for surface-based, airborne and space-based observations for other applications such as global and regional numerical weather prediction (NWP), see WMO UR (2010), SoG (2008) and its former version ReqObs (2001). Three-dimensional humidity fields are key model variables for which observations are needed. The horizontal resolution and coverage are major advantages of satellite observations. The vertical resolution of recent space-borne instruments on polar-orbiting satellites can be considered as acceptable. The temporal resolution of geostationary satellites not only allows analysis of diurnal cycles but also increases the number of clear sky observations. The availability of total column water vapour from MERIS and MODIS over land is also important. It is indicated in ReqObs (2001) that disadvantages through lack of accuracy might be more than overcome through advantages in coverage and spatial resolution.

The ESA DUE GlobVapour project user consultation meeting was convened in order to define a (minimum) Requirements Baseline for water vapour climatology and its use in climate model validation. Representatives from space agencies, experts in the field of satellite remote sensing and climate analysis, and potential users of water vapour products from satellite observations, mainly regional and global scale climate modellers, expressed their interest in total column water vapour (at a small/fine grid size) and considered profile information, even if limited in temporal and spatial



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resolution, useful. In general, the meeting resulted in requirements similar to those stated in GCOS, 2006 (see UWR, 2009 for a meeting summary).

Within ESA's STSE project WACMOS a Requirements Baseline had been defined for merged SEVIRI and IASI and SEVIRI and MERIS products and are summarised in WACMOS RB (2009). The recently announced ESA Climate Change Initiative did not choose water vapour as one of the eleven ECVs choosing other related ECVs such as GHGs, clouds and aerosols.

Finally, EUMETSAT (2000) and EUMETSAT (2004) provide information on requirements of end-users for the EPS and MSG programs, respectively. These documents have been established by representatives nominated by the national meteorological services of EUMETSAT bodies and is reviewed by the EUMETSAT Scientific and Technical Group.

The requirements of the GlobVapour products are summarised in section 4, separately for total column water vapour and water vapour profiles. They are mainly oriented at WMO UR (2010), UWR (2009), and WACMOS RB (2009). Temporal and spatial resolution and coverage are oriented at known characteristics of the satellites observations used as input for the GlobVapour products, in compliance with EUMETSAT (2000), EUMETSAT (2004) and UWR (2009), and are given on the basis of those input observations which allow the highest resolution or largest coverage. In particular, the optimum vertical resolution for the SEVIRI-IASI product is 10 layers in the troposphere as stated in EUMETSAT (2009). This is justified by the number of independent information that can be expected from IASI observations which is about 10 for humidity profiles - in contrast to a maximum of 3 layers that can be expected from SEVIRI measurements. Except for vertical resolution all values are in agreement with requirements stated in WMO UR (2010) and UWR (2009).



Climate modellers prefer to use single sensor products instead of merged products. The modellers need well defined error characteristics which are known for single sensor products.

#### 4. Baseline requirements for water vapour products

On the basis of the requirements analysis in section 3, the Requirements Baseline was developed for the GlobVapour water vapour products and is summarized in Table 2 (TCWV) and Table 4 (water vapour profiles). Each of these Requirements Baseline tables is accompanied by a table which provides an overview of the requirements from different centres being active in diverse application areas. These requirements are to a large extent taken from WMO and GCOS tables (WMO UR, 2010). A significant benefit for the users can probably not be gained when the product quality falls below the "threshold" value. The "goal" requirement is the value at which it is anticipated that no further improvements for the user's application can be expected. The "breakthrough" requirement always lies between "threshold" and "goal" requirement and can be interpreted as value at which user requirements can be met in the most cost-effective way (WMO UR, 2010). Accuracy is given as root mean square error (RMSE) of the water vapour observation. The values given in Table 2 and Table 4 are condensed from Table 1 and Table 3 taking into account known observational satellite characteristics. Therefore, threshold, breakthrough and goal values are given for accuracy (TCWV, profiles) and vertical resolution (profiles) only.

The temporal sampling is less critical for long term trend monitoring but for validation of the hydrological cycle in climate models adequate sampling of the diurnal cycle is a requirement. Concerning the temporal coverage a reliable trend analysis might be feasible when the dataset exceeds a length of 20 years. Certainly, longer time series are preferred but a length of 20 years is considered as a reasonable length to start with. No specification for the stability of the products is given in the table but values are stated in the text for total column water.

For spatial coverage global datasets are a common requirement from GCOS and climate users. Users were asked whether they preferred a merged dataset where the gaps due to clouds were filled by Kriging or if only the cloudfree data was provided. Users stated they preferred to receive the cloudfree data but gaps could be filled as long as the "filled data" was flagged and an uncertainty measure could be assigned to the "filled data". Simple map projections (e.g. lat/long grid) was also a requirement.

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#### 4.1 Total column water vapour

A summary of the requirements from the various applications areas is listed in Table 1. The application areas were global and regional NWP, AOPC (to cover reanalyses and climate applications), regional climate modelling, and nowcasting.

The Requirements Baseline for the GlobVapour total column water vapour product GVap-TCWV is summarized in Table 2. The summary utilises the requirements for all applications in the climate sector rather than NWP or nowcasting applications. Within GlobVapour combined SSM/I and MERIS, homogenised GOME, SCIAMACHY and GOME-2 and (A)ATSR TCWV products in units of  $\text{kg m}^{-2}$  will be generated. Note that uncertainty estimates will be provided with all the datasets.

The GlobVapour project can serve all purposes related to climate modelling research, analysis, reanalyses and monitoring. The products cannot serve the requirements of nowcasting and NWP because requirements on the delay of availability cannot be fulfilled by the approach taken in the DUE GlobVapour project.

Where frequent temporal coverage is a critical requirement the B/T requirement can only be served by products containing SEVIRI observations.

For climate monitoring the requirement on stability is 1% or  $0.4 \text{ kg.m}^{-2}$  per decade in order to be able to infer trends in total column water vapour.



Table 1: Requirements for total column water vapour from different centres (B/T: Breakthrough, Thresh: Threshold).



Requirement for specific humidity	Application area	Horizontal [km]			Observing cycle [h]			Accuracy [ $\text{kgm}^{-2}$ ]		
		Goal	B/T	Thresh	Goal	B/T	Thresh	Goal	B/T	Thresh
Total column	Global NWP	15	50	250	1	6	12	1	2	5
Total column	Nowcasting	5	10.8	50	0.25	0.397	1	1	1.7	5
Total column	Regional NWP	10	29.2	250	0.5	1.442	12	1	1.7	5
Total column	Long term trends	50	100	200	3	4	6	1	1.4	3
Troposphere column	Long term trends	10	25	200	3	4	6	1	1.4	3
Total Column	Global and Regional Climate Modelling	1	7	50	1	3	12	1	1.7	5



Table 2: Requirements Baseline for the GlobVapour total column water vapour products (B/T: Breakthrough).

ID	Name	Input Satellite data	Dissemination			Spatial	
			Type (NRT/off-line)	Means	Format	Coverage	Resolution
GVap-TCWV	Total Column Water Vapour in kg m <sup>-2</sup>	SSM/I, MERIS, GOME, GOME-2, (A)ATSR SCIAMACHY	offline	ftp, DVD or Web	netCDF	ocean land global	≤0.5° / 55km

Temporal resolution		Accuracy [kgm <sup>-2</sup> ] Error estimates included in dataset			Verification method	Applications and users
coverage	resolution	Goal	B/T	Threshold		
>20 years	Daily, monthly	1	2	5	Ground based measurements Inter satellite comparison Reanalyses	AOPC Validation of (R)CM, Climate monitoring, Model process studies Global and regional NWP Reanalyses

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## 4.2 Water vapour profiles

A summary of the requirements for water vapour profiles from the various applications areas is listed in Table 3. The application areas were global and regional NWP, AOPC (to cover reanalyses and trend monitoring) climate applications, regional climate monitoring, nowcasting, aeronautical meteorology and atmospheric chemistry.

The Requirements Baseline for the GlobVapour water vapour profile product GVap-WVP is summarized in Table 4. The summary utilises the requirements for all applications in the climate sector rather than NWP or nowcasting applications. Note that uncertainty estimates will be provided with the datasets.

The GlobVapour project can serve all purposes related to climate research and monitoring. The products cannot serve requirements of nowcasting and NWP because both requirements on observation cycle and delay of availability cannot be fulfilled by the approach taken in GlobVapour.

Observing cycle is a critical requirement where the B/T requirement can only be served by products containing SEVIRI observations.

More than 20 years of data are required for reliable climate analysis. Nevertheless a few years of profile data are still of interest for climate modellers, e.g., for process analyses.



Table 3: User Requirements for water vapour profiles (B/T: Breakthrough, Thresh: Threshold, Aero Met: Aeronautical Meteorology).

Requirement for specific humidity	Application area	Horizontal [km]			Vertical [km]			Observing cycle [h]			Accuracy [%]		
		Goal	B/T	Thresh	Goal	B/T	Thresh	Goal	B/T	Thresh	Goal	B/T	Thresh
Lower troposphere (LT)	Aero Met	50	63	100	0.15	0.238	0.6	1	1.4	3	5	6.30	10
Lower stratosphere (LS)	Atmospheric chemistry	50	107.7	500	1	1.7	5	12	21.8	72	5	7.90	20
Higher troposphere (HT)	Atmospheric chemistry	50	107.7	500	1	1.7	5	12	21.8	72	5	7.90	20
Lower troposphere (LT)	Atmospheric chemistry	50	107.7	500	1	1.7	5	6	13.7	72	5	7.90	20
Higher troposphere (HT)	Global NWP	15	50	250	0.5	1	3	1	6	12	2	5	10
Lower troposphere (LT)	Global NWP	15	50	250	0.3	1	3	1	6	12	2	5	10
Higher troposphere (HT)	Nowcasting	5	17.1	200	1	1.4	3	0.25	0.397	1	5	7.90	20
Lower troposphere (LT)	Nowcasting	5	17.1	200	0.5	0.63	1	0.25	0.397	1	5	7.90	20
Lower troposphere (LT)	Regional NWP	10	21.5	100	0.4	0.684	2	0.5	1.442	12	5	7.90	20



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Requirement for specific humidity	Application area	Horizontal [km]			Vertical [km]			Observing cycle [h]			Accuracy [%]		
		Goal	B/T	Thresh	Goal	B/T	Thresh	Goal	B/T	Thresh	Goal	B/T	Thresh
Higher troposphere (HT)	Regional NWP	10	21.5	100	1	1.4	3	0.5	1.442	12	5	7.90	20
Higher troposphere (HT)	Synoptic Meteorology	20	43.1	200	0.1	0.271	2	3	4.8	12	5	7.90	20
Lower troposphere (LT)	Synoptic Meteorology	20	43.1	200	0.1	0.271	2	3	4.8	12	5	7.90	20
Lower troposphere (LT)	Climate Research	50	63	100	0.5	0.794	2	3	4.8	12	5	7.90	20
Lower troposphere (LT)	Climate Research	50	107.7	500	0.5	0.794	2	6	13.7	72	2	2.70	5
Higher troposphere (HT)	Climate Research	50	63	100	0.5	0.794	2	3	4.8	12	5	7.90	20
Lower stratosphere (LS)	Climate Research	50	85.5	250	0.5	0.794	2	3	4.8	12	5	7.90	20
Lower stratosphere (LS)	Climate Research	50	107.7	500	0.5	0.794	2	6	13.7	72	2	2.70	5
Higher stratosphere & mesosphere (HS & M)	Climate Research	50	85.5	250	1	1.4	3	3	4.8	12	5	7.90	20



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Requirement for specific humidity	Application area	Horizontal [km]			Vertical [km]			Observing cycle [h]			Accuracy [%]		
		Goal	B/T	Thresh	Goal	B/T	Thresh	Goal	B/T	Thresh	Goal	B/T	Thresh
Higher stratosphere & mesosphere (HS & M)	Long term trends	50	107.7	500	0.5	0.794	2	6	13.7	72	2	2.70	5
Lower stratosphere (LS)	Long term trends	50	100	200	2	2.5	3	3	4	6	2	5	20
Higher stratosphere & mesosphere (HS & M)	Long term trends	50	100	200	2	3	5	3	4	6	2	5	20
Lower troposphere (LT)	Long term trends	10	15	25	0.1	0.2	1	3	4	6	2	4	15
Lower troposphere (LT)	Global and Regional Climate Modelling	1	7	50	0.1	0.5	5	1	3	12	5	7.90	20
Higher troposphere (HT)	Global and Regional Climate Modelling	1	7	50	0.5	1	5	1	3	12	5	7.90	20







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Table 4: Requirements Baseline for the GlobVapour water vapour profiles (B/T: Breakthrough). “Layers” refers to layers within the troposphere.

ID	Name	Input Satellite data	Dissemination			Spatial		Vertical resolution		
			Type NRT/ off-line	Means	Format	coverage	resolution	Thresh	B/T	Goal
GVap-WVP	Water Vapour profile concentration in kg m <sup>-3</sup>	SEVIRI, IASI	offline	ftp, dvd or web	netCDF	Ocean, land, global	0.25° /28km	2 layers	5 layers	10 layers

Temporal resolution		Accuracy [%] Error estimates included in dataset			Verification method	Applications and users
coverage	resolution	Goal	B/T	Threshold		
>20 years	Hourly, daily, monthly	5	8	20	ground based measurements , Inter satellite comparison, Reanalyses	Validation of (R)CM, Climate monitoring, Model process studies, Reanalyses

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## 5. Conclusions

This document summarises the Requirements Baseline for ESA's DUE GlobVapour project. On the basis of an extensive requirement analysis and taking into account requirements and comments from the GlobVapour User Group, spatial and temporal resolution as well coverage, vertical resolution and accuracy requirements have been defined for the products total column water vapour (GV-TCWV) and water vapour profiles (GV-WVP).

The GlobVapour can serve all purposes related to climate modelling research, analysis, reanalyses and monitoring. The products cannot serve requirements of nowcasting and NWP because both requirements on observation cycle and delay of availability cannot be fulfilled by the approach taken in GlobVapour.

The summary tables provide the starting point for the definition of the technical specification of the different GlobVapour products.