Water Vapour Climate Change Initiative (WV_cci) - Phase One

User Requirements Document (URD)

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1.0	10 Dec 2018	Formal issue to ESA
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1. INTRODUCTION

1.1 Purpose

This User Requirements Document (**URD**) identifies and consolidates the performance requirements for the data products of the Essential Climate Variable (**ECV**) water vapour that will be generated within the Water_Vapour_cci (WV_cci). These data products feature climate data records (**CDR**) of total column water vapour (**TCWV**), and nadir- and limb-based vertical profiles of water vapour in the troposphere and stratosphere, respectively.

Considered requirement sources include international bodies such as Global Climate Observing System (**GCOS**) and the World Meteorological Organization (**WMO**), CCI-internal feedback from the Climate Modelling User Group (**CMUG**), Climate Research Group (**CRG**) and other Climate Change Initiative (**CCI**) projects, and feedback from the WV_cci user community. These requirements are analysed and condensed into requirements for WV_cci data products. When available we also provide the applicable terminology and discuss our interpretation when analysing the requirements.

1.2 Scope

The general scope of this document is to inform the WV_cci project of the quality and performance standards that the climate data records it envisages to generate need to achieve in order to be useful for the end user and climate research applications. The URD is also intended to inform data users of the guiding requirements WV_cci adopted to develop and produce its CDRs. The URD’s findings will thereby form the basis of the Product Specification Document (**PSD**), in which the CDRs are being characterised.

The CDR user requirements and characteristics that are being defined in this document include

- Accuracy
- Precision
- Spatial Resolution (horizontal and vertical)
- Temporal Resolution (frequency)
- Stability
- Record length

Note, specific data product requirements that deal with the data formatting will be provided in the PSD.

2. RELEVANCE OF WATER VAPOUR IN THE CLIMATE SYSTEM

Water vapour is the single most important natural greenhouse gas in the atmosphere, thereby constraining the Earth's energy balance, and is also a key element of the water cycle. Water vapour is also key to atmospheric chemistry, because it is the source of the hydroxyl radical, which is the most important oxidant (cleansing detergent) in the atmosphere. The following sections explain the relevance of tropospheric and stratospheric water vapour in the climate system, respectively.

2.1 Relevance of water vapour in the troposphere

Most of the atmosphere's water vapour is found in the troposphere, with 95% residing between the surface and 5 km altitude. Water vapour concentrations vary by as much as four orders of magnitude between Earth's surface and the tropopause, with the hygropause defining the lowest water vapour concentrations in the vertical.

Tropospheric water vapour results from evaporation from ocean and land surfaces that is driven by solar heating, with its abundance determining the development of clouds, precipitation, and extreme events (see Figure 2-1). Redistribution of water through these atmospheric processes is a key part of the hydrological cycle, which determines soil moisture and surface fluxes and ultimately, where live on Earth can be sustained. The latent heat of water vapour is thereby responsible for half of the heat transport from the tropics to the extra-tropics that maintains the climate in the extratropics (Sherwood et al., 2010).

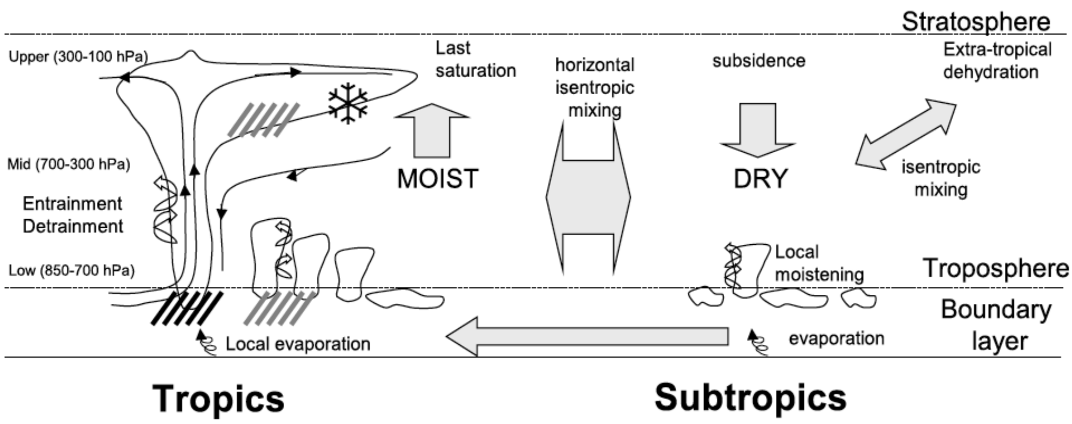

Figure 2-1: Processes affecting the transport and distribution of tropospheric water vapour (from Sherwood et al., 2010).

Water vapour is an essential natural greenhouse gas that influences the Earth's radiation budget both directly and indirectly via clouds. The Clausius-Clapeyron relationship predicts that per degree Kelvin increase in temperature, the atmosphere can contain around 7% more water vapour. Climate models indicate that this important positive feedback may increase the sensitivity of surface temperatures to carbon dioxide by a factor of two to three, depending on whether other Earth system feedbacks (including clouds) are considered (Held and Soden, 2000).

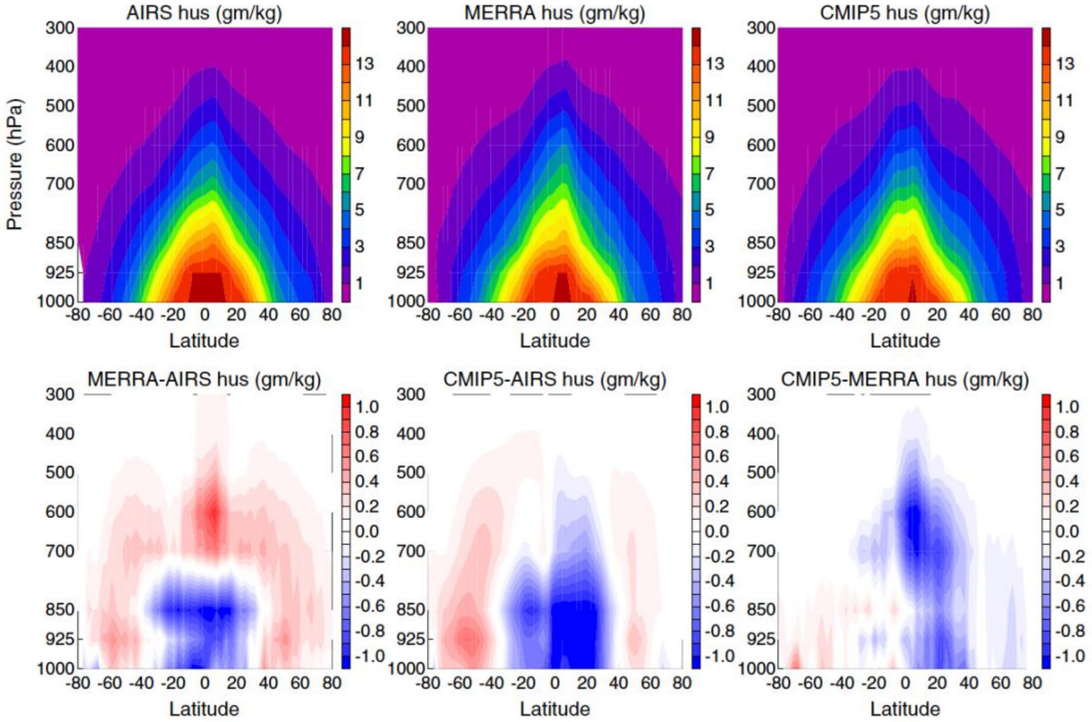

Figure 2-2: Global zonal mean of climatological mean (January 1986- December 2005) tropospheric specific humidity (g/kg) for AIRS, MERRA and CMIP5 and their differences (from Tian et al., 2013).

Total column water vapour (TCWV) measurements are the most commonly used observations to represent the water vapour content of the troposphere. CDRs of TCWV are essential to validate the above processes in global climate models and reanalyses, and also to provide a reference for the climatological distribution and natural variability of tropospheric water vapour, including (particularly regional) trends in these variables. Reanalyses, which are often taken as observational reference, have been shown to have substantial shortcomings in representing the residence time of water in the atmosphere, do not conserve water within the hydrological cycle mainly due to analysis increments (Trenberth et al., 2011), and are affected by stability issues (e.g., Schröder et al., 2016). These limitations need to be taken into account when using them for the evaluation of global climate models. On the other hand, while global climate models have been successfully used to reproduce observed water vapour increases derived from satellite measurements over the oceans, the mechanisms behind a recent decease in the trend over land are still to be investigated (IPCC, 2014). Despite an overall consistency at a global scale, global climate models fail at simulating correctly the observed vertical and latitudinal distribution of moisture (Figure 2-2), on average with a too dry tropical lower troposphere and too moist mid-latitudes. Also, low-resolution models are generally not capable of providing useful information on atmospheric water vapour for downscaling of extreme events (WMO, 2016).

2.2 Relevance of water vapour in the stratosphere

In the stratosphere, knowledge of the vertical distribution, its variability and trends, is of particular importance since the radiative forcing resulting from changes in water vapour exhibits a strong sensitivity to the altitude at which the changes occur, with the largest changes found around the tropopause where temperatures are coldest (Forster and Shine, 1999; 2001). An increase in stratospheric water vapour thereby results in a cooling (warming) of the stratosphere (troposphere). In contrast, an increase of humidity in the upper troposphere would lead to a warming due to increased absorption of outgoing longwave radiation. This effect is strongest at the dry end of the humidity PDF.

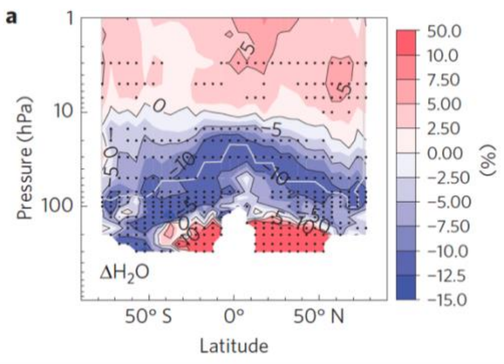

Figure 2-3: Zonal mean water vapour changes as derived from merged satellite limb sounders between the late 1980s and 2010 (from Hegglin et al., 2014). Note, lower stratospheric water vapour changes are negative.

Stratospheric water vapour changes are not well understood due to a lack of accurate long-term measurements (both in-situ and remote) that would be able to capture very small changes against small background values. Not surprisingly, there exist conflicting results between trends in stratospheric water vapour derived from in-situ balloon (Hurst et al., 2011) and space-based remote sensing instruments (Hegglin et al., 2014) (see Figure 2-3 and Figure 2-4).

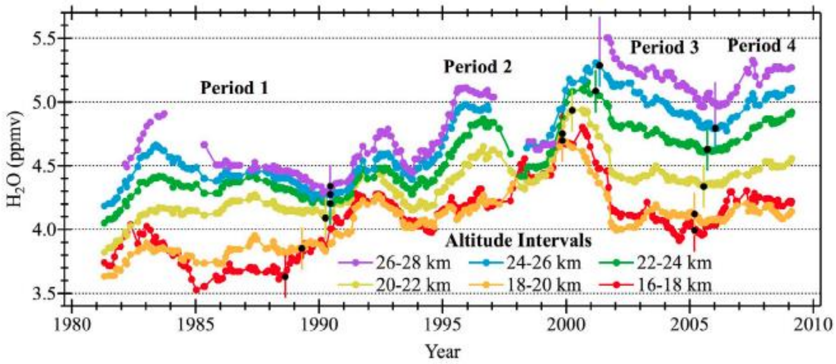

Figure 2-4: Water vapour changes between 1980s and 2010 from balloon frost point hygrometer measurements (from Hurst et al., 2011). Note, lower stratospheric water vapour changes are positive.

A knowledge gap in particular exists even for climatological water vapour distributions in the upper troposphere and lower stratosphere (**UTLS**) due to the lack of an observing system that can handle the difficulties of measuring in this region due to increasing opacity of the atmosphere that challenges remote sensors and the low pressures and temperatures that challenges in-situ observations.

Finally, the importance of accurately representing water vapour in global models and reanalyses can be understood from the impact that has been shown from water vapour changes around the tropopause on climate sensitivity (Nowack et al., 2015) and also (as recently pointed out in a technical report by ECMWF) in determining weather forecast skills (Shepherd et al., 2018). That accurate representation of water vapour in reanalyses and global climate models is a general problem for modelling tools has been shown recently by Davies et al. (2017) and Hegglin et al. (2010) (see Figure 2-5), with models consistently showing too large water vapour values in the UTLS.

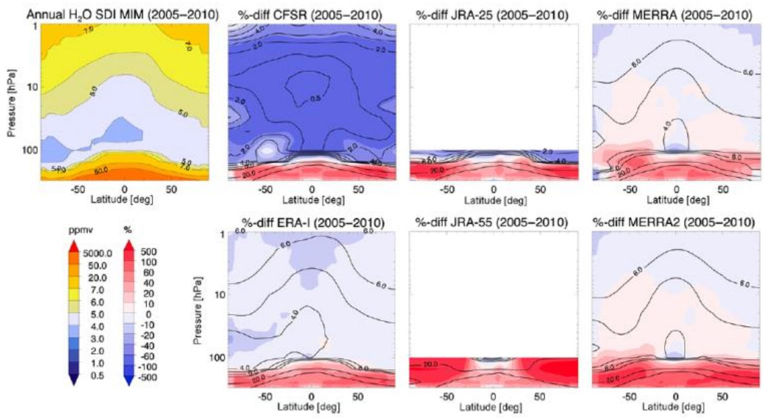

Figure 2-5: Comparison of zonal mean water vapour climatologies from reanalyses and the SPARC Data Initiative multi-instrument mean (from Davies et al., 2017). Note the large positive biases in water vapour in the UTLS.

3. REQUIREMENTS FOR ECV WATER VAPOUR

This section summarises requirements on the ECV water vapour, i.e., TCWV and tropospheric and stratospheric profiles of water vapour. It considers various requirement sources and if not stated otherwise all sources require global coverage. Note that explicit user requirements on temporal coverage are typically not available. However, the climate user group was asked to provide feedback on this variable (see consolidated results in Section 6).

Some sources provide different categories of requirement standards (e.g., threshold, target, objective) in order to accommodate different levels of stringency of climate user needs. The following definitions are adopted to define threshold, breakthrough (also referred to as target), and goal (also referred to as objective) for observation requirements.

- **Threshold:** The limit beyond which the data is of no use to a given application.
- **Breakthrough / Target:** The level at which significant improvement in the given application would be achieved.
- **Goal / Objective:** The level beyond which further improvement would be of no value for the given application.

The following definitions are adopted for the different requirements, closely following the VIM uncertainty definition guidelines (JGCM, 2012), where not otherwise stated:

- **Accuracy:** Here refers to the closeness between a measured value and the true value of the measurand, including the effects of systematic errors. JGCM (2012) also states that “the concept ‘measurement accuracy’ is not a quantity and is not given a numerical quantity value. A measurement is said to be more accurate when it offers a smaller measurement error.”
- **Bias**: An estimate of the systematic measurement error.
- **Precision:** Here describes the random (unpredictable) variability of repeated measurements of the measurand.
- **Uncertainty:** Non-negative parameter, associated with the result of a measurement that characterizes the dispersion of the values that could reasonably be attributed to the measurand.
- **Temporal resolution:** Frequency the observations are provided in.
- **Spatial resolution (horizontal and vertical):** Nominal resolution of an observation (taking into account the influence of the satellite’s viewing geometry).
- **Stability:** Refers to the property of a measuring instrument, whereby its metrological properties remain constant in time. Alternatively, the maximum acceptable long-term change in the systematic error, usually per decade.
- **Length of data record:** Time period a data record covers.

3.1 GCOS

Table 3-1 provides requirements as defined in GCOS-200. These requirements should be considered target requirements, here defined as the requirements that data providers should aim to achieve over the next 10 years. As this would be applicable in 2026 we consider the GCOS requirements to be the goal requirements when applied to the WV_cci CDR products.

Table 3-1: Requirements as provided in GCOS-200 and GCOS-154. Note, lower stratospheric water vapour requirements from GCOS-200 are used for the stratospheric vertically resolved water vapour (VRes WV) measurements entries here, since values for the 'deeper' stratosphere (which would be less stringent) are not available.

Product	Frequency	Resolution (spatial/vertical)	Measurement Uncertainty	Stability
TCWV	4 h	25 km / na	2%	0.3% dec^{-1}
Tropospheric VRes WV	4 h	25 km / 2 km	5%	0.3% dec^{-1}
Stratospheric VRes WV	daily	100–200 km / 2 km	5%	0.3% dec^{-1}

It is further noted in GCOS-200 that "the required measurement uncertainties are presented as 95% confidence intervals (approximately two standard deviations)", following WMO (2012). WMO (2012) further outlines that the uncertainty should include contributions "from random effects and from imperfect correction of the results of systematic effects". However, WMO (2012) also states that "a compensation factor can be applied to compensate for the systematic effect. Typically, appropriate calibrations and/or adjustments should be performed to eliminate systematic errors of sensors". Such approaches would introduce uncertainties by themselves which subsequently would need to be quantified.

3.2 WMO

WMO OSCAR defines the following application areas with direct links to climate: climate monitoring (GCOS), climate application (WMO, Commission for Climatology, climate services) and climate science (WCRP, international research). While WMO is currently updating the requirements that are compiled and accessible via https://www.wmo-sat.info/oscar/requirements, we here provide the requirements for the different areas (Climate-AOPC, Global NWP, Climate Modelling Research/WCRP, and Atmospheric Chemistry/GAW) (despite partly being deprecated) in Table 3-2.

Table 3-2: Requirements as defined by WMO OSCAR RRR (source: https://www.wmo-sat.info/oscar/requirements, accessed 16 November 2018). Threshold, breakthrough, and goal requirements are given.

Product	Frequency	Resolution (spatial/vertical)	Measurement Uncertainty	Stability
Climate-AOPC				
TCWV	6 h 4 h 3 h	200 km 100 km 50 km	3 kg/m^2 1.4 kg/m^2 1 kg/m^2	Not available
UTLS VRes WV	6 h 4 h 3 h	200 km / 3 km 100 km / 2.5 km 50 km / 2 km	20% 5% 2%	Not available
Stratospheric VRes WV	6 h 4 h 3 h	200 km / 5 km 100 km / 3 km 50 km / 2 km	20% 5% 2%	Not available
Global NWP				
TCWV	12 h 6 h 1 h	250 km 50 km 25 km	5 kg/m^2 2 kg/m^2 2 kg/m^2	Not available
UT VRes WV	12 h 6 h 1 h	250 km / 3 km 50 km / 1 km 15 km / 0.5 km	20% 5% 2%	Not available
Climate Modelling (WCRP)				
UTLS VRes WV	12 h 6 h 3 h	50 km / 2km 37 km / 1 km 25 km / 0.5 km	20% 10% 5%	Not available
Stratospheric VRes WV	12 h 6 h 3 h	250 km / 3 km 100 km / 2.5 km 50 km / 2 km	20% 10% 5%	Not available
Atmospheric Chemistry				
UTLS and stratospheric VRes WV	3 days 24 h 12 h	500 km / 5 km 100 km / 1.7 km 50 km / 1km	20% 8% 5%	Not available

Requirements from SPARC (deprecated) are not summarised in this section. Instead we refer to Section 3.3 (includes requirements from SPARC). Note that the above climate modelling research (WCRP) requirements are also deprecated and only given as a reference here. New requirements for climate modelling (include requirements from CMUG) should replace those (see Section 3.4).

3.3 GEWEX AND SPARC

Table 3-3 provides requirements from GEWEX and SPARC.

GEWEX requirements are taken from the G-VAP assessment plan (available at http://gewex-vap.org/?page_id=19). GEWEX requires global products covering the period 1979 to present and verified quality. The SPARC requirements are obtained from the OSCAR WMO RRR website (https://www.wmo-sat.info/oscar/requirements). Note SPARC is contributing regularly to the GCOS observation requirement updates.

Table 3-3: Requirements from SPARC and GEWEX. GEWEX considers GCOS requirements on accuracy and stability as baseline guidance. For the SPARC entry, threshold, breakthrough, and goal requirements are given.

Product	Frequency	Resolution (spatial/vertical)	Measurement Uncertainty	Stability
GEWEX				
TCWV	3 h	10 km	2%	0.3%
profiles of specific humidity	3 km	10 km	5%	0.3%
SPARC				
UTLS and stratospheric VRes WV	3 days 24 h 12 h	500 km / 2 km 100 km / 1 km 50 km / 0.5 km	5% 3% 2%	Not available

3.4 Other sources of information

3.4.1 EE7 candidate PREMIER

Another source for measurement requirements that can be seen to reflect community consensus is obtained from mission selection reports such as from the EE7 candidate PREMIER instrument. Table 3-4 compiles the target and threshold values of the (unsuccessful) mission candidate.

Table 3-4: Target and threshold requirements from the PREMIER mission selection report, equivalent to the atmospheric dynamics and atmospheric chemistry measurement mode, respectively.

Product	Frequency	Resolution (spatial/vertical)	Measurement Accuracy	Stability
PREMIER				
UTLS and stratospheric VRes WV	daily	50 km / 0.5 km 100 km / 2 km	5% 30%	Not available

3.4.2 ESA DUE GlobVapour

Within the ESA DUE GlobVapour project a survey of user requirements was carried out and summarised in the requirements baseline document (Saunders et al., 2010, not available online anymore). Requirements were collected for TCWV and tropospheric profiles. Their results are recalled in Table 3-5.

Table 3-5: Threshold, target and objective requirements for TCWV from the ESA DUE GlobVapour project. Results are largely based on previous versions of GCOS-200 and WMO OSCAR.

Product	Frequency	Resolution (spatial/vertical)	Measurement Accuracy	Spatial, temporal coverage	Stability
TCWV	daily and monthly	≤ 0.5°, 55 km	5 kg/m^2 2 kg/m^2 1 kg/m^2	Global, ≥20 years	Not available
Tropospheric VRes WV	hourly, daily, monthly	0.25°, 28 km / 10, 5, 2 layers	20% 8% 5%	Global, ≥20 years	Not available

4. ANALYSIS OF USER FEEDBACK ON ECV WATER VAPOUR REQUIREMENTS

The aim of the user requirements survey was to help identify user needs and data requirements for water vapour CDRs in climate applications, which complement and potentially update and complement GCOS requirements and which then will guide the project in the CDRs design and evaluation.

The survey was carried out between September and November 2018 and included 18 questions on the primary and secondary CDRs that people are interested in (**Q1, Q2, Q5**), the kind of applications these CDRs are being used for (**Q3, Q5**), other ESA CCI CDRs that the people use (**Q4**), spatial domain (**Q6**), preferred data level (L2, L3, L4) (**Q7**), spatial resolution (vertical **Q8**; horizontal **Q9**), CDR length (**Q10**), temporal resolution (**Q11**), accuracy requirements (**Q12**), precision requirements (**Q13**), stability requirements (**Q14**), other uncertainty information (**Q15**), clarifications and further comments (**Q16**), other aspects of CDR development (**Q17**), and interest in contributing to WV_cci (**Q18**). The questionnaire has been kept short (about 12 minutes on average to provide answers to all questions) in order to enhance the likelihood of obtaining answers to all of the questions.

This survey was sent out to members of the WV_cci Climate Research Group (CRG), the WV_cci extended user group, CMUG, participants of the SPARC OCTAV-UTLS activity, and the wider research community identified to have a potential interest in atmospheric water vapour (including IGAC/SPARC CCMI and GEWEX G-VAP mailing lists). The survey received **34 responses** in total by the end of November. Note, not all questions have been answered comprehensively.

4.1 Primary and secondary uses of water vapour CDRs (Q1/Q2)

Here we will look at the first two questions

Q1 – Please indicate the WV climate data record(s) you are most interested in

Q2 – Please indicate other WV climate data record(s) you may be interested in

The answers to Q1 and Q2 are compiled in Figure 4-1 and Figure 4-2, respectively. The analysis indicates that there is about equal interest in stratospheric (VRes) and tropospheric (TCWV) water vapour CDRs. Notably, the most chosen answer was the CDR in the UTLS (VRes), potentially due to no such consolidated dataset being available as of yet. While the water vapour isotopologues have not obtained any answer in Q1, Q2 indicates that there is substantial interest in such a CDR as well (see Figure 4-2) as a secondary source of information. Scientifically, these results make sense since water vapour isotopologues on their own are not enough to infer process-knowledge, but their use is most often together with vertical profiles of water vapour. For Q2, an additional answer by one user was planetary boundary layer water vapour.

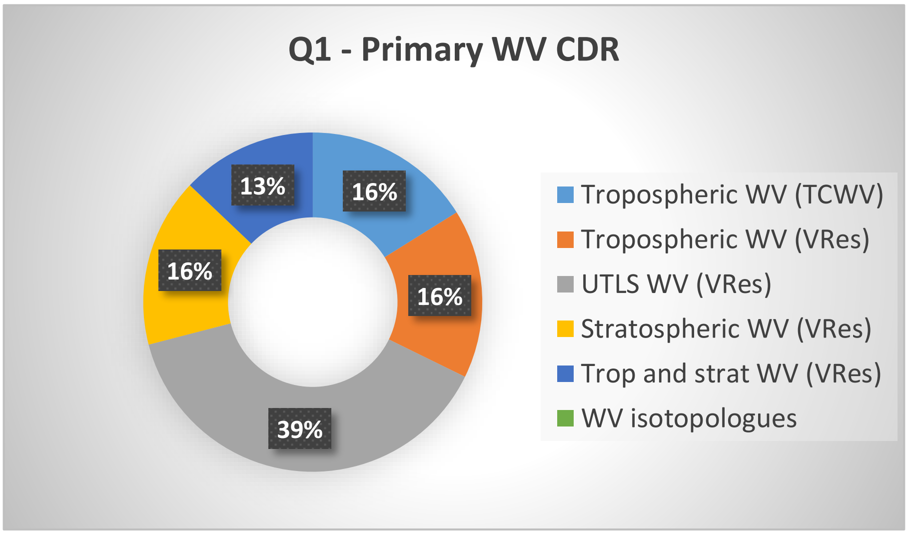

Figure 4-1: Analysis of Q1. The primary water vapour CDR of interest to our users as expressed in percentage numbers.

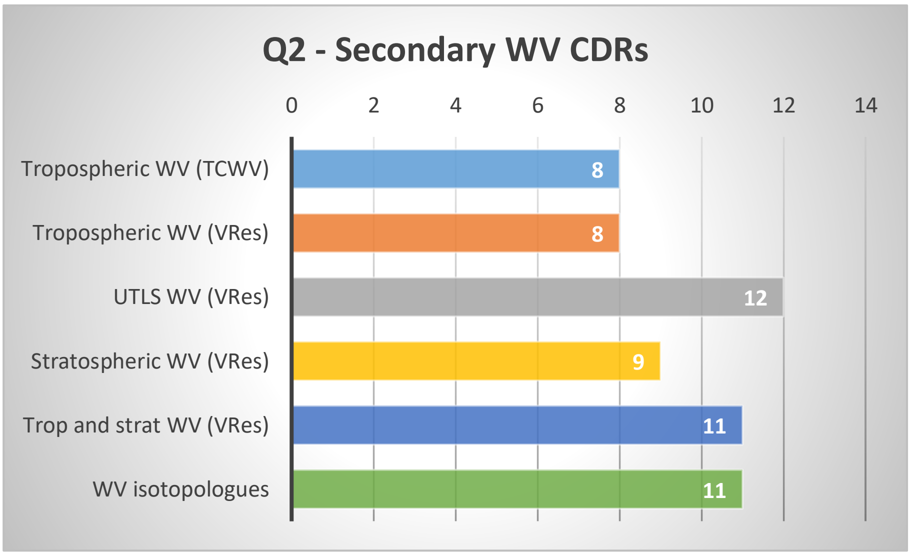

Figure 4-2: Analysis of Q2. The secondary water vapour CDR of interest to our users as expressed in absolute numbers.

4.2 What are the main applications of WV CDRs? (Q3, Q5)

Q3 – Please choose up to five activities you are using WV CDRs for

Q5 – Do you currently use WV CDRs?

About half of the respondents have indicated that they already use WV CDRs, while the other half (except one respondent) are intending to use WV CDRs in the future (Q4). Q3 thereby asked for information on the main application the users intend to use the WV CDRs for. The results can be seen in Figure 4-3. Most of the users use or will use the WV CDRs for climate monitoring and the study of climate variability and climate processes. 15% of the users use WV CDRs for budget considerations (atmospheric radiation budget, water cycle, and energy cycle, although the latter to a lesser extent). Currently, around 12% of the users use WV CDRs for the study of climate and weather impacts (but did not specify droughts and flooding as such). More users are interested in the extratropics and polar regions than in the tropics. Other applications the respondents mentioned under the category 'other applications' were model evaluation, chemistry-climate interactions, study of dynamical processes in the UTLS, and cloud distribution and changes.

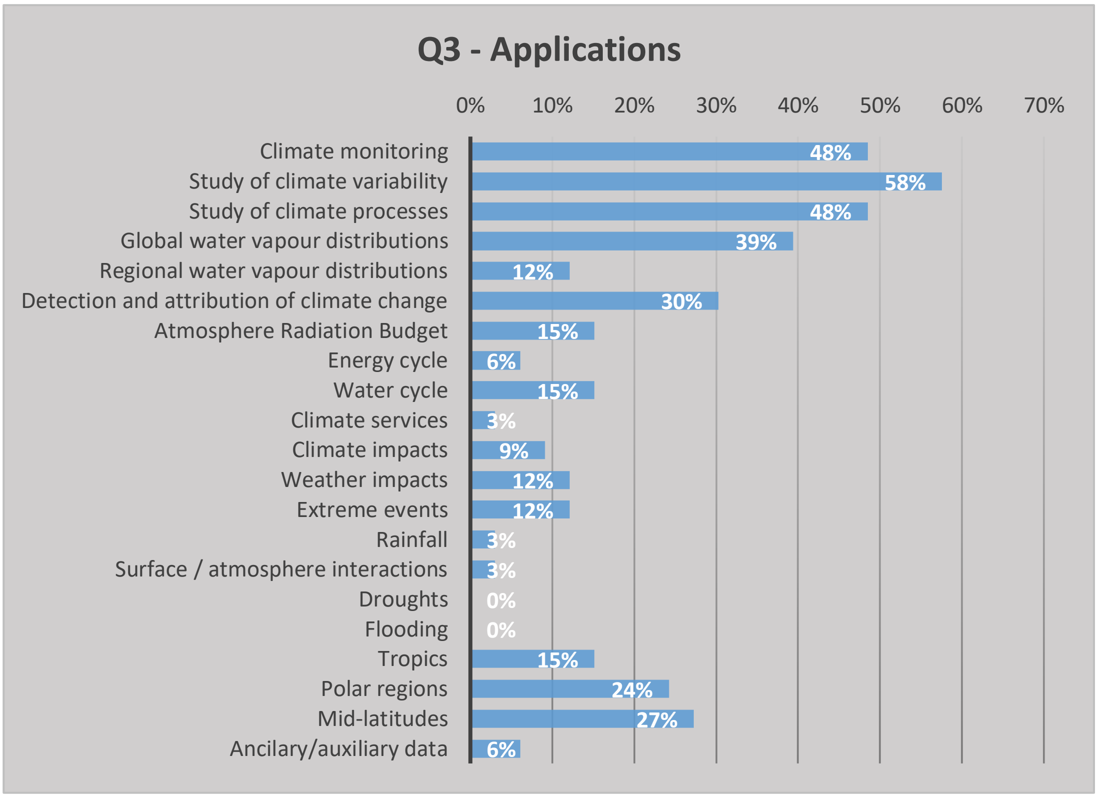

Figure 4-3: Analysis of Q3. Main applications given as percentage numbers from total users.

4.3 Other ESA ECVs of interest (Q4)

Q4 – What other CDRs from ESA CCI are/will you be using along with the WV CDR?

About 30% of the respondents to our survey expressed interest to use each of the following ESA CCI ECVs along with the WV CDR: **Salinity, ozone, GHGs, glaciers, land cover, sea ice, sea level, snow, ice sheets**. The ECVs of **sea surface temperature, land surface temperature, clouds, aerosol, and soil moisture** attracted on average more interest (up to 50% of all respondents), while **fire, biomass, ocean colour, and permafrost** were chosen less frequently (by only 10% of all respondents). A CDR of interest that is currently not among the list of the ESA CCI ECVs **is vertically resolved atmospheric temperature** (indicated by 10% or three respondents).

4.4 WV CDR spatial domain (Q6)

Q6 – Over what spatial domain do you require WV CDRs for your primary application?

The requested WV CDR spatial domain is **global** (and three dimensional where applicable), but there are also roughly 25% of the respondents who are interested in zonal mean WV CDRs (presumably referring to a WV CDR in the stratosphere). More respondents were valuing information on the tropics (34%) than the extratropics (21%) or polar regions (26%). Note this is in contrast to Figure 4-3, for which we currently do not have an explanation, but which may reflect the difference between current use and future (preferred) use. Interestingly, the answers to this question were indicating interest between stratospheric and tropospheric focus to be about equal.

4.5 WV CDR data level (Q7)

Q7 – What is the preferred data level for your primary application?

Data users indicate to use **L2 (swath data)** and **L3 (gridded data)** about equally frequently. Only 2 out of 34 respondents would use **L4 (gridded and model enhanced**, e.g. through data assimilation). The latter tendency is consistent with attitudes from researchers within the SPARC/IGAC Chemistry-Climate Model Initiative, who tend not to trust data assimilation products as much as original, ‘clean’ observations despite the benefits of being able to address sampling issues and data gaps.

4.6 WV CDR spatial resolution requirements (Q8/Q9)

Information on spatial resolution requirements were asked for both, vertical and horizontal resolution.

Q8 – For vertically resolved WV CDRs, what vertical resolution do you require?

Q9 – At what horizontal scale do you require WV CDRs?

Table 4-1 and Table 4-2 provide the numbers of answers for threshold, breakthrough, and objective as defined in Section 3. Note, for a future survey, the specifications for the horizontal requirement should be divided up into stratospheric (VRes WV), UTLS (VRes), and tropospheric (TCWV) CDRs. From the results and looking at each of the answers individually it becomes clear that there is a bimodal distribution. Peak values have been marked. This bimodal distribution reflects in most cases the quite different requirements of the TCWV and VRes WV CDRs. For the vertical resolution, requirements are also quite different when looking at UTLS VRes WV or stratospheric VRes WV.

Table 4-1: Analysis of Q8. Threshold, breakthrough, and goal vertical resolution requirements for vertically resolved WV CDRs. The number of answers is given.

	<100 m	100m	500m	1km	2km	3km	5km	8km
threshold	2	0	3	6	7	**8**	5	0
breakthrough	1	10	**11**	4	3	1	0	0
objective	8	**9**	2	4	1	1	0	0

Table 4-2: Analysis of Q9. Threshold, breakthrough, and goal horizontal resolution requirements for WV CDRs. The number of answers is given.

Column1	<1km	1km	5km	10km	25km	50km	100km	200km	500km
threshold	0	0	1	4	**7**	4	2	4	**7**
breakthrough	1	4	**7**	3	5	6	**4**	1	0
objective	**9**	5	2	3	**4**	1	1	1	0

4.7 WV CDR temporal characteristics requirement (Q10/Q11)

This section presents the results for the temporal characteristics (CDR length and temporal resolution) that users require for their primary applications. The following two questions were asked in the survey:

Q10 – What is the length of the WV CDR that your primary application requires?

Q11 – What is the temporal resolution of the WV CDR that your primary application requires?

Table 4-3 and Table 4-4 show the answers to Q10 and Q11. From the answers to these survey questions, the threshold for a useful CDR length is set at 10 years, while 20 years is considered breakthrough, and more than 30 years objective. Note that if only answers on UTLS vertically resolved requirements are looked at, the threshold is 2 years, indicating the appetite for this unique dataset.

Table 4-3: Analysis of Q10. Threshold, breakthrough, and goal for length requirements of WV CDRs. The number of answers is given.

	<1 yr	1 yr	2 yrs	5 yrs	10 yrs	20 yrs	30 yrs	>30 yrs
threshold	1	4	2	3	**10**	1	1	2
breakthrough	0	0	0	3	5	**9**	5	2
objective	0	0	0	0	4	4	5	**6**

For the temporal resolution, the same problem as seen for the horizontal resolution (see Section 4.6) occurs. On close inspection a bi-modal distribution can be identified from the table, attributable to the answers mixing requirements for stratospheric/UTLS (VRes WV) and tropospheric (TCWV) CDRs. This interpretation is confirmed when looking at the individual answers.

Table 4-4: Analysis of Q11. Threshold, breakthrough, and goal for temporal resolution requirements of WV CDRs. The number of answers is given.

	<6-hrly	6-hrly	12-hrly	daily	weekly	monthly	yearly
threshold	1	1	2	**5**	2	**9**	1
breakthrough	4	**5**	1	6	**6**	2	0
objective	**10**	2	0	**4**	2	2	0

4.8 WV CDR quality (Q12/Q13/Q14)

Possibly the most relevant questions for the specification of the new WV CDRs are the ones around the quality requirements of the WV CDRs including accuracy, precision, and stability.

Q12 – What is the required accuracy for your primary application?

The term '*accuracy'* in this question should be understood as '*measurement uncertainty',* which determines whether a CDRs is useful for a given climate application or not.

Table 4-5 shows the answers to Q12. The requirement for accuracy were generally defined by both the TCWV and VRes WV users at the same level with 10%, 5%, and 1% for threshold, breakthrough, and objective, respectively.

Table 4-5: Analysis of Q12. Threshold, breakthrough, and goal for accuracy requirements of WV CDRs. The percentage number of answers is given.

	<1%	1%	5%	10%	20%	25%	>25%
threshold	9.1%	4.6%	13.6%	**59.1%**	4.6%	9.1%	0.0%
breakthrough	4.4%	30.4%	**52.2%**	13.0%	0.0%	0.0%	0.0%
objective	22.7%	**45.5%**	27.3%	4.6%	0.0%	0.0%	0.0%

Q13 - What is the required precision for your primary application?

Table 4-6 shows the answers to Q13. Maximum percentages are highlighted in bold.

Table 4-6: Analysis of Q13. Threshold, breakthrough, and goal for precision requirements of WV CDRs. The percentage number of answers is given.

Column1	<1%	1%	5%	10%	20%	25%	>25%
threshold	4.8%	4.8%	33.3%	**38.1%**	9.5%	4.8%	4.8%
breakthrough	4.6%	40.9%	**45.5%**	4.6%	0.0%	0.0%	4.6%
objective	28.6%	**42.9%**	23.8%	0.0%	0.0%	0.0%	4.8%

Q14 - What is the required stability for your primary application?

Table 4-7 shows the answers to Q14. The higher values highlighted in bold are reflecting the choice for VRes WV CDRs, the lower values highlighted in bold those for the TCWV CDRs. Single and bimodal peak values have been marked in bold.

Table 4-7: Analysis of Q14. Threshold, breakthrough, and goal for stability requirements of WV CDRs. The percentage number of answers is given.

	<0.5%/dec	<1%/dec	1%/dec	2.5%/dec	5%/dec	>5%/dec
threshold	5.3%	5.3%	**31.6%**	26.3%	**31.6%**	0.0%
breakthrough	5.0%	**45.0%**	40.0%	10.0%	0.0%	0.0%
objective	**55.6%**	22.2%	22.2%	0.0%	0.0%	0.0%

4.9 Other important quality indicators

Precision, accuracy, and stability as presented in Section 4.8 may not be the only quality requirements an end user may have, so the survey was also inquiring for other quality indicators of use to the users specific application with the question

Q15 - Please indicate what type of uncertainty you would like to obtain along with your water vapour CDR

Answers to this question are ordered here in the order of priority, with those highlighted in bold indicating those requested by more than 40% of the respondents:

- **Quality flags**
- **Full budget error analysis**
- **Systematic contribution to uncertainty (overall/mean bias)**
- Random uncertainty
- Uncertainty correlation (spatial and temporal)
- Bulk uncertainty

4.10 Other comments (Q16/Q17/Q18)

Q16 – Please provide us here with any clarifications/comments on above questions

Only few clarifications were noted, of which needs to be taken into account that

- Precision can only be associated with L2 profiles, it is hence meaningless for L3 CDRs.
- Accuracy and stability are related terms, and accuracy is only meaningful if stability is assured.

Q17 – Please provide us here with any other comments about what you find important for the development of WV CDRs

Important points to consider when defining our WV CDRs according to the respondents are

- Stability, calibration, and anchoring of CDRs.
- CDR should be generated from recognised FCDRs.

Q18 – Would you be interested in establishing further links to our project?

In addition to the WV_cci extended user group, 14 respondents are interested in establishing further links to the WV_cci, obtaining notification of new data releases, or getting involved in the research user group.

5. REQUIRED CLIMATE DATA RECORDS

Due to the importance of water vapour as ECV, there is a need to consolidate our knowledge of past and current changes as derived from observations and to establish climate data records for use in climate research. In accordance with the above research, the WV_cci goal is defined at delivering four climate data records, which will be designed towards satisfying the key user requirements of the climate research community as identified in this URD. The CDRs include both total column water vapour (TCWV) and vertically resolved (VRes) data products, with the different CDRs sketched out in Figure 5-1 and explained in more detail below.

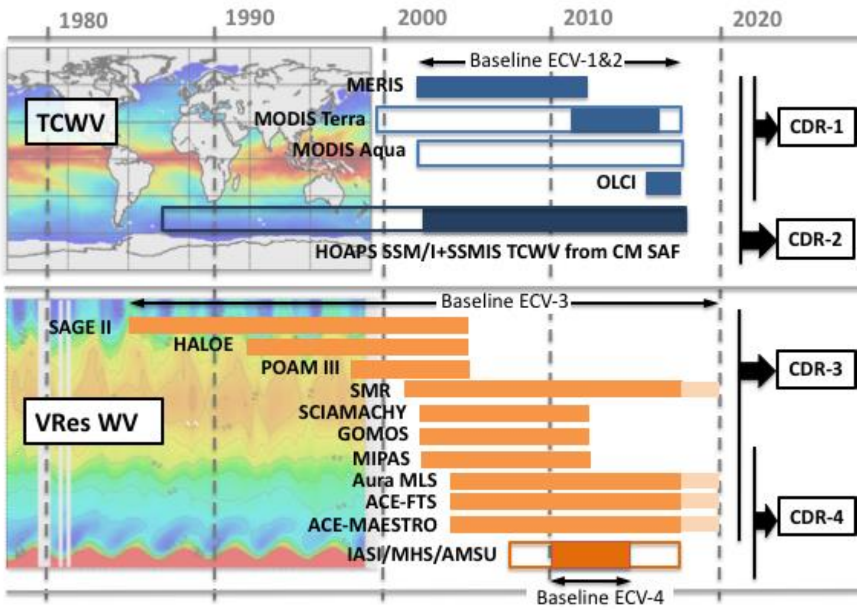

Figure 5-1: Climate data records (CDRs) prepared within the WV_cci.

In Figure 5-1, the different input observations are given in blue for the TCWV CDR outputs (CDR-1 and CDR-2) and in orange for the vertically resolved CDR outputs (CDR-3 and CDR-4). The black vertical line with the thick arrow on the righthand side of the figure indicates which observations will be merged in the different CDRs. The black double-headed horizontal and thin arrows indicate the time periods over which we propose to merge the data in this project. In the following a more detailed description of the different ECVs that are the main deliverables of the WV_cci is provided:

1) **TCWV CDR-1:** This total column water vapour CDR will be based on NIR observations by MERIS, MODIS, and OLCI spanning the time period 2002 to 2017 with a spatial resolution of 0.05°/0.5° and as daily averages. Key challenges are to harmonise the time series due to issues around calibration performance, long term stability and inconsistency between records. Consequently, sub-periods with at least one year of

temporal overlap between MERIS and MODIS as well as between MODIS and OLCI are processed and validated first to improve the stability of the product.

2) **TCWV CDR-2:** This total column water vapour CDR will be based on NIR observations by MERIS, MODIS, and OLCI and complemented by microwave imager observations of HOAPS SSM/I and SSMIS spanning the time period 2002 to 2017 from EUMETSAT CM SAF with a spatial resolution of 0.05°/0.5° and as daily averages. The product takes advantage of the developments carried out within the ESA DUE GlobVapour project and makes use of the spatial complementarity of the land based NIR and ocean-based microwave observations. Thus, the combined product has global coverage. Key challenges are to fill coastal and ice-covered areas and to achieve consistency between both products. The former aspect will be addressed as in the GlobVapour project while the latter was not observed to be an issue within the precursor project.

3) **Stratospheric zonal mean water vapour CDR-3:** This vertically resolved, zonal mean (2D) water vapour CDR will be based on a range of ESA, third-party and NASA instruments starting from SAGE II, HALOE, POAM III, Odin SMR, MIPAS, SCIAMACHY, GOMOS, ACE-MAESTRO, ACE-FTS and Aura-MLS, spanning the time period 1985 to the end of 2019. Before merging, the data records of the individual instruments will be validated following the approaches applied in the SPARC WAVAS-II activity, in order to characterize the data records in terms of biases and stability. The merged data records will undergo another independent validation. Key challenge here is to overcome sampling issues and homogenisation of instruments that utilise rather different observation techniques, feature different vertical resolutions, precision and accuracies.

4) **Vertically resolved water vapour CDR-4:** This product will deliver a prototype CDR of 3-dimensional vertically resolved water vapour in the troposphere and lower stratosphere from 2010 to 2014 based on IASI, MIPAS, ACE-MAESTRO and Aura-MLS. Key challenge is that the upper troposphere/lower stratosphere (UTLS) is the interface between the troposphere and the stratosphere with very complex dynamical, physical, and chemical properties, greatly challenging the performance of EO instruments. Production and validation of a water vapour ECV that spans this region needs to identify and take into account instrument limitations and sampling issues that will require the development of new merging and validation methodologies. The quality of the CDR thereby will be strongly dependent on the quality of the observations used in the merging process (little of which is currently known).

6. USER REQUIREMENTS ON WV_cci PRODUCTS

In this section we present the consolidated information on water vapour CDR requirements as obtained from the user requirements survey conducted within WV_cci (see Section 4), but also taking into account the user requirements established from different sources (Section 3). Where conflicting requirements resulted, we justified our choice of WV_cci product requirements. We also accounted for the often very different answers for TCWV, vertically resolved WV in the UTLS, and vertically resolved WV in the stratosphere.

For the CDR length requirements threshold, target, and objective are 10, 20, and 30 years, respectively, with the exception of vertically resolved WV in the UTLS, which indicated a lower threshold of only 2 years. This is notable since it clearly indicates the need for information (i.e., an observational reference) on UTLS water vapour distributions (presumably for model evaluation), independent of its length.

Generally, the user requirements derived from the survey provided more stringent requirements than those defined in other locations (see Section 3). An exception to this were the temporal requirements, where the survey seemed to request somewhat lower temporal resolution than those specified in these other sources. This is mostly due to the fact that our users reflect climate researchers and to a lesser extent people interested in numerical weather prediction, for which higher resolution data would be more valuable.

Finally, climate services define their products as '*climate information prepared and delivered to meet a user's needs*' (GCOS-200). The WV_cci will design its products according to this definition, with the aim to fulfil the above user requirements and support climate services. Consequently, requirements given in GCOS-200 are considered to be applicable for climate services as well. However, climate services in addition include the timely production and delivery of science-based trustworthy climate data, which is beyond what WV_cci could deliver. Other principles of climate services, such as involvement of customers and stakeholders (here users) in product development, free open access to essential data and metadata, and mechanisms to allow for user feedback will be incorporated in WV_cci.

Table 6-1: Threshold, breakthrough (target), and objective (goal) requirements obtained from the user requirements survey for L3 CDR-1 and CDR-2. Results from the survey are interpreted as follows: threshold – weakest requirement with more than one response; target – peak in response; and objective – most demanding requirement with more than one response.

Product	Frequency	Resolution (spatial/vertical)	Accuracy: Systematic component	Accuracy: Random component	Stability
WV_cci CDR requirements					
CDR-1 and CDR-2 (TCWV)					
L3	monthly daily <6-hourly	100 km 5 km <1 km	10% 5% 1%	10% 5% 1%	5% dec^{-1} 1% dec^{-1} <0.5% dec^{-1}

Table 6-2: Threshold, breakthrough (target), and objective (goal) requirements obtained from the user requirements survey for L2 and L3 CDR-3 and CDR-4.

Product	Frequency	Resolution (spatial/vertical)	Accuracy: Systematic component	Accuracy: Random component	Stability
WV_cci CDR requirements					
CDR-3					
L2 & L3 (strat)	monthly weekly daily	500 km / 5 km 100 km / 1 km 50 km / 500 m	25% 5% 1%	25% 5% 1%	2.5% dec^{-1} 1% dec^{-1} <0.5% dec^{-1}
CDR-4					
L2 & L3 (UTLS)	monthly daily <6 hourly	200 km / 2 km 25 km / 500 m <1 km / <100 m	20% 5% <1%	20% 5% <1%	5% dec^{-1} <1% dec^{-1} <0.5% dec^{-1}

For the following reasons it is proposed to consider separation of accuracy requirements into systematic and random components in case of global satellite remote sensing of atmospheric water vapour: 1) it is anticipated that it is hardly possible to estimate and verify a bias which is applicable on global scale and over the full period. Thus, if estimated and verified for a subsample of atmospheric conditions it may over-/under correct in other conditions and indicates superior quality what is at least not known, 2) the bias should be understood and then reduced by improved calibration or retrieval schemes. If not understood it seems fair to increase the uncertainty rather than correcting for an unknown effect. WMO (2012) states that “the observed mean value has to be corrected for the systematic error insofar it is known.” 3) For applications which include adaptations of resolution or averaging it is desirable to have separate uncertainty terms for systematic and random uncertainty components.

7. SUMMARY AND CONCLUSIONS

Generally, the user requirements for the WV_cci derived from the survey answers provided more stringent requirements than those defined in other sources. These may reflect the achievements made in instrument development over the past decade, which led generally to better performance of remote sensors.

An exception to this were the temporal requirements, where the survey seemed to request somewhat lower temporal resolution than those specified. Likely reason for the latter is that our users represent researchers from the climate and to a lesser extent from the weather community. Nonetheless, the requirements pose a great challenge to WV_cci given the currently available observations. In particular, for the vertically resolved observations in the UTLS, users require a threshold for vertical resolution that is just about achievable, but with breakthrough and objective values being much higher than what any of the current instruments can offer. Also, both the thresholds for systematic and random components of the uncertainty will be very difficult to comply with for the CDR-4 product. While a ‘proper’ evaluation of the quality of satellite observations in the UTLS is still lacking, current estimates look at biases that are ±15% from the multi-instrument mean (or 30% maximum for inter-instrument biases; see Hegglin et al., 2013). We further note that an uncertainty requirement of 10% as threshold for TCWV can be challenging at least on regional scale because the clear-sky bias is in the order of 10%.

The PSD compares in detail how the expected data specification agrees with the user requirements.

8. ACKNOWLEDGEMENTS

We would like to thank all the respondents to our survey for their time and helpful input. We also thank Geir Braathen (WMO) for guiding us towards the online WMO GCOS requirements.

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APPENDIX 2: GLOSSARY

Term	**Definition**
CCI	Climate Change Initiative
CDR	Climate Data Records
CMUG	Climate Modelling User Group
CRG	Climate Research Group
ECV	Essential Climate Variable
GCOS	Global Climate Observing System
PSD	Product Specification Document
TCWV	Total Column Water Vapour
URD	User Requirements Document
UTLS	Upper Troposphere and Lower Stratosphere
WCRP	World Climate Research Programme
WMO	World Meteorological Organization

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