



EUMETSAT Contract No.: EUM/CO/19/4600002222/BBo
Order n°4500017708

**'AIRWAVE-SLSTR: an algorithm to retrieve TCWV from SLSTR
measurements over water surfaces'**

Requirements Baseline

D4-AIRWAVE-SLSTR-RB

Issue 1.1

21 October 2019

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TABLE OF CONTENTS

1.	CHANGE LOG	3
2.	ACRONYMS	3
3.	REFERENCES	3
4.	INTRODUCTION	5
	4.1 PURPOSE OF THIS DOCUMENT	5
	4.2 RELEVANCE OF WATER VAPOUR PRODUCTS AND APPLICATIONS.....	5
	4.3 REQUIREMENTS ANALYSIS	6
5.	TCWV PERFORMANCE REQUIREMENTS FROM PREVIOUS STUDIES	6
	5.1 GCOS, WMO, ESA DUE GLOBVAPOUR AND GEWEX, GNSS, OLCI L3 BASELINE REQUIREMENTS	6
	5.2 COASTAL ALTIMETRY TCWV REQUIREMENTS FROM WTC.....	7
	5.3 SLSTR TCWV ESTIMATED PERFORMANCES VS REQUIREMENTS	7
6.	SUMMARY AND CONCLUSIONS.....	8

1. Change Log

Version	Date	Changes
1.0	08/09/2019	First Draft
1.1	21/10/2019	Updated version taking into account comments raised by EUMETSAT at PM#1

2. Acronyms

AIRWAVE	Advanced Infra-Red Water Vapour Estimator
ARSA	Analyzed RadioSounding Archive
ECVs	Essential Climate Variables
ESA DUE	ESA Data User Element programme (http://due.esrin.esa.int/)
GCOS	Global Climate Observing System
GEWEX	Global Energy and Water Exchanges Project
GNSS	Global Navigation Satellite System
G-VAP	GEWEX Water Vapour Project
MWR	MicroWave Radiometer
NWP	Numerical Weather Prediction
OLCI	Ocean and Land Colour Instrument on board Sentinel-3
SLSTR	Sea and Land Surface Temperature Radiometer
SSH	Sea Surface Height
SSM/I	Special Sensor Microwave Imager
TCWV	Total Column Water Vapour
URD	User Requirements Document
WMO	World Meteorological Organization
WTC	Wet Tropospheric Correction

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4. Introduction

4.1 Purpose of this document

The purpose of this document is to identify the requirements for the TCWV to be retrieved from SLSTR measurements. For this task we have examined the requirements published in the literature or documented by the relevant agencies and international organisations or coming from workshop reports and recommendations. These documents are reported in the reference section.

4.2 Relevance of Water Vapour products and applications

Water vapour in the atmosphere is crucial for the Earth energy balance since it is the most relevant greenhouse gas of natural source. Moreover, the concentration of water vapour in atmosphere is a key element in the water cycle.

The water vapour distribution plays a major role for both meteorological phenomena and climate via its influence on the formation of clouds and precipitation, the growth of aerosols, and the reactive chemistry related to ozone and the hydroxyl radical [1].

The TCWV is critical for understanding the impacts and risks of climate change, with global long time series being crucial for this task. In the Arctic, the rate of the climate change is two times larger than the global one due to greenhouse gas increase. In this scenario, the water vapour is responsible for the Arctic amplification [2]. For all these reasons, the GCOS has therefore included TCWV among the ECVs. Satellite data are crucial for monitoring ECVs due to their global coverage and extended time of operations. In particular, for the TCWV ECV, satellite measurements are vital to achieve the desired global coverage and accuracy.

Due to the importance of TCWV in climate and atmospheric studies, several International bodies, such as GCOS and WMO, have assessed the requirements for the measurement of the TCWV.

Apart from the afore mentioned applications, TCWV is also crucial for application such as the computation of WTC. WTC is a critical correction applied to altimetric measurements for the accurate (at centimetre level) retrieval of SSH, being one of its major error sources. WTC can be calculated from TCWV measurements or modelled with NWM. However, the accuracy of these models is still not enough for most altimetry applications. An accurate modelling of WTC effect can, thus, be achieved only through the use of concurrent measurements. For these reasons, in most recent altimetric missions, a MWR has been included. The spatial resolution of the MWR sensors goes from 50 km to 10 km in most advanced instruments [3].

The MWR spatial resolution allows for highly accurate WTC corrections in open ocean. However, in coastal regions, the accuracy of the correction is highly degraded by contamination from land and ice in the MWR FOV. Despite the minor coverage of coastal areas with respect to open ocean, the importance of altimetry measurements in this area is crucial because here the sea state has the larger effects on human society [4].

Several approaches have been developed in recent years trying to overcome this issue. In the next years the quality of WTC in coastal regions will rely on dedicated



retrieval algorithm and from new generations of instruments with high spatial resolution.

4.3 Requirements analysis

User performance requirements and characteristic for TCWV are generally given in terms of:

- 1) Accuracy: reported in absolute or percentage value is “the closeness between a measured value and the true value of the measurand, including the effects of systematic errors”. Often accuracy and measurements uncertainties are considered equivalent (see for example [5]).
- 2) Precision: the random (unpredictable) variability of repeated measurements of the measurand.
- 3) Spatial resolution.
- 4) Temporal resolution.
- 5) Timeliness.

For long datasets, the requirement on the time length and stability of the records is also necessary.

Requirements can be defined through the use of different values:

- 1) **Threshold** (limit value for data to be useful for a given application).
- 2) **Target** value (limit value to get significant improvements for a specific application).
- 3) **Goal** (limit value below which no further improvement is foreseen).

5. TCWV performance requirements from Previous Studies

In this section we analyse the requirements on TCWV on the basis of their applications: for NWP and/or climatological studies and for costal altimetry applications.

5.1 GCOS, WMO, ESA DUE GlobVapour and GEWEX, GNSS, OLCI L3 baseline requirements

International organization have set different requirements for temporal and spatial resolution for TCWV, depending on the different application for which the dataset is used and on the needs of the identified end users. For this reason, the requirements differ from one application to another and from one organization to another. Those requirements are mainly related to model application, both Global NWP and Regional or Local NWP or for Climate studies and atmospheric chemistry applications.

The requirements are extracted from [5, 6] for GCOS and GEWEX, from [7] for GNSS and from [8] for Sentinel/3 OLCI. The values of the requirements for a given application are quite similar in terms of accuracy and horizontal resolutions among different agencies while some differences can be found for the observing cycle.

The main outcome of these requirements is that at global scale a spatial resolution going from 20 km to 250 km is required, while at Local and Regional scale we get 3/1 to 100/50 km. The stability of measurements, when provided ranges between 1% to 0.3% dec^{-1} . The observing cycle (temporal resolution) goes from 1 hour to daily. Globally, the accuracy of TCWV ranges from 1 kg/m^2 to 5 kg/m^2 or between 2% to 20%,



regarding precision, an indication is given in [5] from the Survey among users and highlights that the goal value is 1%, the target is 5% and threshold 10%, same results were reported for the accuracy.

These requirements are more applicable to averaged TCWV SLSTR products (Level 3) than to TCWV SLSTR Level 2 products.

5.2 Coastal altimetry TCWV requirements from WTC

As reported in section 4.2, the accurate determination of TCWV at high spatial resolution is crucial for the calculation of the WTC correction, and thus for the SSH accurate retrieval, especially in coastal regions (but this is also true for inland water, some comments on that are given in section 6).

An estimate of the requirements for WTC is reported in the GMES Sentinel-3 Mission Requirement document [9]. From this document the required accuracy for WTC from MWR on-board Sentinel-3 has a threshold correction accuracy of 2 cm with a goal of 1.2 cm in WTC for ground processing. Considering that a rough estimate of the ratio between WTC and TCWV can be given by [3]:

$$WTC [m] \cong -0.0067 \cdot TCWV [mm] \quad [Eq.1]$$

And that 1 kg/m² of WV is equivalent to 1 mm of WV we can conclude that the requirement on TCWV for altimetry applications goes from 1.8 kg/m² to 3 kg/m². The spatial resolution should be really high (at least below 10 km (Thershold), of the order of km (Goal)).

Regarding the temporal resolution, temporal coincidence is, obviously, preferable. However, in several algorithms for WTC correction, ERA Interim data are used, implying a temporal resolution of 6 hours.

5.3 SLSTR TCWV estimated performances vs requirements

SLSTR measurements used for AIRWAVE TCWV retrieval have a mean global coverage revisit time at the equator of 1.9 days (one spacecraft) or 0.9 days (two spacecraft) and global coverage for dual view and day and night measurements. The horizontal resolution is about 1 km.

Due to their characteristics, and in particular of the high spatial resolution, the TCWVs from SLSTR should fit very well for coastal altimetry applications, provided that the required accuracy level is reached.

Up to now, we are not able to assess TCWV AIRWAVE SLSTR accuracy while we can have a rough estimate of the precision connected to the random error due to noise



(about 0.02K in both channels). This value is about 3-5% depending on the used scenario [10].

However, a rough estimate of the accuracy of AIRWAVE TCWV retrievals can be given extrapolating the results obtained from the validation of the AIRWAVEv2 ATSR dataset and reported in [11].

Here, the performances of AIRWAVE have been evaluated against both satellite instrument (SSM/I) and radiosondes (ARSA archive). This exercise, performed over the whole ATSR mission (from 1991 to 2012), produced a bias of 0.02 kg/m² with respect to SSM/I and of 0.19 kg/m² with respect to radiosondes. Both these values are below the accuracy level for both the altimetry and the climatological applications requirements. While the bias calculated versus SSM/I is more representative at global scale and is performed over TCWV values aggregated at SSM/I spatial resolution (0.25x0.25 degrees), the bias versus radiosondes, performed at native ATSR spatial resolution, is more representative of points near coastal areas/inland waters.

A further hint on the performances of AIRWAVE TCWV when applied to altimetry studies can come from [12]. The objective of this work was to develop, assess and validate a GPD+ WTC computed with the AIRWAVE dataset of TCWV. GPD+ is an algorithm, developed by the University of Porto, aiming at computing WTC for coastal region where MWR observations are invalid and for missions without an on-board MWR (e.g. CryoSat-2). GPD+ with AIRWAVE takes advantage of the high spatial resolution AIRWAVE TCWV (1x1 km²) and of the existence of these data up to the coast. Results for the North-West Mediterranean Sea and for ENVISAT show that that GPD+ with AIRWAVE shows an improvement in coastal regions (0-100 km) when used instead of ESA-MWR- and ERA- derived WTC. Overall, the results underline the potential of AIRWAVE data for coastal altimetry applications (some strategy to reduce AIRWAVE noise should be applied to get even better results, [13]).

6. Summary and Conclusions

TCWV is an essential climate variable as water vapour is the most relevant greenhouse gas of natural source. The precise knowledge of its distribution is a key element for climate studies and for this reason TCWV is an ECV. In addition, a precise knowledge of TCWV at high spatial resolution is highly desirable for other applications such as the calculation of the WTC for SSH retrievals, being the present WTC corrections not adequate for coastal altimetry [14].

TCWVs retrieved with AIRWAVE algorithm applied to SLSTR measurements have a frequency at the equator of 1.9 days (one spacecraft) or 0.9 days (two spacecraft) and global coverage for dual view and day and night clear sky measurements. The spatial resolution is about 1 km. With these characteristics, these data are particularly suitable for coastal altimetry applications and, in addition, also to inland water altimetry. While for coastal cases several algorithms for WTC correction have been developed, in inland water case the algorithms have not been customized [15]. In both these cases, because of their footprints, MWR measurements become invalid due to land contamination near the coasts or in small lakes and rivers. In those regions alternative approaches should be used. However, both the use of meteorological



models or in situ measurements have well known limitations.

In this context, the SLSTR TCWV dataset should be valuable, provided that a certain level of accuracy is reached.

The requirements analysed in this document highlight that values from 1.8 kg/m^2 to 3 kg/m^2 should be reached for altimetric applications, while values from 1 kg/m^2 to 5 kg/m^2 or between 2% to 20% are needed for climatological purposes.

At the moment we cannot assess the accuracy of AIRWAVE SLSTR TCWV retrievals, even if some (positive) estimates can be given using validation results obtained from AIRWAVE application to ATSR missions. During the project the values of accuracy and precision of AIRWAVE SLSTR TCWV retrievals will be assessed.