2023 Ocean Surface Topography Science Team Meeting

Improved algorithms for the wet tropospheric correction over coastal regions: application to the Sentinel-3 mission

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Introduction

- The wet tropospheric correction (WTC) is one of the most significant error sources for the precise estimation of sea surface heights derived from satellite altimetry.

- Microwave radiometers (MWR) measurements provide the most accurate way to retrieve the WTC over open-ocean.

- Over coastal regions, the MWR-derived WTC retrieval errors start to increase rapidly at distances from the coast in the range 20–30 km.

- A common approach over coastal regions is to correct the MWR brightness temperatures (TBs) from land contamination effects and to use these uncontaminated TBs in the open-ocean algorithms.

Objective

- No study was found of enhancement of the WTC in coastal regions focused on the usage of observations from missions with dual-band MWR, namely the Sentinel-3 mission.

- Over open-ocean, the need for improvement of the two Sentinel-3 MWR-derived WTC in the operational products has already been addressed (Vieira et al., 2022; Frery et al., 2020).

- The consideration of a dynamic sea surface temperature (SST) from the ECMWF ERA5 atmospheric model improves the WTC retrieval (Vieira et al., 2022); the additional dynamic atmospheric temperature lapse rate input, γ_{800}, provides redundant information.

- **Objective:** improvement of the WTC retrieval in coastal regions for the Sentinel-3 mission, based on the dual-band MWR observations.

Methodology Outline

1. Modification of the two Sentinel-3A MWR TBs, in order to remove the respective land contamination effects.

    - These modified TBs are then used alongside the Sentinel-3A SRAL σ_0 parameter in the open-ocean UP3S0 algorithm, developed by Vieira et al. (2022).

2. Modification of the Sentinel-3A SRAL σ_0 and exploration of an alternative wind-speed (WS) input from the ERA5 model.

    - For the WS input, the open-ocean UP3WS algorithm developed by Vieira et al. (2022) was exploited (inputs: Sentinel-3A MWR TBs and the 10-m U and V components of WS from the ECMWF ERA5 model).

3. Development of WTC retrieval algorithms specifically trained over coastal regions.

Data Description

- Sentinel-3A Non-Time Critical (NTC) Level 2 ocean data products at 1 Hz (baseline collection 004) were processed over coastal regions.

- **Filtering conditions:** measurements with no rain or ice contamination, between the [-50°, 50°] latitude range, and with a distance from the nearest coast between 0-60 km.

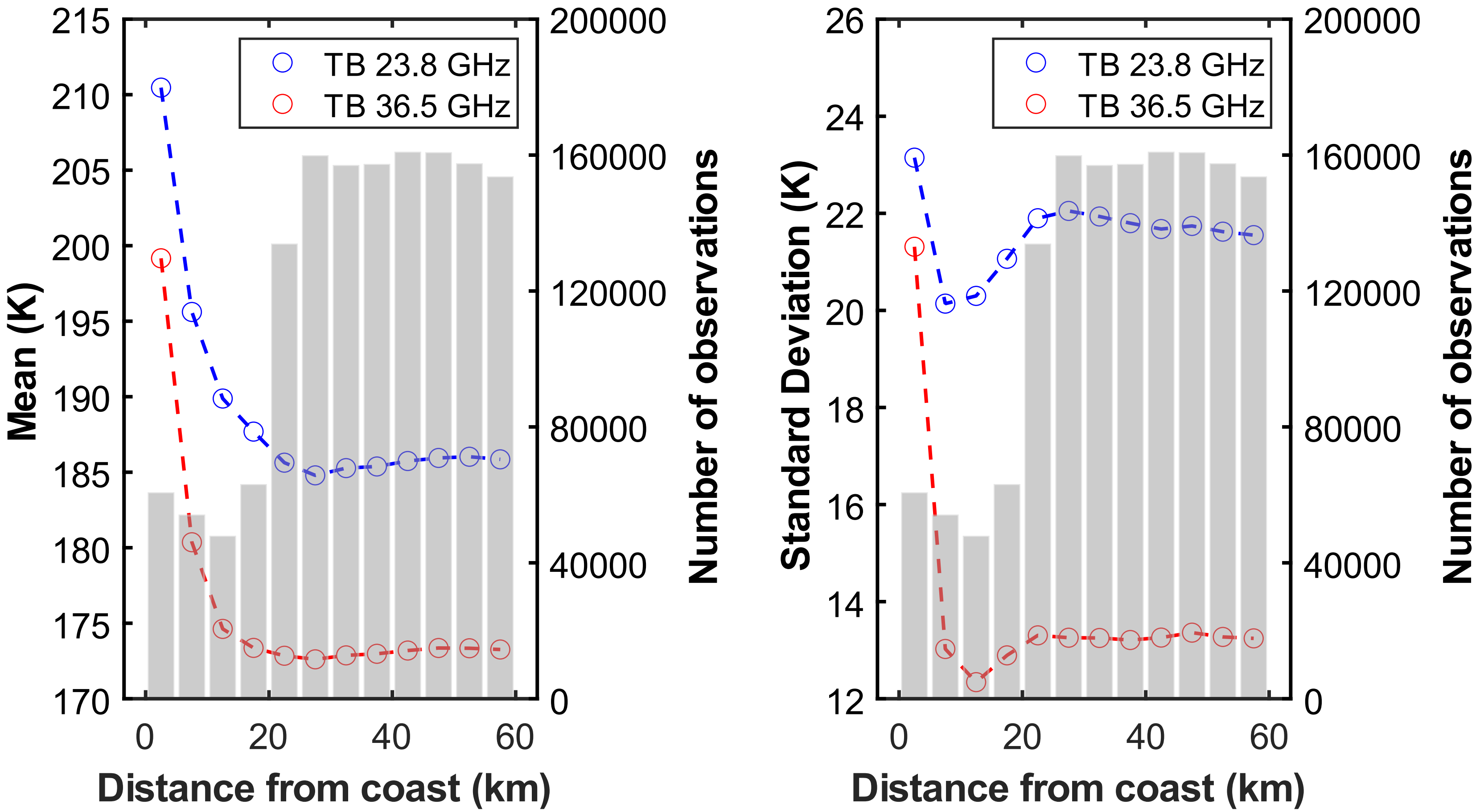
- Two datasets were developed, each comprising two years of Sentinel-3A SRAL/MWR measurements from cycles 12 to 38 (**development dataset**) and measurements from cycles 39 to 66 (**test dataset**), respectively.

- The **test dataset** was used for the independent assessment:

  - using a non-collocated comparison against zenith wet delays (ZWD) from coastal GNSS stations;

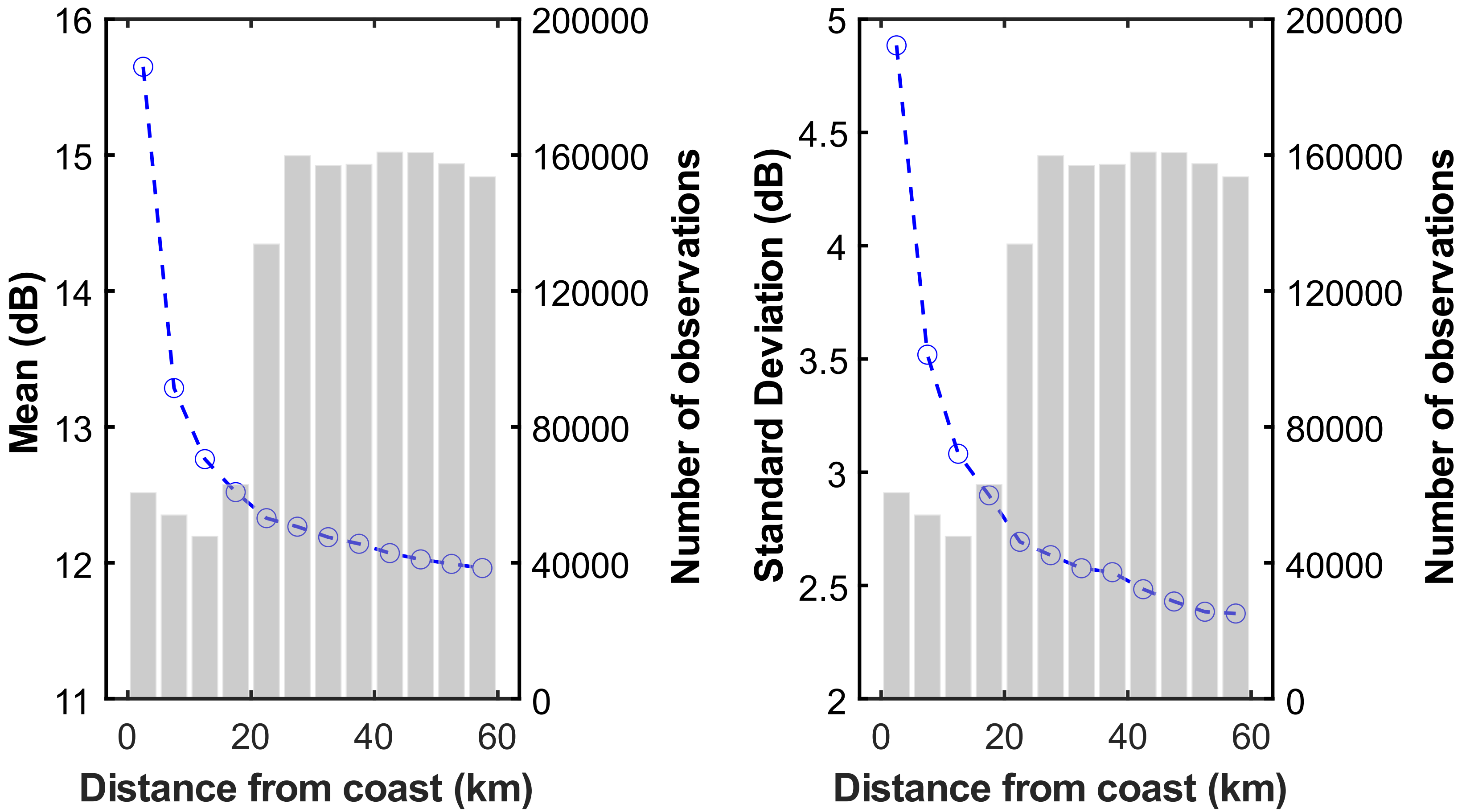
  - against the WTC derived from the ECMWF ERA5 atmospheric model (not shown).

Analysis of the Sentinel-3A SRAL and MWR parameters in coastal regions



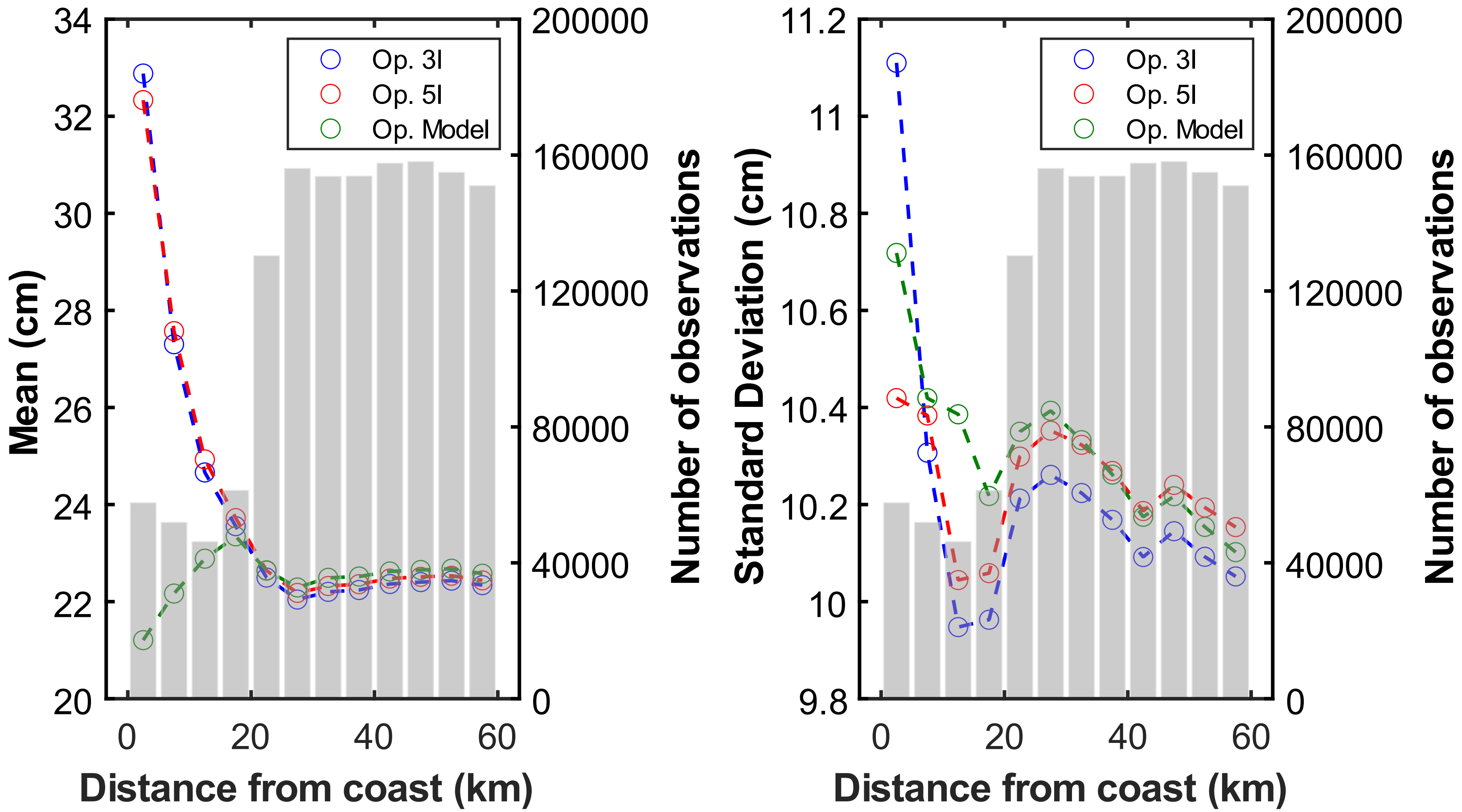
Mean (left) and standard deviation (right) of the Sentinel-3A MWR 23.8 and 36.5 GHz TBs, computed in classes of 5 km width from distance to the nearest coast using data from the Sentinel-3A development dataset.

Analysis of the Sentinel-3A SRAL and MWR parameters in coastal regions



Mean (left) and standard deviation (right) of the Sentinel-3A SRAL backscatter coefficient σ_0, at Ku band.

Analysis of the Sentinel-3A SRAL and MWR parameters in coastal regions



Mean (left) and standard deviation (right) of the two Sentinel-3A MWR wet path delay operational products (Op. 3I and Op. 5I, respectively), and the wet path delay derived from the ECMWF operational model (Op. Model).

Modification methods of the Sentinel-3A SRAL and MWR parameters

- A first proposal of modification of the Sentinel-3A MWR TBs, in order to mitigate the land contamination effects, is of the form:

$$Corr = \langle TB(f) \rangle_{(d,WPD)} - \langle TB(f)_{ocean} \rangle_{WPD} \quad (1)$$

- A second modification method, based on MWR land-fraction (LF):

$$Corr = \langle TB(f) \rangle_{(LF,WPD)} - \langle TB(f)_{ocean} \rangle_{WPD} \quad (2)$$

- The proposal of modification of the Sentinel-3A SRAL σ_0 parameter, at Ku-band, is of the form:

$$Corr = \langle \sigma_0 \rangle_d - \langle \sigma_{0\ ocean} \rangle \quad (3)$$

Development of the coastal WTC retrieval algorithms

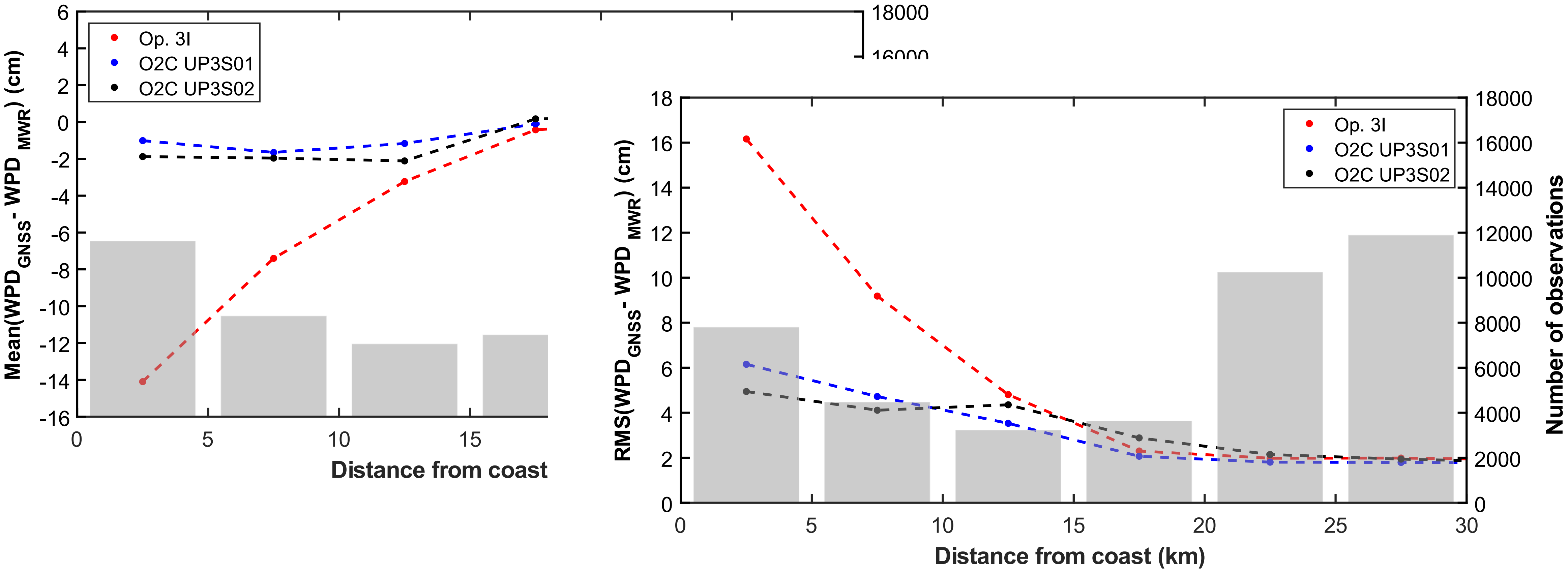
- Only observations from the development dataset in the range 0-20 km of distance from the coast were considered (179 961 measurements for train and 44 990 measurements for validation).

- All coastal algorithms consider the same neural network formalism used for the operational WTC retrieval algorithms of the Sentinel-3 mission.

Developed coastal algorithms description.

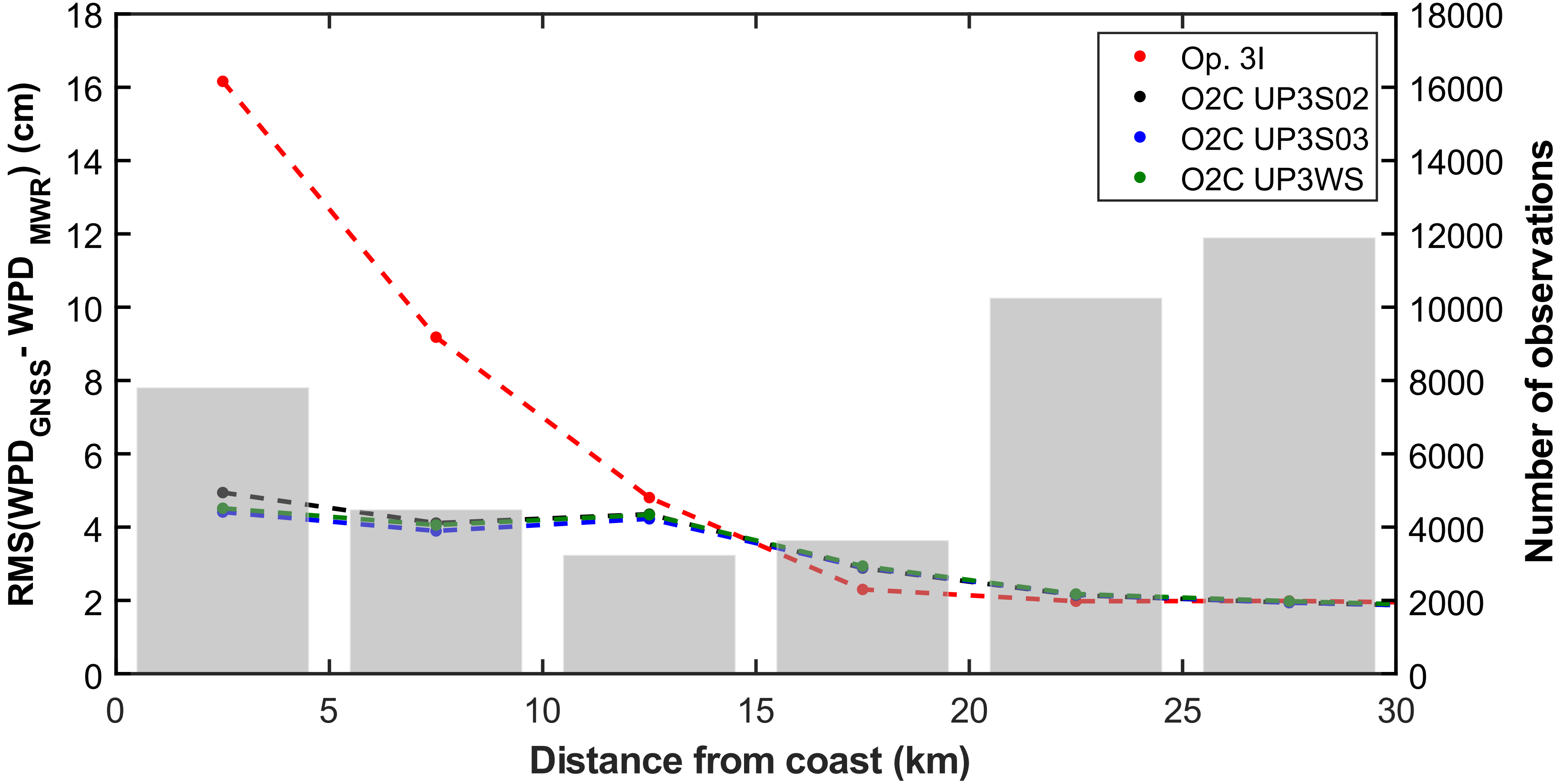
Algorithm	Number of inputs	Algorithm Description
C2C UP1	3	Unmodified MWR TBs and unmodified SRAL σ_0
C2C UP2		Modified MWR TBs and modified SRAL σ_0
C2C UP3	4	Modified MWR TBs, modified SRAL σ_0 and SST from the ERA5 model
C2C UP4	5	Modified MWR TBs, modified SRAL σ_0 and SST and γ_{800} from the ERA5 model

Results



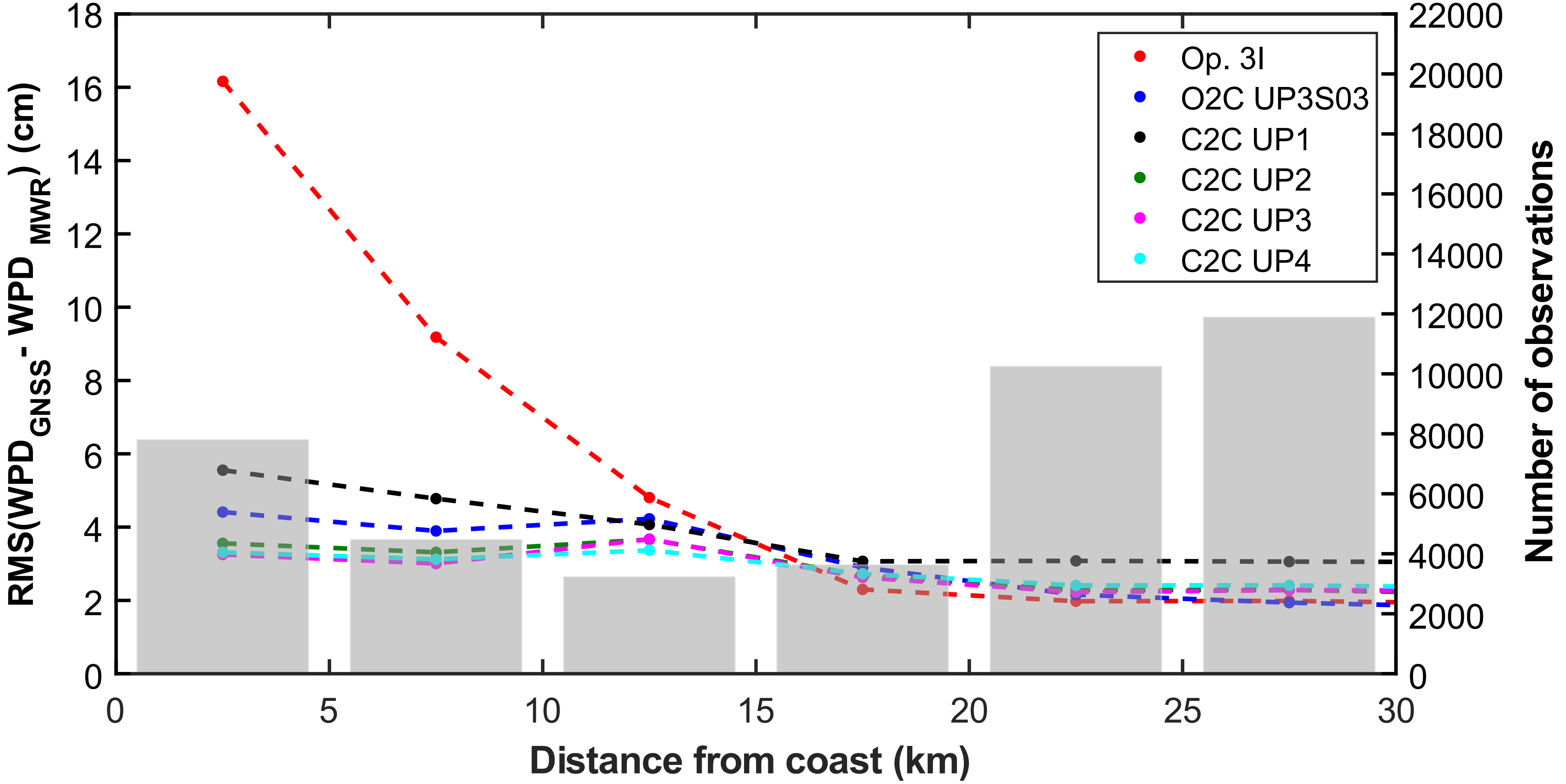
Mean and rms of the differences $WPD_{GNSS} - WPD_{MWR}$, in classes of 5 km width of distance from coast, for the Sentinel-3A three-inputs MWR operational algorithm (Op. 3I), and the UP3S0 algorithm with TBs modified by distance from coast and WPD classes (O2C UP3S01) and modified by MWR land fraction and WPD classes (O2C UP3S02).

Results



RMS of the differences $WPD_{GNSS} – WPD_{MWR}$, in classes of 5 km width of distance from coast, for the Sentinel-3A three-inputs MWR operational algorithm (Op. 3I), the UP3S0 algorithm with modified TBs (O2C UP3S02) and a modified σ_0 (O2C UP3S03), and the UP3WS algorithm with modified TBs and the 10-m U and V wind-speed components of the ERA5 model (O2C UP3WS).

Results



RMS of the differences $WPD_{GNSS} – WPD_{MWR}$, in classes of 5 km width of distance from coast, for the Sentinel-3A three-inputs MWR operational algorithm (Op. 3I), the UP3S0 algorithm with modified TBs and a modified σ_0 (O2C UP3S03), and the four developed coastal algorithms.

Summary of results

Mean and rms of the differences $WPD_{GNSS} – WPD_{MWR}$, in cm, for the first class of distance from coast.

Algorithm	Algorithm Description	0-5 km		
		Mean	RMS	RMS improv.
Op. 3I	Open-ocean Sentinel-3A operational algorithm, MWR TBs and SRAL σ_0	-14.1	16.2	-
O2C UP3S03	Open-ocean UP3S0 algorithm, MWR TBs modified by LF and WPD classes, and SRAL σ_0 modified by DistCoast classes	-1.2	4.4	11.8
C2C UP2	Coastal algorithm, MWR TBs modified by LF and WPD classes, and SRAL σ_0 modified by DistCoast classes	-0.7	3.6	0.8
C2C UP4	Coastal algorithm, MWR TBs modified by LF and WPD classes, SRAL σ_0 modified by DistCoast classes, and SST_{skin} and γ_{800} from the ERA5 model	-0.5	3.3	0.3

Conclusions

- The WTC retrieval over coastal regions is still a challenging process.

- The use of the open-ocean UP3S0 algorithm with modified inputs significantly improved the retrieval errors in the WTC.

- Moreover, the developed coastal algorithms, with the same modified inputs, further improved the WTC retrieval errors, from ~16 cm to 3.3 cm close to the coast.

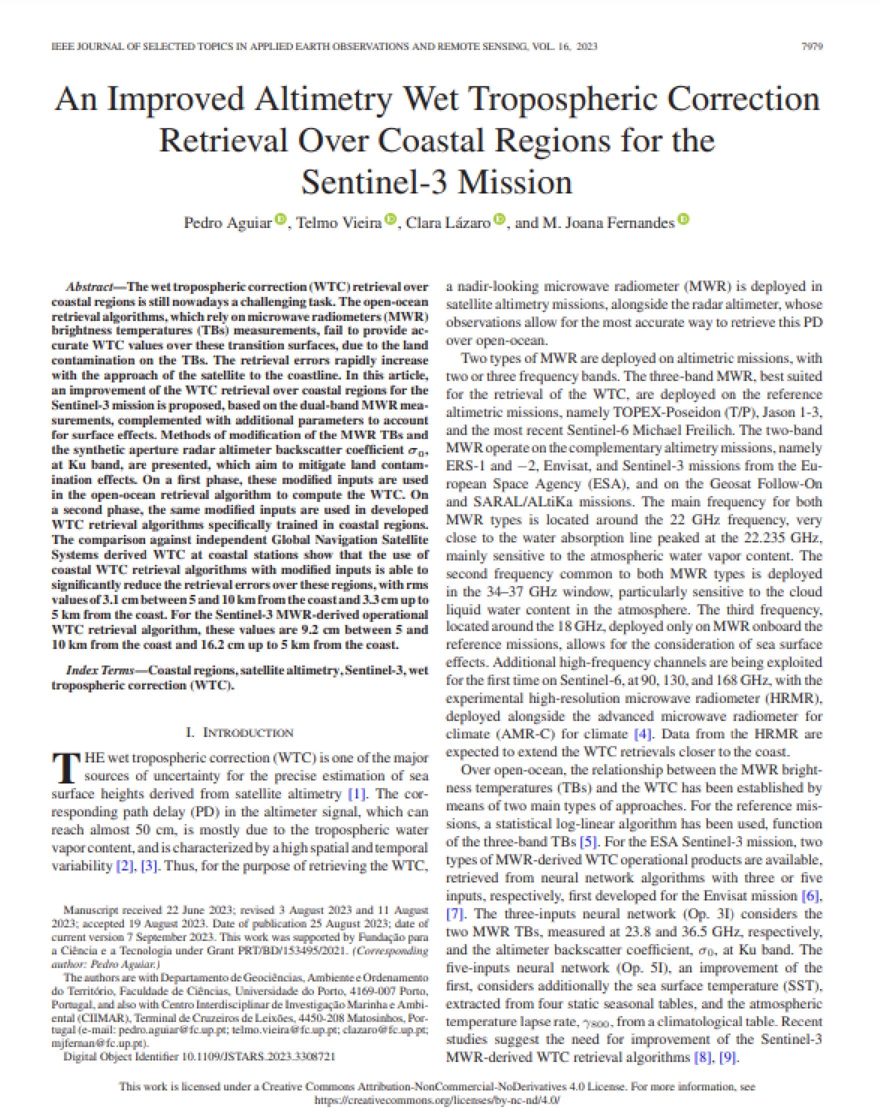
- All the results shown are in line of agreement with the comparison against the ERA5 model (not shown).

- More work needs to be done to further improve the retrieval errors and meet the requirements for coastal altimetry applications (e.g., technological improvements on the radiometer and altimeter sensors).

For more information, please check the corresponding published paper, or contact us via email (email address: pedro.aguiar@fc.up.pt) or via the AVISO+ forums.

Thank you for your time!

P. Aguiar, T. Vieira, C. Lázaro and M. J. Fernandes, "An Improved Altimetry Wet Tropospheric Correction Retrieval Over Coastal Regions for the Sentinel-3 Mission," in IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, vol. 16, pp. 7979-7991, 2023, doi: 10.1109/JSTARS.2023.3308721.



An Improved Altimetry Wet Tropospheric Correction Retrieval Over Coastal Regions for the Sentinel-3 Mission

Pedro Aguiar, Telmo Vieira, Clara Lázaro, and M. Joana Fernandes

***Abstract*—The wet tropospheric correction (WTC) retrieval over coastal regions is still nowadays a challenging task. The open-ocean retrieval algorithms, which rely on microwave radiometers (MWR) brightness temperatures (TBs) measurements, fail to provide accurate WTC values over these transition surfaces, due to the land contamination on the TBs. The retrieval errors rapidly increase with the approach of the satellite to the coastline. In this article, an improvement of the WTC retrieval over coastal regions for the Sentinel-3 mission is proposed, based on the dual-band MWR measurements, complemented with additional parameters to account for surface effects. Methods of modification of the MWR TBs and the synthetic aperture radar altimeter backscatter coefficient σ_0, at Ku band, are presented, which aim to mitigate land contamination effects. On a first phase, these modified inputs are used in the open-ocean retrieval algorithm to compute the WTC. On a second phase, the same modified inputs are used in developed WTC retrieval algorithms specifically trained in coastal regions. The comparison against independent Global Navigation Satellite Systems derived WTC at coastal stations show that the use of coastal WTC retrieval algorithms with modified inputs is able to significantly reduce the retrieval errors over these regions, with rms values of 3.1 cm between 5 and 10 km from the coast and 3.3 cm up to 5 km from the coast. For the Sentinel-3 MWR-derived operational WTC retrieval algorithm, these values are 9.2 cm between 5 and 10 km from the coast and 16.2 cm up to 5 km from the coast.**

***Index Terms*—Coastal regions, satellite altimetry, Sentinel-3, wet tropospheric correction (WTC).**

I. Introduction

THE wet tropospheric correction (WTC) is one of the major sources of uncertainty for the precise estimation of sea surface heights derived from satellite altimetry [1]. The corresponding path delay (PD) in the altimeter signal, which can reach almost 50 cm, is mostly due to the tropospheric water vapor content, and is characterized by a high spatial and temporal variability [2], [3]. Thus, for the purpose of retrieving the WTC, a nadir-looking microwave radiometer (MWR) is deployed in satellite altimetry missions, alongside the radar altimeter, whose observations allow for the most accurate way to retrieve this PD over open-ocean.

Two types of MWR are deployed on altimetric missions, with two or three frequency bands. The three-band MWR, best suited for the retrieval of the WTC, are deployed on the reference altimetric missions, namely TOPEX-Poseidon (T/P), Jason 1-3, and the most recent Sentinel-6 Michael Freilich. The two-band MWR operate on the complementary altimetry missions, namely ERS-1 and −2, Envisat, and Sentinel-3 missions from the European Space Agency (ESA), and on the Geosat Follow-On and SARAL/ALtiKa missions. The main frequency for both MWR types is located around the 22 GHz frequency, very close to the water absorption line peaked at the 22.235 GHz, mainly sensitive to the atmospheric water vapor content. The second frequency common to both MWR types is deployed in the 34–37 GHz window, particularly sensitive to the cloud liquid water content in the atmosphere. The third frequency, located around the 18 GHz, deployed only on MWR onboard the reference missions, allows for the consideration of sea surface effects. Additional high-frequency channels are being exploited for the first time on Sentinel-6, at 90, 130, and 168 GHz, with the experimental high-resolution microwave radiometer (HRMR), deployed alongside the advanced microwave radiometer for climate (AMR-C) for climate [4]. Data from the HRMR are expected to extend the WTC retrievals closer to the coast.

Over open-ocean, the relationship between the MWR brightness temperatures (TBs) and the WTC has been established by means of two main types of approaches. For the reference missions, a statistical log-linear algorithm has been used, function of the three-band TBs [5]. For the ESA Sentinel-3 mission, two types of MWR-derived WTC operational products are available, retrieved from neural network algorithms with three or five inputs, respectively, first developed for the Envisat mission [6], [7]. The three-inputs neural network (Op. 3I) considers the two MWR TBs, measured at 23.8 and 36.5 GHz, respectively, and the altimeter backscatter coefficient, σ_0, at Ku band. The five-inputs neural network (Op. 5I), an improvement of the first, considers additionally the sea surface temperature (SST), extracted from four static seasonal tables, and the atmospheric temperature lapse rate, γ_{800}, from a climatological table. Recent studies suggest the need for improvement of the Sentinel-3 MWR-derived WTC retrieval algorithms [8], [9].

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