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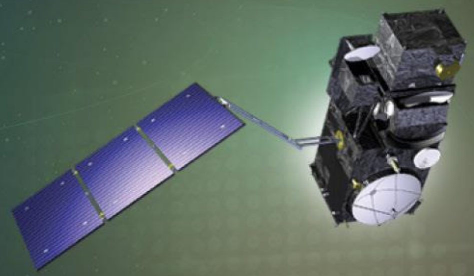

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Sentinel-3 SRAL/MWR and SLSTR Sensors Synergy for the Retrieval of the Wet Tropospheric Correction

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Introduction

- The wet tropospheric path delay is one of the most significant error sources for the precise estimation of sea surface heights derived from satellite altimetry.

- Mostly due to the interaction of the altimeter emitted signal with the atmospheric water vapour.

- The wet tropospheric correction (WTC), can reach, in absolute terms, almost 50 cm, with a standard deviation that can reach 15 cm.

- Best determined from the measurements of three-band microwave radiometers (MWR) on board the reference altimetric missions.

Introduction

- In the case of the Sentinel-3 mission, with dual-band MWR, additional parameters have been considered to compensate for the lack of the lower frequency channel:
  - Sea Surface Temperature (SST), extracted from four static seasonal tables;
  - Atmospheric temperature vertical decrease rate (γ_{800}), extracted from a static climatological table.
- Recent studies suggest that the Sentinel-3 WTC operational algorithms can be improved (Frery et al., 2020; Vieira et al., 2022).
- More precisely, Vieira et al. (2022) suggest that a dynamic SST (extracted from the ERA5 model) improves the WTC retrieval, while γ_{800}, when added to the dynamic SST, provides redundant information.

Introduction

- Besides the dual frequency (Ku and C band) Synthetic Aperture Radar Altimeter (SRAL) and the dual frequency passive MWR, the Sea and Land Surface Temperature Radiometer (SLSTR) is also part of the Sentinel-3 mission.

- The SLSTR sensor provides, among other observations, SST_{skin} gridded measurements collocated with the SRAL/MWR sensors observations.

- **Objective:** assessment of the SLSTR-derived SST_{skin} measurements as input for the retrieval of the WTC of Sentinel-3 SRAL observations over open ocean.

Data and Methods

- This work comprises three main tasks:

  (1) synergistic use of the Sentinel-3A SLSTR and SRAL/MWR sensors data;

  (2) evaluation of the SLSTR-derived SST_{skin} against the SST_{skin} interpolated from the ERA5 atmospheric model;

  (3) assessment of the impact of using the SST_{skin} derived from each retrieval source, alongside additional parameters, for the retrieval of the WTC.

- In addition, the WTC computed in task (3) were also compared against the WTC present in the Sentinel-3 products.

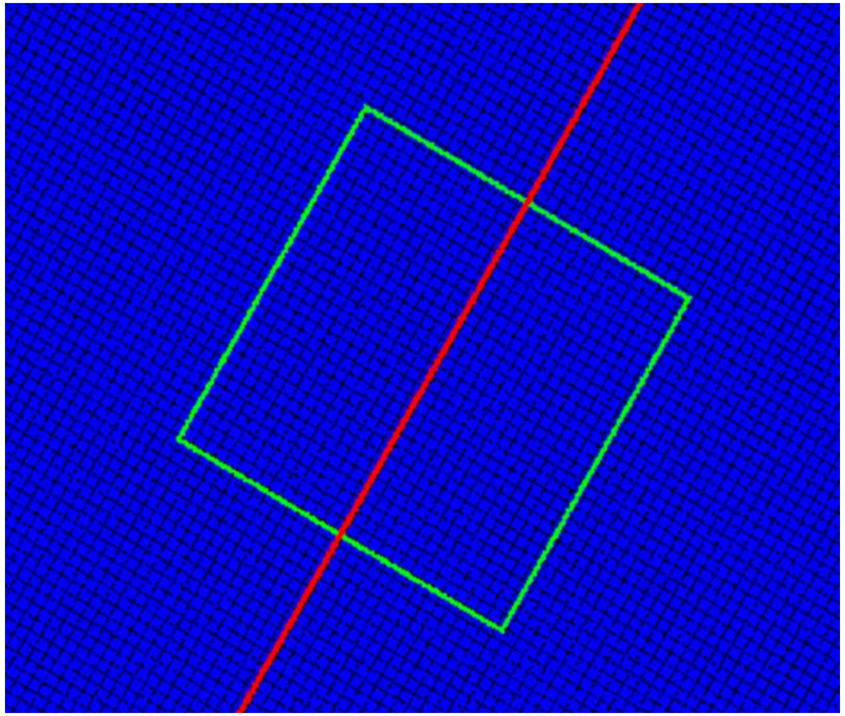
Data and Methods

- **Sentinel-3A SRAL/MWR data:**
  - Non-Time Critical (NTC) Level 2 ocean data products (1 Hz) from cycles 13, 17, 21 and 24 (winter, spring, summer, and fall of 2017);
  - distance from the nearest coast equal or larger than 30 km;
  - within [-50º, 50º] latitude range.
- **Sentinel-3A SLSTR data:** NTC Level 2 Water Surface Temperature (WST) data products for the same cycles.

1) Sentinel-3A SRAL/MWR and SLSTR Sensors Synergy

- The SLSTR image pixels within a square box with 6 km length (chosen based on the SRAL observations acquisition frequency), centred in the SRAL observation position, are first determined.

- From this subset of pixels, the mean value of the SLSTR SST_{skin} measurements is computed, using only the pixels with the best quality flag (QL = 5).



2) Evaluation of Sentinel-3A SLSTR SST_{skin} against the ERA5 model

- The SLSTR-derived SST_{skin} observations were compared against those of the ERA5 atmospheric model.
- A space-time interpolation method was applied to the ERA5 model in order to obtain the SST_{skin} for each SRAL observation.
- This evaluation was carried out against four SST_{skin} grid versions of the ERA5 model:
    - **Spatial resolutions:** 0.25° by 0.25° and 0.50° by 0.50°;
    - **Temporal resolutions:** 3 hours and 6 hours;

3) Assessment of the Impact of Using Each SST_{skin} for the WTC Retrieval

- A learning, validation and test datasets of Sentinel-3A SRAL/MWR measurements were built, considering only measurements with the SST_{skin} successfully derived from both sources.

- The same neural network algorithm architecture of the Sentinel-3 WTC operational algorithms was used.

- Within the scope of this work, four neural network algorithms were developed.

- All algorithms consider the following three inputs in common:

    - MWR brightness temperatures (TB) at 23.8 GHz and 36.5 GHz;
    - SRAL backscatter coefficient, σ_0 (Ku band).

3) Assessment of the Impact of Using Each SST_{skin} for the WTC Retrieval

Algorithm	Inputs	
1	MWR $TB_{23.8}$ MWR $TB_{36.5}$ SRAL σ_0 (Ku band)	SST_{ERA5}
2		SST_{SLSTR}
3		SST_{ERA5} and γ_{800}
4		SST_{SLSTR} and γ_{800}

- **γ_{800}:** describe the linear decrease in atmospheric temperature with altitude, between the surface and the 800 hPa pressure level.

- Computed from ERA5 atmospheric temperature grids at pressure levels (0.25º by 0.25º spatial resolution every 3 hours), and space-time interpolated for each SRAL observation.

3) Assessment of the Impact of Using Each $\mathrm{SST}_{\mathrm{skin}}$ for the WTC Retrieval

- As output, each neural network algorithm returns the wet path delay ($\mathrm{WPD} = -\mathrm{WTC}$), in centimetres.

- The independent assessment of each developed algorithm was performed against Scanning Imaging MWR (SI-MWR).

- SI-MWR Total Column Water Vapour (TCWV) products were converted into WTC using Stum's formula (Stum et al., 2011).

- Collocation between Sentinel-3A SRAL/MWR sensors and SI-MWR:
    - Maximum distances of 50 km;
    - Maximum time differences of 30 min.

Results

- The synergy process was only possible in ~30% of the SRAL measurements, limited to clear sky conditions.

- There is a good agreement between the SLSTR and ERA5 SST_{skin}, among all ERA5 SST_{skin} grid versions:

    - Mean Difference (SST_{SLSTR} – SST_{ERA5}) in the range [0.16, 0.20] K;
    - Standard deviation ranging between [0.42, 0.46] K.

- The ERA5 model with a 0.50º by 0.50º spatial resolution and available every 6 hours was used henceforth.

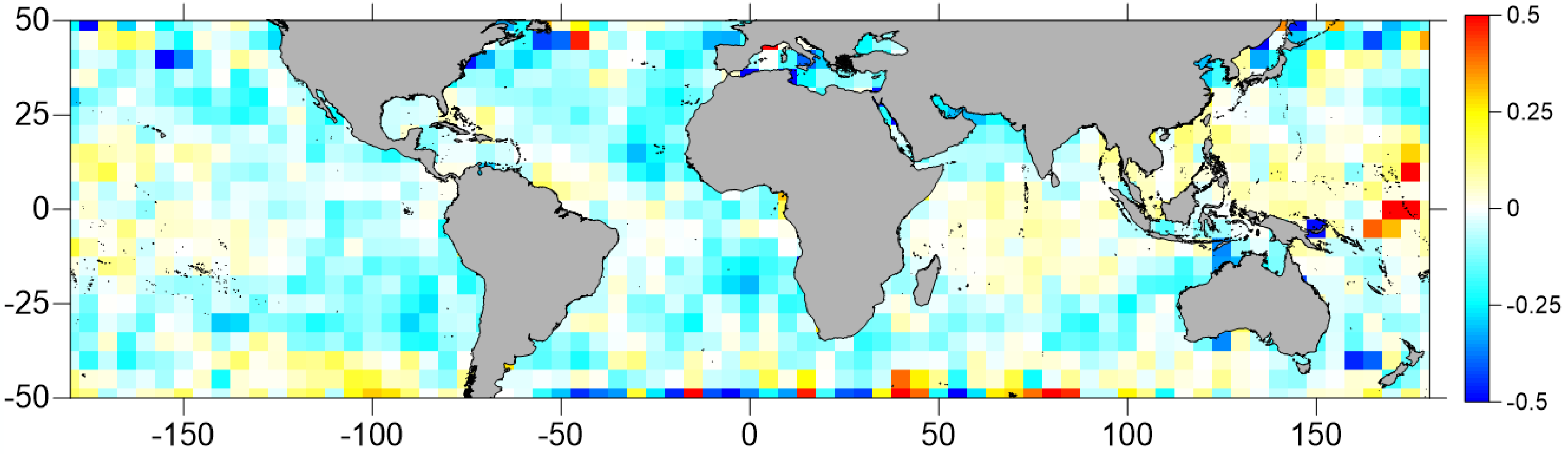
Dataset	Number of measurements
Train	102 131
Validation	48 210
Test	61 257

Results

Root Mean Square (RMS) of the WPD diferences for operational and developed algorithms against SI-MWR.

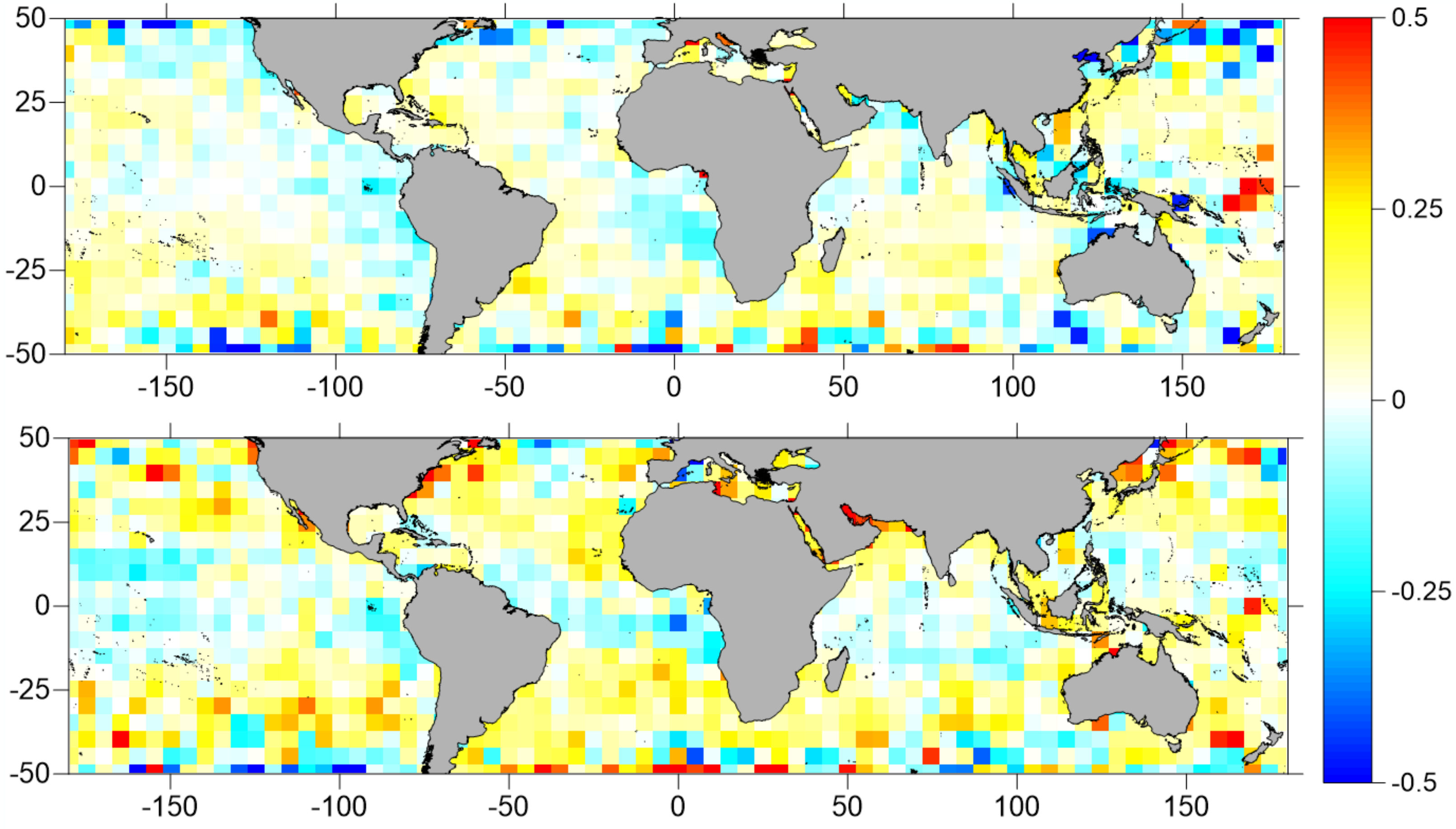
<table>
<tr><th>Algorithm</th><th colspan="2">Inputs</th><th>RMS (cm)</th></tr>
<tr><td>Operational
3-Inputs</td><td rowspan="6">MWR TB$_{23.8}$
MWR TB$_{36.5}$
SRAL σ_0
(Ku band)</td><td>-</td><td>1.12</td></tr>
<tr><td>Operational
5-Inputs</td><td>Static SST and
Static γ_{800}</td><td>1.15</td></tr>
<tr><td>1</td><td>SST$_{ERA5}$</td><td>1.05</td></tr>
<tr><td>2</td><td>SST$_{SLSTR}$</td><td>1.08</td></tr>
<tr><td>3</td><td>SST$_{ERA5}$ and γ_{800}</td><td>1.02</td></tr>
<tr><td>4</td><td>SST$_{SLSTR}$ and γ_{800}</td><td>1.02</td></tr>
</table>

Results



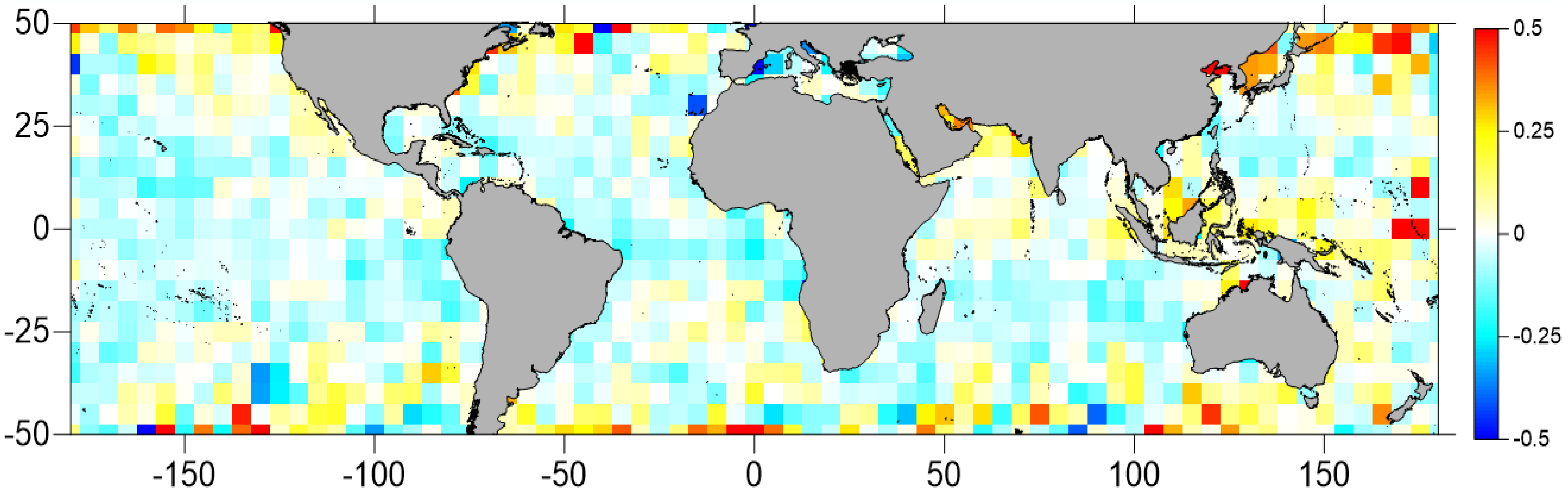
Differences, in cm, between RMS values for Algorithm 1 – Algorithm 2 (5º by 5º resolution).

Results



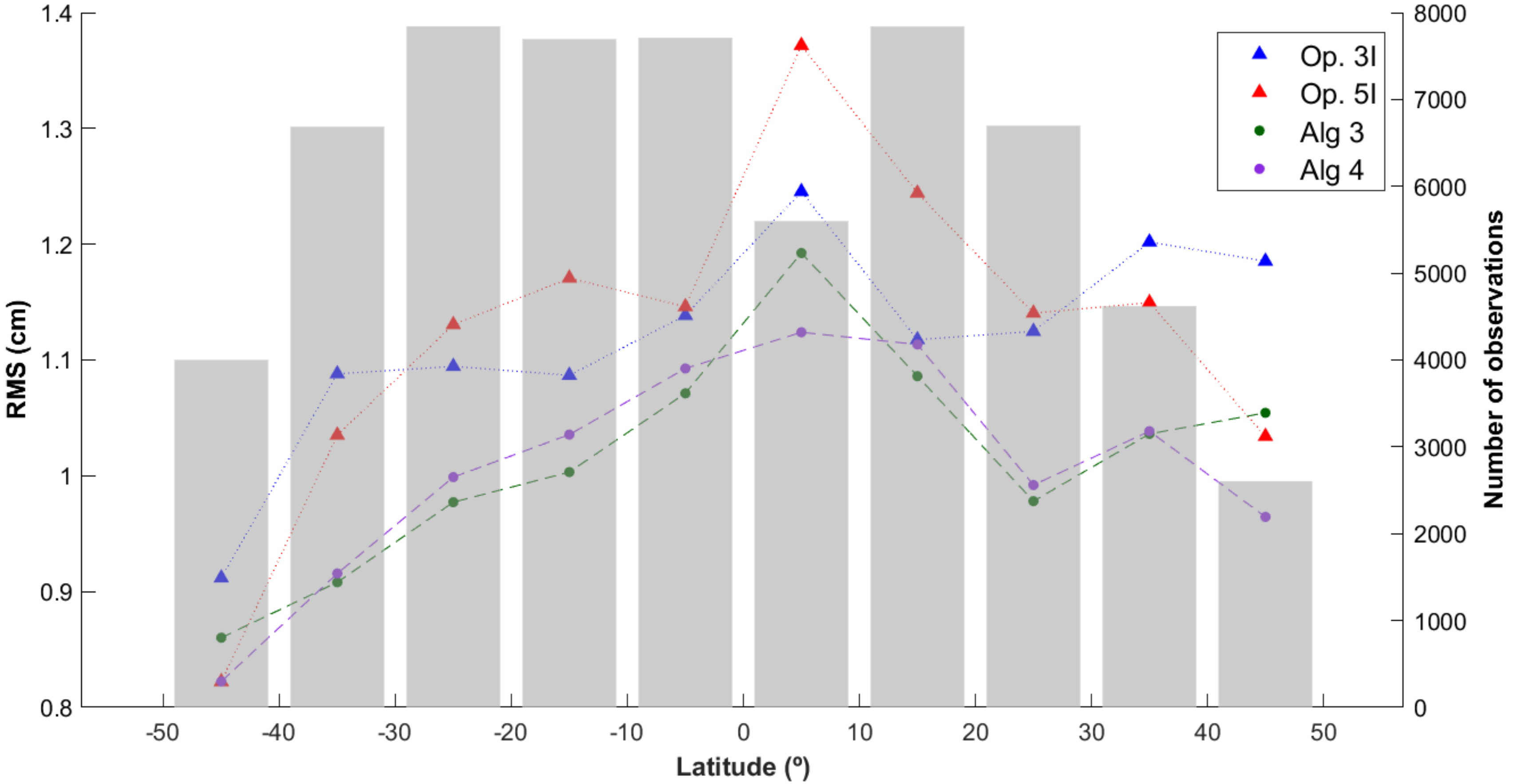
Differences, in cm, between RMS values for Algorithm 1 – Algorithm 3 (**top panel**), and Algorithm 2 – Algorithm 4 (**bottom panel**, 5º by 5º resolution).

Results



Differences, in cm, between RMS values for Algorithm 3 – Algorithm 4 (5º by 5º resolution).

Results



RMS of WPD differences, in cm, function of latitude, for Algorithms 3 and 4 and the operational algorithms against SI-MWR.

Conclusions

- The proposed synergistic methodology was only possible for 30% of the SRAL data, limited to clear sky conditions.

- Both SST_{skin} sources (SLSTR sensor and ERA5 model) showed a good agreement.

- The use of the SST_{skin} input from the SLSTR sensor resulted in an RMS increase, at millimetre scale, against the ERA5 SST_{skin} input.

- The addition of γ_{800} was not significantly impactful.

- There is room for improvement of the Sentinel-3 WTC operational algorithms.

Conclusions

- The ERA5 atmospheric model is a good SST input source for the WTC retrieval and is available for most altimeter observations.
- The lower dependence of the WTC with the SST, compared to other input parameters, sustain the non-impactful results when using SLSTR SST_{skin} observations against ERA5.
- The use of the ERA5 model presented a lower execution time and lesser computational complexity when compared to the use of the SLSTR data.
- For this particular application, there seems to be no added value in having collocated SST and altimeter observations in the future topographic remote sensing missions.

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Article

Synergistic Use of the SRAL/MWR and SLSTR Sensors on Board Sentinel-3 for the Wet Tropospheric Correction Retrieval

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Abstract: The Sentinel-3 satellites are equipped with dual-band Microwave Radiometers (MWR) to derive the wet tropospheric correction (WTC) for satellite altimetry. The deployed MWR lack the 18 GHz channel, which mainly provides information on the surface emissivity. Currently, this information is considered using additional parameters, one of which is the sea surface temperature (SST) extracted from static seasonal tables. Recent studies show that the use of a dynamic SST extracted from Numerical Weather Models (ERA5) improves the WTC retrieval. Given that Sentinel-3 carries on board the Sea and Land Surface Temperature Radiometer (SLSTR), from which SST observations are derived simultaneously with those of the Synthetic Aperture Radar Altimeter and MWR sensors, this study aims to develop a synergistic approach between these sensors for the WTC retrieval over open ocean. Firstly, the SLSTR-derived SSTs are evaluated against the ERA5 model; secondly, their impact on the WTC retrieval is assessed. The results show that using the SST input from SLSTR, instead of ERA5, has no impact on the WTC retrieval, both globally and regionally. Thus, for the WTC retrieval, there seems to be no advantage in having collocated SST and radiometer observations. Additionally, this study reinforces the fact that the use of dynamic SST leads to a significant improvement over the current Sentinel-3 WTC operational algorithms.

Keywords: satellite altimetry; wet tropospheric correction; Sentinel-3

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