A novel operational Sea State Bias correction for Sentinel-3 Delay/Doppler altimeter measurements incorporating wind directional effect

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General Description

The Delay/Doppler altimetry technique, also known as SAR altimetry, has opened a new era for satellite altimetry applications since the launch of the CryoSat-2 mission, followed by Sentinel-3A/B and the more recent Sentinel-6A missions. This high-resolution (HR) dataset offers significant advantages over conventional low-resolution (LR) altimetry, including reduced measurement errors and enhanced along-track spatial resolution. However, this technological advancement has also raised questions regarding the differing sensitivities of Delay/Doppler measurements to ocean surface characteristics: such as wave state, wave motion, surface roughness, and currents, compared to conventional data. These evolving effects necessitate adaptations to traditional processing methods to ensure the continuity and quality of satellite sea level observations.

In this study, we address a known issue reported since 2019 concerning HR/LR range biases between ascending and descending orbits, which have been found to correlate with meridional wind patterns. Initially observed in Sentinel-3 data [**Nencioli et al, 2023**] , this phenomenon also affects Sentinel-6 measurements. Several studies have investigated this feature and attributed it to HR data, linking the observed biases to wind-wave-induced Doppler shifts that manifest as apparent horizontal wave motion. The bias is stronger and with opposite sign for up-wind and down-wind, zero for cross-wind situations, and is significant wave height dependent [**Amarouche et al, 2023**].

To mitigate this, we developed an empirical correction in the form of a two-dimensional look-up table (LUT), designed as an additional component to the standard two-dimensional Sea State Bias (SSB) correction applied to range data. This correction effectively removes most of the wind-direction-dependent biases observed between the two operational modes, thereby improving the quality of Sentinel-3 SAR altimetry data across the global ocean. Our results demonstrate the value of this correction in ensuring consistent sea level measurements across all nadir altimeter missions. It is included In the newly release Marine Baseline Collection 006 "G62" for Sentinel-3. This poster aims to describe this newly developed operational correction and to report its performance evaluation.

Model developed based on S3A data

- New SSB correction based on the preliminary BC006 Test Dataset (covering mid-2020 to mid-2022) generated by EUMETSAT, used both to update the standard SAR 2D SSB and to develop an additional SAR-specific correction (ΔSSB), defined as:

  $$\Delta SSB = SAR\_(range + updated\ 2D\ SSB) - PLRM\_(range + 2D\ SSB)$$

- total SAR SSB is thus :

  $$SAR\ total\ SSB = updated\ 2D\ SSB\ (SWH, WS) + \Delta SSB(W\_PROJ\_AL, SWH)$$

  with:

  - SWH: corrected SAR Significant Wave Height using the NOAA LUT
  - WS: SAR Wind Speed from Abdalla's algorithm (based solely on SAR σ_0)
  - W_PROJ_AL: ECMWF wind-vector projection along the track

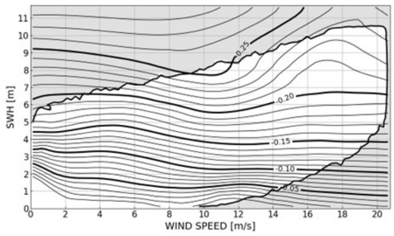

Figure 1: 2025 SAR 2D SSB model estimates (in m), based on preliminary BC006.2 TDS data and computed using the modified non-parametric approach described in **Tran et al. [2021]**.

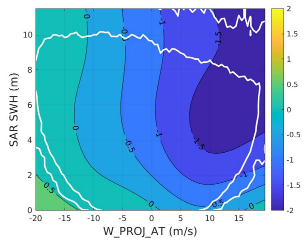

Figure 2: Two-dimensional lookup table for ΔSSB (in cm) computed using a spline-based method [**Feng et al., 2010**].

Validation & Performance evaluations

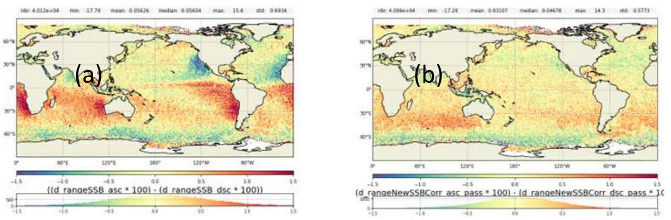

Figure 3: Differences (in cm) between ascending–descending binned maps of (SAR – PLRM) range after applying: (a) the standard 2D SSB correction (2025 version for SAR, 2020 version for PLRM), and (b) the 2025 total SSB for SAR together with the 2020 2D SSB for PLRM. The additional ΔSSB correction applied to SAR data significantly reduces geographical inconsistencies between SAR and PLRM. The source of the remaining pattern in (b) likely originates at the instrumental level and may be related to the known waveform centering issue in S3, driven by the OLTC table. This issue could still have a minor impact on (SAR minus PLRM) range estimation differences between ascending and descending tracks, while the largest impact on SWH data has been mostly resolved by improving zero-masking in SAMOSA retracking.

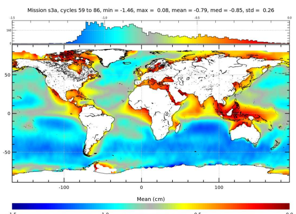

Figure 4: Global maps of mean SSB differences (in cm) between the 2025 total SSB and the 2020 2D SSB used in BC005 to correct SAR SSH.

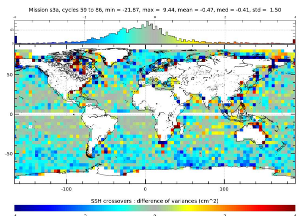

Figure 5: Map of differences in SAR SLA variance at crossovers (cm²) for S3A, using either the 2025 total SSB or the standard 2020 SSB in the SLA computation. The new total SSB correction reduces SLA variance in all blue-shaded regions, demonstrating a clear improvement.

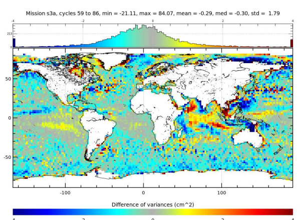

Figure 6: Global map of SAR SLA variance differences (cm²) for the S3A mission, computed using either the 2025 total SSB or the standard 2020 SSB in the SLA calculation. The new total SSB correction provides an average variance reduction of approximately −0.7 cm².

Conclusions & Perspectives

- **Updated 2D SSB correction**

  close to the 2020 version used in BC005, with differences mostly between –0.9 cm and +0.3 cm. Slight improvement observed in Sentinel-3A SSH precision.

- **ΔSSB correction**

  significantly reduces wind-directional effects in SAR BC006 data and improves the geographical consistency between SAR and PLRM SSH.

- **Total SAR SSB correction**

  replaces the standard SAR 2D SSB correction in the newly release Marine Baseline Collection 006 "G62" for Sentinel-3.

- **Recommendation for Sentinel-6**

  as the same effect is also observed in Sentinel-6 SAR data, CLS recommends applying this additional correction to improve the Sentinel-6 dataset.

- **Further development**

  a future improvement would be to develop the total SAR SSB correction independently of PLRM/LRM data (range and SSB), in order to avoid importing inconsistencies that may arise from imperfections in the other dataset.

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