Improved shallow waters tidal estimates using satellite radar altimetry data and numerical modeling

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Tidal estimate from satellite altimetry in shallow North Sea waters.

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INTRODUCTION

- Estimating **tides from satellite benefits from a prior solution.** E.g., XTRACK tidal constituents use FES2014 and DAC as tide and surge priors.
- **Reducing noise improves** least-squares-based **harmonic estimates.**
- XTRACK + DAC provides state-of-the-art tide surge corrections for deep waters.
  - The set is less accurate in shallow waters than deep waters.
  - It treats tides and storm surges as a linear sum.
  - In shallow waters of the North Sea, it ignores the tide surge non-linear interactions.
- DCSMv7 model includes non-linear interactions. Suggesting, it could be a better prior for shallow waters.

Objective

We want to learn if considering the combined effect of tides, surges, and their interaction in a prior estimate, based on the DCSM v7 tide-surge model, improves the shallow water tidal estimates of the North Sea.

Motivation

- **DCSMv7 provides** users with **accurate water level representation**.
- **Tide stations h**ave been widely exploited **for calibration and validation**.
- **Satellite radar altimetry data complements a wealth of information** over the model's domain. Our motivation:
- Use it to **calibrate the model's** bottom friction and bathymetry uncertainties.
- Assimilate satellite residuals (**SLA**) into the DCSMv7.
- Very accurate tides benefit SLA estimation.
- Removing estimates retain **tide surge errors in the residual** signal.
- Due to **low sampling, filtering satellite high-frequency errors** by daily or monthly averages is not consistent. These highlights the importance of more accurate tidal estimates.

Methodological approach

Replace parts of the tide estimation to study the resulting accuracy of the estimates in the North Sea region.

Improving tidal estimates in shallow waters

Shallow waters have a tidal influence given by many constituents (>100). **Therefore, refrain from retrieving all** these **constituents** with satellite radar altimeter data alone.

Series length requirements imposed by the Rayleigh criteria to separate constituents **have yet to be there**.

This **variance reduction is the core** of the remove-compute-restore approach commonly used. It consists of **adding residual harmonics to a background model estimate**.

The residual harmonic set is computed with the residual from observation (y_s) and model background estimate (y_m).

$$\hat{\boldsymbol{X}} = \boldsymbol{X}_B + \boldsymbol{B}\boldsymbol{A}^T(\boldsymbol{R} + \boldsymbol{A}\boldsymbol{B}\boldsymbol{A}^T)^{-1}(\boldsymbol{y}_s - \boldsymbol{y}_B) \qquad (1)$$

Including model background error covariance helps weighing between constituents well represented in the model and the ones we should correct.

Validation: k-fold cross-validation with n three contiguous years validation windows.

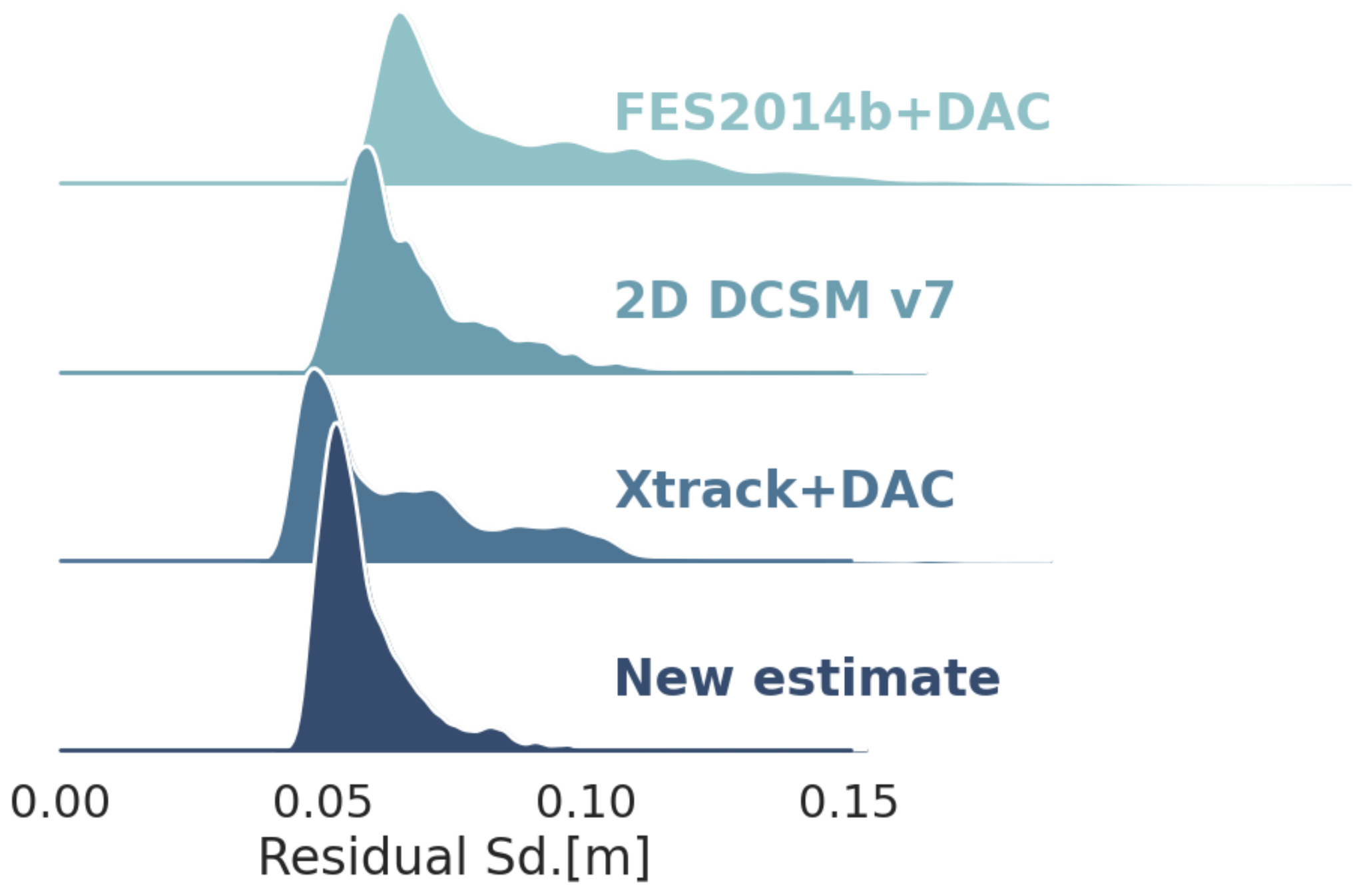

FIGURE 4 – Satellite residual sd. kernel density estimates for the different products.

RESULTS.

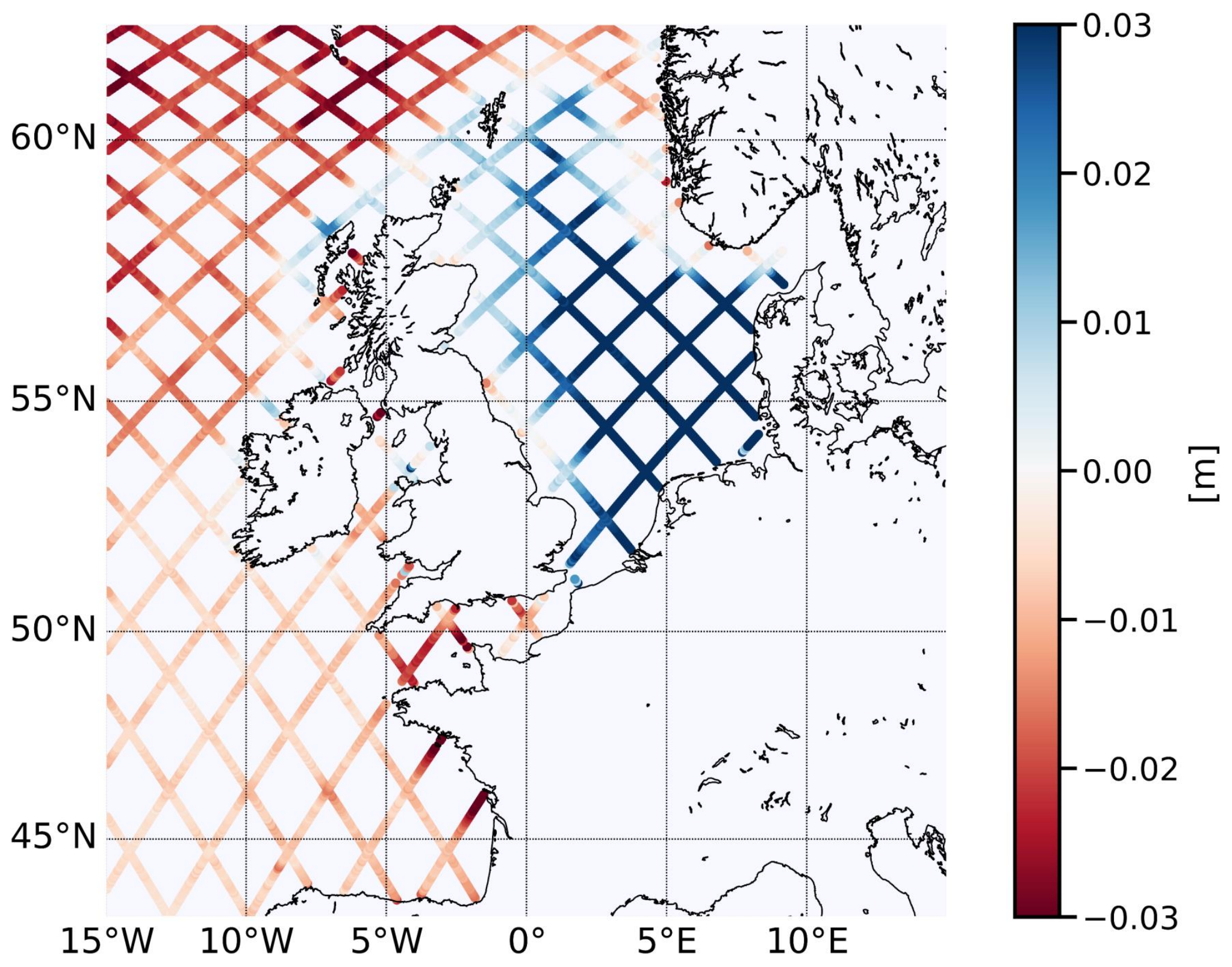

FIGURE 1 - Along track residual standard deviation. XTRACK+DAC – DCSMv7.

New estimates

General performance

DCSMv7 + tidal correction and XTRACK+DAC:

1. Significant more variance is reduced in shallow waters (FIGURE 2a, 4).
2. Similar mean values (reduction of 0.07 cm) but a **50% reduction** (1 cm) **of standard deviation and 20% reduction (2 cm) in the 95th percentile**.
3. The **improvements** in shallow water can be attributed to **the presence of non-linear interactions**. In deep waters, DCSMv7 showed no advantage over XTRACK+DAC.
4. XTRACK uncertainty calculation has a technical advantage over DCSMv7 accuracy. Here XTRACK estimates are computed on top of training data. For DCSMv7 the k-fold cross-validation avoids that but decreases the number of years available for tidal analysis.

DCSMv7 + tidal correction and DCSMv7:

1. The new estimate **improves** upon the prior consistently over the **whole domain** (FIGURE 3b).
2. Reduction of **mean-standard deviation** by **14% (1 cm)** and **30% reduction in standard deviation** (.4 cm) (FIGURE 3b).
3. The English Channel and the shallow part of the Bay of Biscay are the regions with the largest improvements. **Reductions of standard deviation** in these regions are close to **5 cm**.
4. Irish Sea, German Bight, and English east coast also have considerable improvements with reductions of standard deviation close to 3 cm.

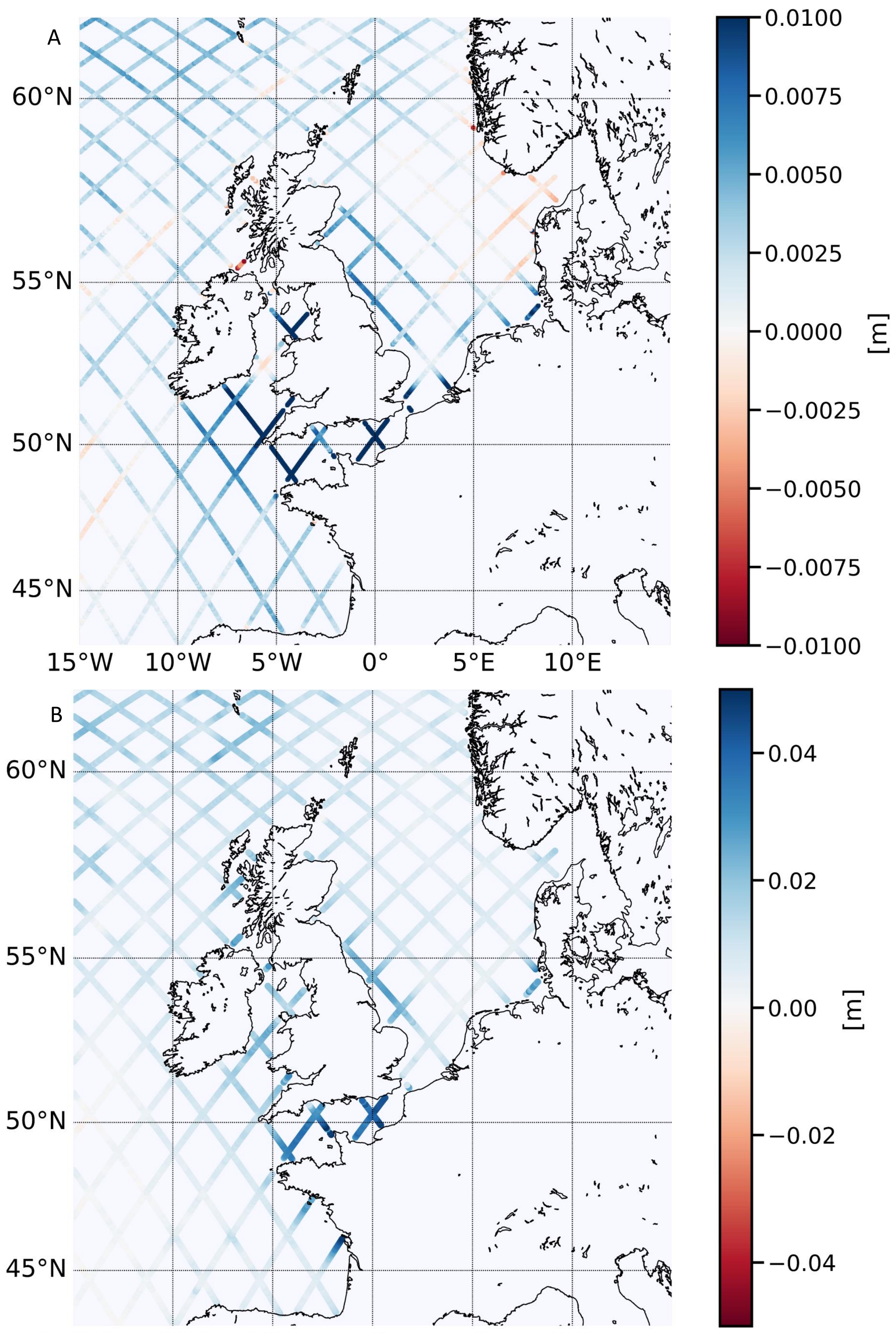

FIGURE 3 - Along track residual standard deviation differences. Left: XTRACK – new tidal estimate. A: XTRACK – new tidal estimate. B: DCSMv7 – new tidal estimate.

Priors

Residual variances (FIGURE 4):

1. DCSMv7 and FES2014b+DAC: Mean standard deviation is reduced by 2cm (22%) and standard deviation by 1.5cm (50%).
2. **DCSMv7 and XTRACK+DAC: Similar overall performance.** The first has an advantage in shallow water and the second in deep waters.
3. **DCSMv7 tides and XTRACK: Comparable overall tidal accuracy**.
4. Despite the high accuracy of XTRACK estimates, results suggest it would not be suitable for calibrating DCSVMv7 uncertain parameters in shallow water.
5. DCSMv7 is a better prior in shallow waters because it reduces more variance.
6. We can expect better tidal estimates using DCSMv7 as a prior.

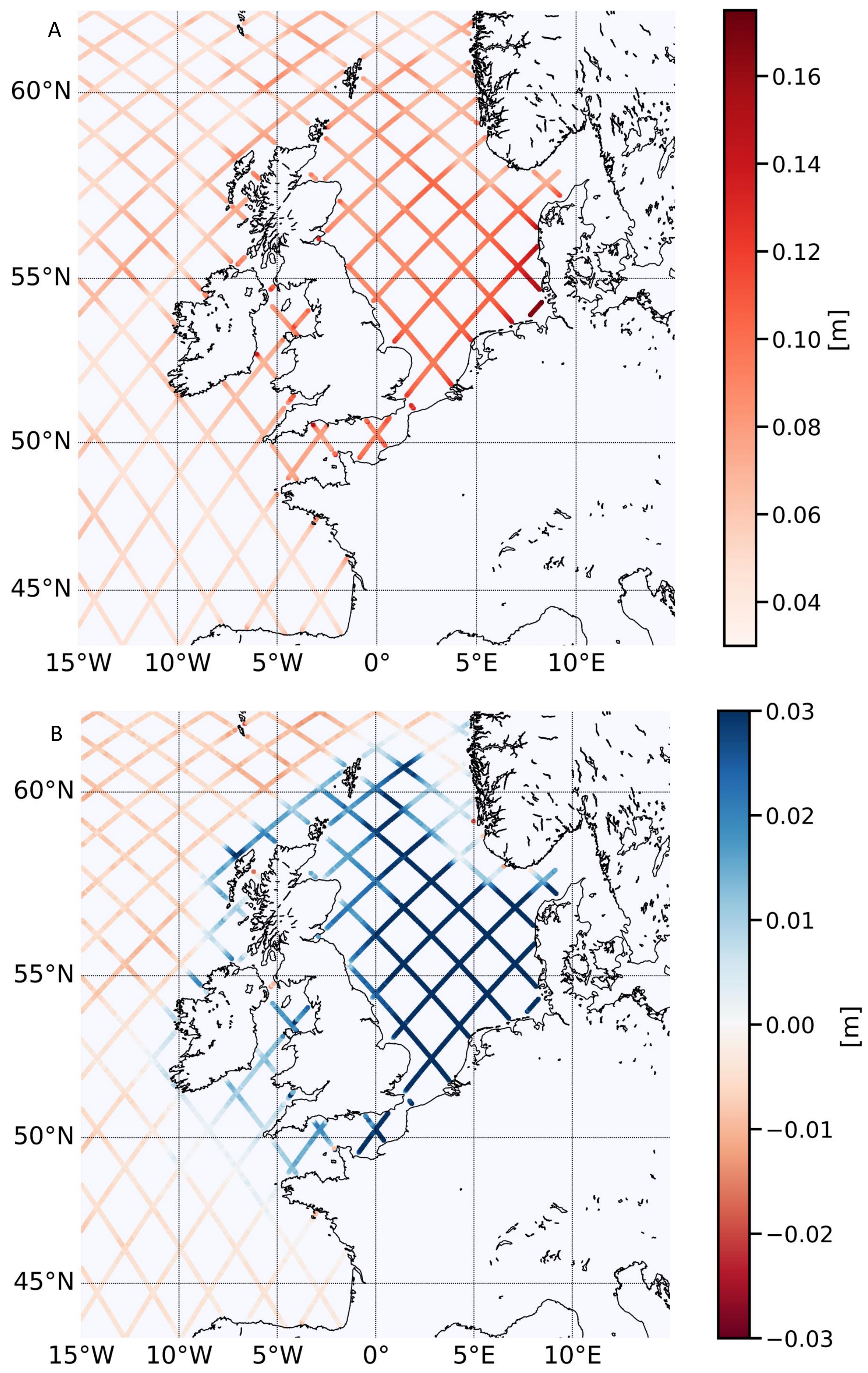

FIGURE 2 - Along track residual standard deviation. A: XTRACK B: XTRACK+DAC – new tidal estimate.

Tidal performance

Overall tidal performance improved.

Improvement is seen in the whole domain except close to the entrance of the Baltic sea, scattered regions across the Atlantic and at the entrances of the Irish Sea (FIGURE 3a).

1. The English Channel, the Celtic and Irish Sea, the Netherlands coast, and the German Bight are the **most benefited regions where reductions of standard deviation reach 4 cm.**
2. Removing only tidal estimates from satellite water levels results in residuals with large magnitudes. Calculating improvements in tidal estimation by increases in variance reduction is possible.
3. In our estimation, **DCSMv7 improves standard deviation reduction** overall by less than 1cm. However, this is not representative of the actual difference but a low bound. Therefore, We can expect real gain to be larger than that.
4. Removing DAC from both products could give a better representation of the actual magnitude of improvements, but because DAC is also a prior for XTRACK constituents we can expect biased results.
5. The residual standard deviation difference between DCSMv7 + tidal correction and DCSMv7 contains only the tidal improvements. Here we can see the a more realistic magnitude of gains (FIGURE 3b).

CONCLUSIONS

1. The combined effect of **tides, surges,** and their **interaction** in a prior estimate, based on the DCSM v7 tide-surge model, **improves the shallow water tidal estimates** of the North Sea.
2. The tidal improvements shown here **could be used to calibrate** DCSMv7 bottom friction and bathymetry for better modeling tidal representation.
3. Necessary tests to assert the potential extent of improvements are currently being studied.
4. Despite state-of-the-art estimates, for the next steps of this study, XTRACK does not seem like a viable option for improving DCSMv7.
5. Next steps include the generation and validation of an improved SLA product to be assimilated by a bias Kalman filter.

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