Feedbacks of sea-level rise induced topographic changes of the Wadden Sea on tidal dynamics

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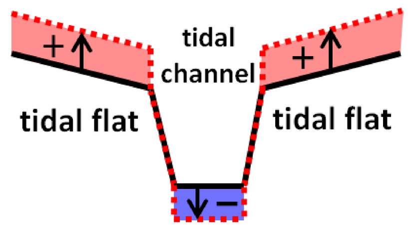
Introduction

Tidal flats of the Wadden Sea (German Bight) play a significant role for coastal defense and maintenance of navigational channels as they dissipate tidal and wave energy in the foreshore area. In principle tidal flats of the Wadden Sea are capable to adapt to sea-level rise (SLR) by growth due to a more flood dominant tidal asymmetry with increased sediment import in tidal basins and internal redistribution of sediment between morphologic elements of tidal basins (see sketch below). However, estimates of tidal flat growth and associated critical SLR rates vary largely and have been proposed only for single tidal basins so far (e.g. van Goor et al. 2003, Dissanayake et al. 2012, Becherer et al. 2017). This study investigates feedbacks of hypothetic SLR-induced morphological changes of the entire Wadden Sea on tidal dynamics and whether these changes reinforce or compensate hydrodynamic effects, which arise from SLR alone.

channel-flat cross-section with schematic topographic changes under a high rate of sea-level rise:



Methods

In a German Bight model we set up a range of hypothetic topographic changes (TC) of the Wadden Sea (Fig. 1), which are considered likely under specific SLR scenarios such as 0.8 m within the 21st century (see right panel in Fig. 1). We combine these topographic scenarios with the respective SLR scenarios in 3D hydrodynamic simulations using the model UnTRIM (Casulli and Walters 2000).
The applied scenarios of hypothetic morphological changes are based on empirical models on one hand (e.g. Friedrichs and Aubrey 1988, Stive et al. 1998) and results of process-based model studies on the other hand. The considered topographic changes represent only a simplified scenario ignoring local factors, such as sediment availability, tidal basin geometry and tidal range.

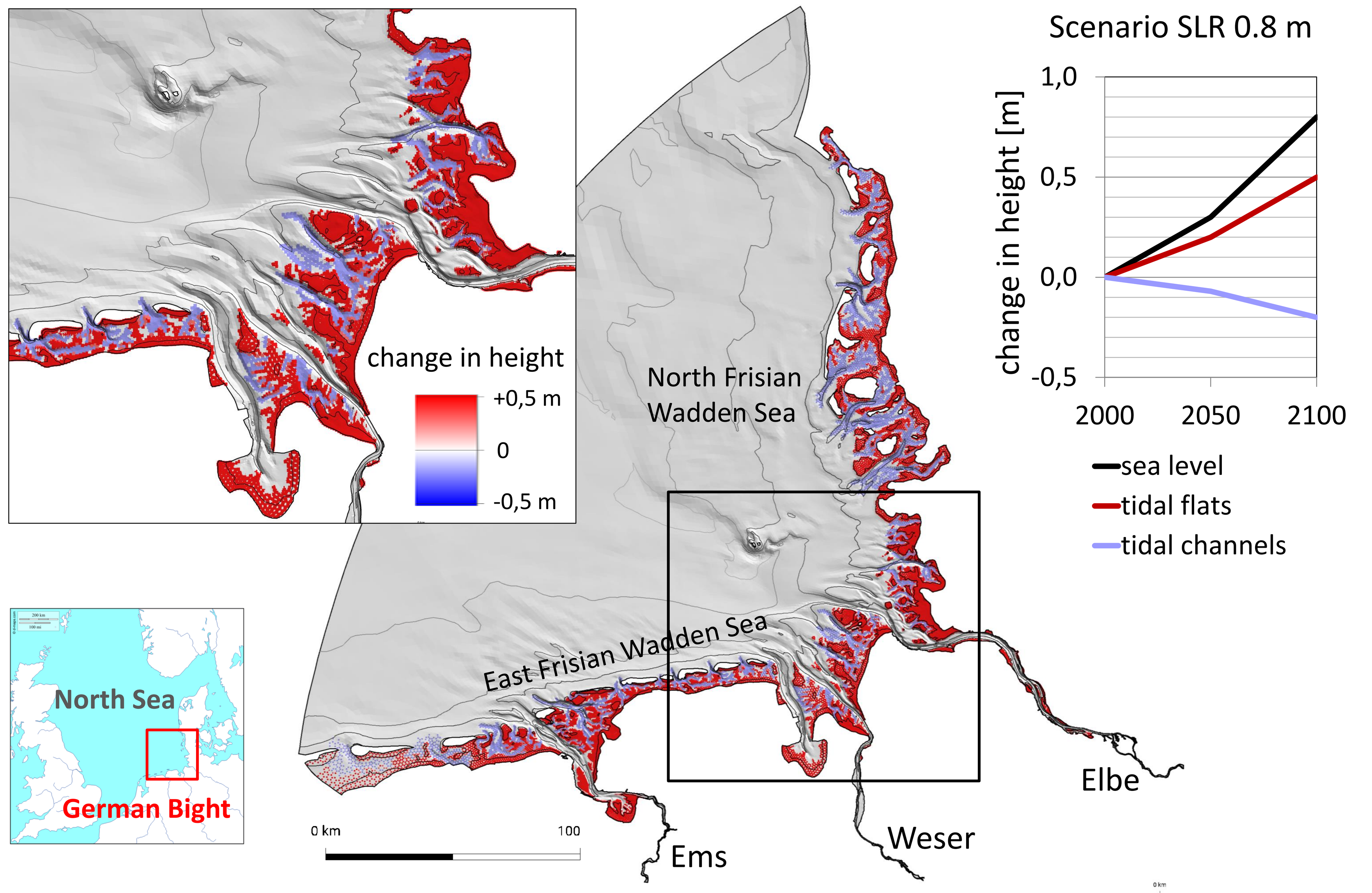


Figure 1: Applied schematic topographic changes considered likely under a SLR of 0.8 m within the 21st century.

Results

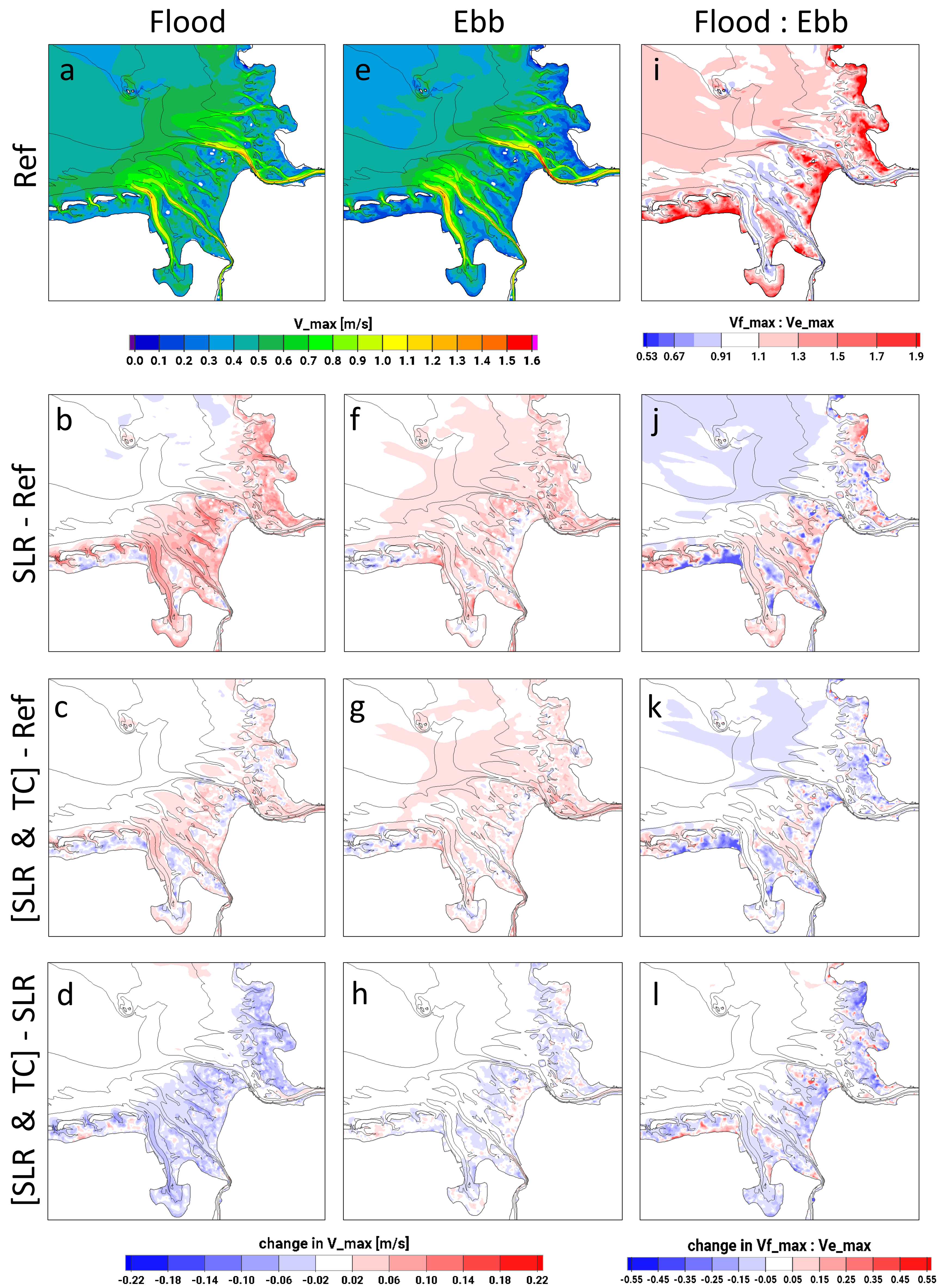


Figure 2: Maximum flood current velocity in the reference case (Ref) (a), changes due to sea-level rise (SLR - Ref) (b), changes due to sea-level rise and topographic changes ([SLR & TC] – Ref) (c) and residual changes due to topographic changes ([SLR & TC] – SLR) (d). The same for maximum ebb current velocity (e-h) and the ratio of maximum flood current velocity to maximum ebb current velocity (i-l). Depth contour lines are displayed for 2, 12, 22 and 32 m below NHN.

Feedbacks of the topographic changes on maximum flood current velocity:

- **Tidal channels:** While SLR induces an increase of maximum flood current velocity (Fig. 2b), the TC reduce the maximum flood current velocity (Fig. 2d).
- **Tidal flats:** Maximum flood current velocity is either increased or decreased by SLR revealing locally different responses (Fig. 2b). However, the local response to SLR is again mainly compensated by the TC though not as prominent as compensational effects in the channels (Fig. 2d).

Feedbacks of the topographic changes on maximum ebb current velocity:

- **Tidal channels:** Changes in maximum ebb current velocity due to SLR range from decreasing to increasing, while the landward sections of the channels show the most prominent decreases (Fig. 2f). Although the TC show only minor effects, they mostly compensate the SLR effects (Fig. 2h).
- **Tidal flats:** Maximum ebb current velocity is mainly increased by SLR (Fig. 2f), which is mostly compensated by the TC (Fig. 2h). However, the effects are weak.

General observations:

- SLR effects as well as effects of the TC on maximum ebb current velocity are not as strong as on maximum flood current velocity (compare Fig. 2f with 2b and Fig. 2h with 2d). This is due to the lower water depth and stronger friction during ebb currents damping any hydrodynamic response of the falling tide.
- Effects of the considered TC on tidal currents are generally smaller (Fig. 2d,h) than effects of SLR (Fig. 2b,f), but can be in the same order of magnitude locally. Hence SLR-induced TC of the Wadden Sea should be considered when estimating the range of potential SLR effects on local tidal dynamics.

Conclusions

Changes in tidal current velocities induced by sea-level rise are mostly compensated by the applied topographic changes of the Wadden Sea. The results demonstrate the significance of sea-level rise induced topographic changes in the Wadden Sea for estimating local effects of sea-level rise on tidal dynamics.

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