EFFECT OF LARGE-SCALE FORCING ON THE LOCAL SEDIMENT TRANSPORT POTENTIAL AT THE SCHLESWIG-HOLSTEIN BALTIC SEA COAST

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BACKGROUND

The Schleswig-Holstein (SH) Baltic Sea coast consists of different morphological features (e.g., bars, beaches, dunes, cliffs), which are continuously shaped by various along- and cross-shore sediment transport patterns driven by local currents generated from tides, seiches, winds and waves (Soomere et al., 2012). Understanding local scale sediment transport is of utmost importance to manage the scarce coastal sediments and to identify suitable mitigation strategies against extreme forcing scenarios (Hofstede and Hamann, 2022).

This investigation was carried out at the exemplary cliff coast at Stohl (Fig. 1), at which the glacial till cliff (maximum height about 20 m) is the source of nearshore sediments (Averes et al., 2021). The investigation area extends about 12 km alongshore, and follows the convex shape of the coastline from SE to W (Fig. 2b). Water levels at this semi-diurnal micro-tidal coast combined with seiches vary ± 1.6 m. This coastal stretch is sheltered from the dominant SW wind but significant wave heights during NE wind conditions have exceeded 2 m (at 13 m water depth).

OBJECTIVE

The main objective of this study is to investigate the relative importance of different forcing conditions on local sediment transport pathways.

APPROACH

Four numerical experiments were carried out using the process-based modelling system Delft3D to investigate the local sediment transport potential based on different boundary forcing scenarios; E1: *Water levels* + *Waves*, E2: *Water levels only*, E3: *Tides* + *Waves* and E4: *Seiches* + *Waves*. Tides and Seiches were decomposed from water levels using a Fast-Fourier-Transformation following the approach of Dissanayake and Brown (2022). Spatiotemporal wind fields were used to force each simulation.

A model nesting of 3 domains was used to downscale local hydrodynamics (Fig. 1). The CG domain has a maximum grid resolution of 300 m × 500 m (cross- × alongshore) at the coast, while it is about 75 m × 125 m of IG. The smallest domain (SG) has the highest grid resolution of 2 m × 50 m, which sufficiently represents the variations of the nearshore morphology (e.g., cliff, bar). The resolution of each grid decreases towards offshore to optimise the computational time.

For each scenario, water level boundary was first set at the open boundaries of CG and the wave boundary was implemented using the spectral wave parameters (JONSWAP). Based on the simulated water levels, currents and waves (except in E2) of CG, the boundary forcing for IG was derived at north (water level) and east (current). Finally, SG was simulated applying three-boundary forcing at west (current), north (water level) and east (currents) based on the results from IG. Sediment transport was simulated using only SG in which flow- and wave-module were online coupled. This facilitates different wave propagation to the coast based on the prevailing water level. Waves in SG were simulated by coupling all three domains together.

A spatially uniform bed sediment composition was implemented representing an exemplary fine and a medium sand fraction. Initial sediment thickness was set to 0.5 m considering the sediment scarcity of the SH coast. These models were simulated to investigate the sediment transport potential under a morpho-static condition.

Simulation period spans four days from 02.10 to 05.10.2016 during N-NE winds, which consist of the longest fetch generating high waves at Stohl.

Simulated results of the last two days (04.10-05.10.2016) were analysed, allowing the first two-day for the model spin-up. The model was first calibrated, and then validated for two independent periods.

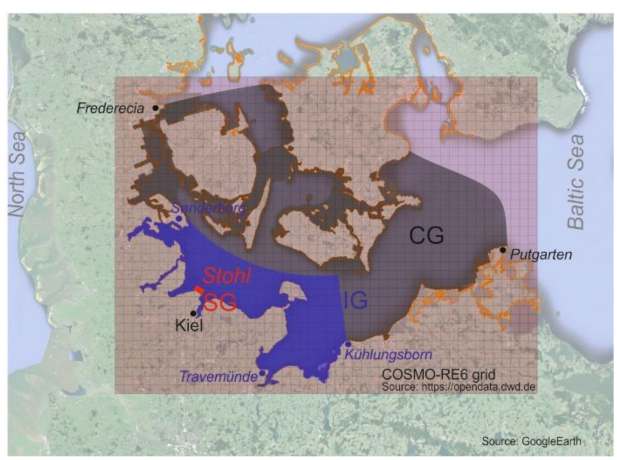

Figure 1 – Location of Stohl on the SH coast, and the chain of model nesting from coarse to local area: Coarse Grid (CG), Intermediate Grid (IG) and Stohl Grid (SG).

RESULTS

Calibration and validation show good agreements with the measured water levels ($RMSE_{max}$= 0.14 m) and significant wave heights ($RMSE_{max}$ = 0.30 m). These agreements are better in winter periods than in summer. For each scenario, the maximum velocity condition along the coast was analysed at cross-shore locations. In the foreshore (e.g., at A on Fig 2c), all models predict almost similar velocity irrespective to the boundary forcing (Table 1), whereas close to the beach (e.g., at B on Fig 2c), wave experiments E1 and E4 show higher velocities, and E1 results in the largest velocity, 0.53 m/s. Wave driven currents are limited up to a maximum depth of around 3 m. Bed shear stress is significantly higher at B in wave experiments than E2. However, in E3, both velocity and bed shear are zero.

Model		Observation points	
		A	B
Velocity (m/s)	E1	0.09	0.53
	E2	0.08	0.07
	E3	0.09	0.00
	E4	0.09	0.46
Bed shear stress (N/m^2)	E1	0.16	4.32
	E2	0.08	0.05
	E3	0.17	0.00
	E4	0.17	3.60

Table 1 Variation of maximum velocity and bed shear stress at A (6 m maximum water depth) and B (0.5 m)

Residual sediment transport potential along the coast for the investigation period is towards west with the maximum rates at the apex (Fig. 2c). Variation of total cumulative transport is almost similar in both E3 and E4, which show a maximum decrease of 30% (within a two-day period) compared to that of E1. In each experiment, contribution of the coarse sediment fraction to the total transport is less than 10%. Sediment transport potential in E2 is negligible in comparison to the other experiments.

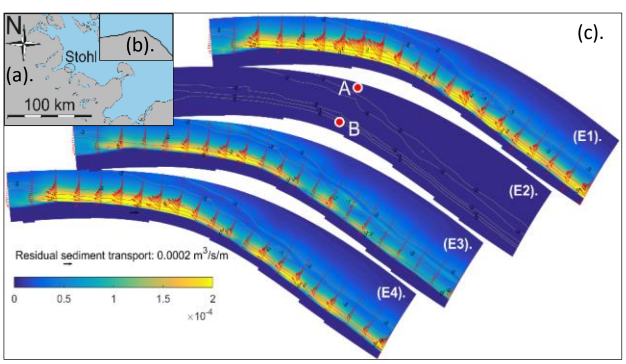

Figure 2 Location of Stohl on the SH coast (a), model area (b) and simulated residual sediment transport over a two-day period for E1, E2, E3 and E4 (c).

DISCUSSION

Only wave experiments show a narrow band of high velocities close to the beach along the coast. During the analysis period, strong wind up to 12 m/s from N - NE occurred generating high waves (maximum Hs: 1.5 m). Due to breaking of these waves, westward oriented strong velocities along the coast are generated close to the beach, and they are responsible for reworking, sorting and transport processes of sediment (Davidson-Arnott, 2010). In relatively closed basins (no swells) similar to Baltic Sea, waves are determined by the existing fetch for wind (Mason et al., 2018). All experiments show weak westward currents in the offshore area, which are driven by wind. Applied fine and coarse fractions are only mobilized by the wave driven currents (E1, E3 and E4), rather with the wind driven currents (E2).

Cross-shore location of sediment transport depends on the implemented water level boundary. Results indicate a wide dry beach forcing with tide only (e.g., B in E3 is dry). A narrow dry beach in E1 accommodates wave breaking farther landward creating the strongest velocities (Table 1) and transport closest to the land. Therefore, the magnitude of nearshore velocity and thus sediment transport decreases in sequence from E1, E4 to E3. Micro-tide in Baltic Sea has a non-trivial role in estimating local scale sediment transport potential (E3).

Present experiments used a highly schematised bed sediment composition, which is sufficient for an inter-comparison of potential sediment transport due to different forcing scenarios. However, Stohl consists of heterogeneous materials and areas of hard bottom (Averes et al., 2021), which need to be considered in estimating sediment transport.

CONCLUSIONS

Obviously wave driven currents are the main driver for sediment transport at the study domain on the SH coast. Currents from water level gradients only are too weak to move sediment. Forcing water levels with tides or seiches alone, and waves results in fairly similar sediment transport potential. Micro-tidal contribution to water levels has an important role in estimating local sediment transport along the SH coast.

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