Long-term dune dynamics in the Lower Weser Estuary

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ABSTRACT: The dynamics of primary dunes in the Lower Weser Estuary have been studied for over 40 years due to their importance for sediment transport and the safety of navigation. In this work, a dataset of monthly bathymetric surveys over a period of 10 years is analyzed to investigate the relations between hydrological parameters and corresponding dune morphodynamics. Dune heights show a negative correlation with freshwater discharge whereas dune lengths exhibit a positive correlation. The tidal range inversely correlates to dune height and length. The dune migration celerity increases with increasing discharge and is independent of tidal range across temporal scales from individual discharge events to decadal trends.

1 INTRODUCTION

The Weser is a 452 km long river which flows in northwestern Germany and discharges into the German Bight, southern North Sea (Fig. 1). The lower reach of the river is tidally-influenced over 130 km from the river mouth until the tidal weir in Bremen. The fresh water discharge at gauge station Intschede ranges from 120 to 1,200 m³/s with an annual average of 320 m³/s. The mean tidal range of 3.76 m in Bremerhaven classifies the Weser Estuary as mesotidal. The riverbed is mainly covered by medium to coarse sand with an exception of a muddy stretch between river kilometers 50 and 65. The morphology of the sandy reaches is dominated by dunes with lengths of up to 100 m and heights of around 2 m.

The estuary is an important waterway connecting the ports of Bremen and Bremerhaven to the North Sea. To guarantee access for the large number of ships sailing through the Weser Estuary, the navigational channel has been repeatedly shifted and deepened over the last 100 years (Garrelts et al., 1973). Its depth is periodically monitored by the responsible authorities and maintained by dredging when required. A large part of the annual dredging costs is expended for removing individual dune crests by water-injection dredging.

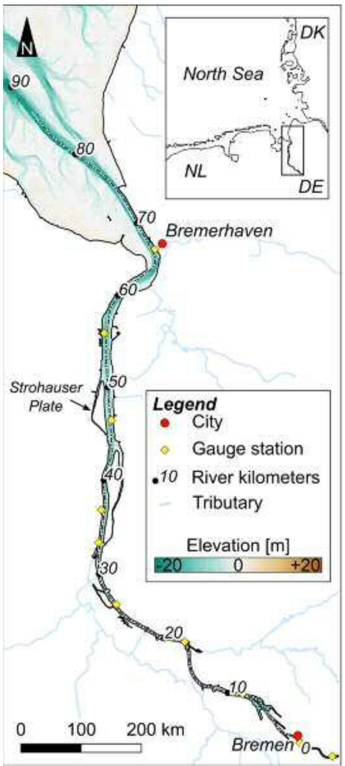

Figure 1. The Lower Weser Estuary

The tidal bedforms which cover most of the Weser Estuary are not only important for the navigational hazard they cause. They are also the main transport agent of bed material and are the main constituents of hydraulic roughness. Therefore, they are of high importance for the understanding and modeling of estuarine hydrodynamics, transport and morphological evolution.

Bedforms in estuaries are influenced by fresh water discharge as well as tidal forcing. Nasner (1974) and Allen (1976) investigated relations and time-lags between discharge and dune geometry and migration in the Lower Weser, but the contribution of tidal flow has received little attention.

This study analyzes the state and variability of bedform parameters based on monthly measurements of high-resolution bathymetry, upstream freshwater discharge, and tidal characteristics to improve the understanding of bedform related roughness and the performance of hydro-numerical models of estuarine scale.

2 DATA AND METHODS

2.1 Bathymetry data

Bathymetric surveys in the Lower Weser are carried out by the waterway and shipping administration (WSV) on a monthly basis to guarantee safe navigation. Bathymetry data from multibeam echosounder surveys with RTK-DGPS positioning were made available by Waterways and Shipping Agency (WSA) Bremerhaven, for the reach between river kilometer 40 and 120, for the period between January 2008 and December 2017. The preprocessed data was provided as xyz ASCII. The overall reach was divided into twenty sections of 2.4–4.6 km length. Surveys were repeated for individual sections. The ASCII data were gridded to obtain digital elevation models (DEMs) with a resolution of 2x2 m in GMT (Generic Mapping Tools) compatible NetCDF format.

2.2 Extraction of transects

The federal waterway (Bundeswasserstraße) in the Lower Weser marks the centerline of the navigational channel. For a 2D analysis of dune geometries, three profiles were extracted from the DEMs: One following the centerline and two at a lateral distance of ±50 m from the centerline.

2.3 Dune dimensions and celerity

To separate different bedform regimes (small dunes, large dunes and bars), the extracted transects were bandpass filtered with a passband of 250 to 10 m. Dune dimensions were then extracted from the individual transects by picking local crests and troughs as peaks with a minimum along-profile distance of 10 m and a minimum prominence of 10% of the overall profile elevation range. Mean and standard deviation for dune height and length were calculated (Fig. 2a,b,d,e).

The average migration celerity was determined for the entire section by cross-correlation of successive profiles (Fig. 2c,f).

2.4 Hydrological data

Time series of freshwater discharge were obtained from gauge station Intschede, 31 km upstream of the tidal weir. Time series of the tidal range were obtained from gauge stations along the estuary (Fig. 1).

3 PRELIMINARY RESULTS

A 10 km long test section in the area Strohauser Plate (Fig. 1) was evaluated over a period of 3 years. Dune heights, lengths and migration rates were compared to the hydrological parameters freshwater discharge and tidal range. Dune heights show a negative correlation with freshwater discharge (Fig. 2a) whereas dune lengths exhibit a positive correlation (Fig. 2b). The tidal range measured at a gauge station in the middle of the transect exhibits a negative effect on both dune height and length (Fig. 2d,e). The dune migration celerity increases with increasing discharge (Fig. 2c) and is independent of tidal range (Fig. 2f).

4 CONCLUSIONS AND OUTLOOK

Dimensions and migration celerities of large bedforms in the Lower Weser Estuary have been shown to depend on river discharge and tidal range. While a general correlation can be shown, the short-term effect of individual discharge events, in combination with the concurrent tidal forcing and wind setup, remains to be investigated.

5 ACKNOWLEDGEMENTS

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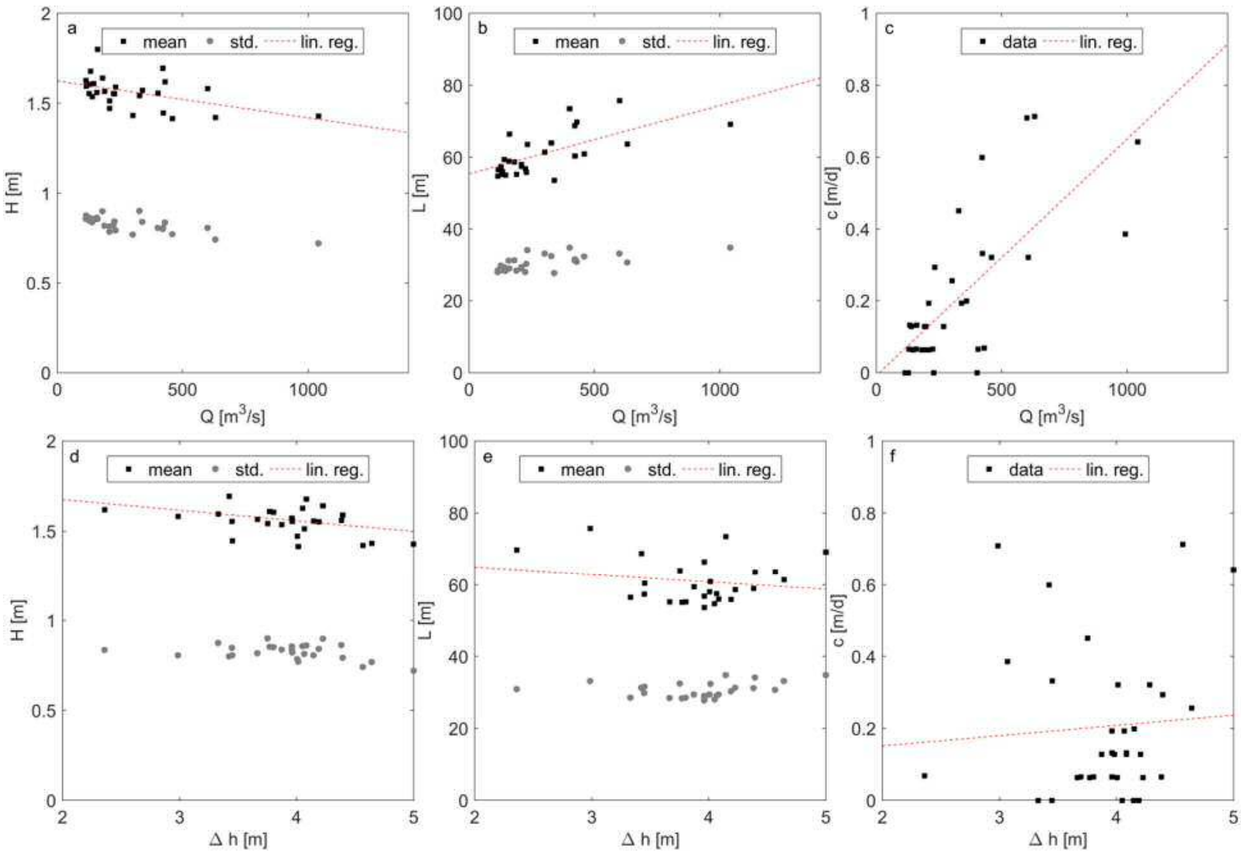

Figure 2. Correlations of dune dimensions (height H and length L) and celerity c with hydrological parameters discharge Q and tidal range Δh.