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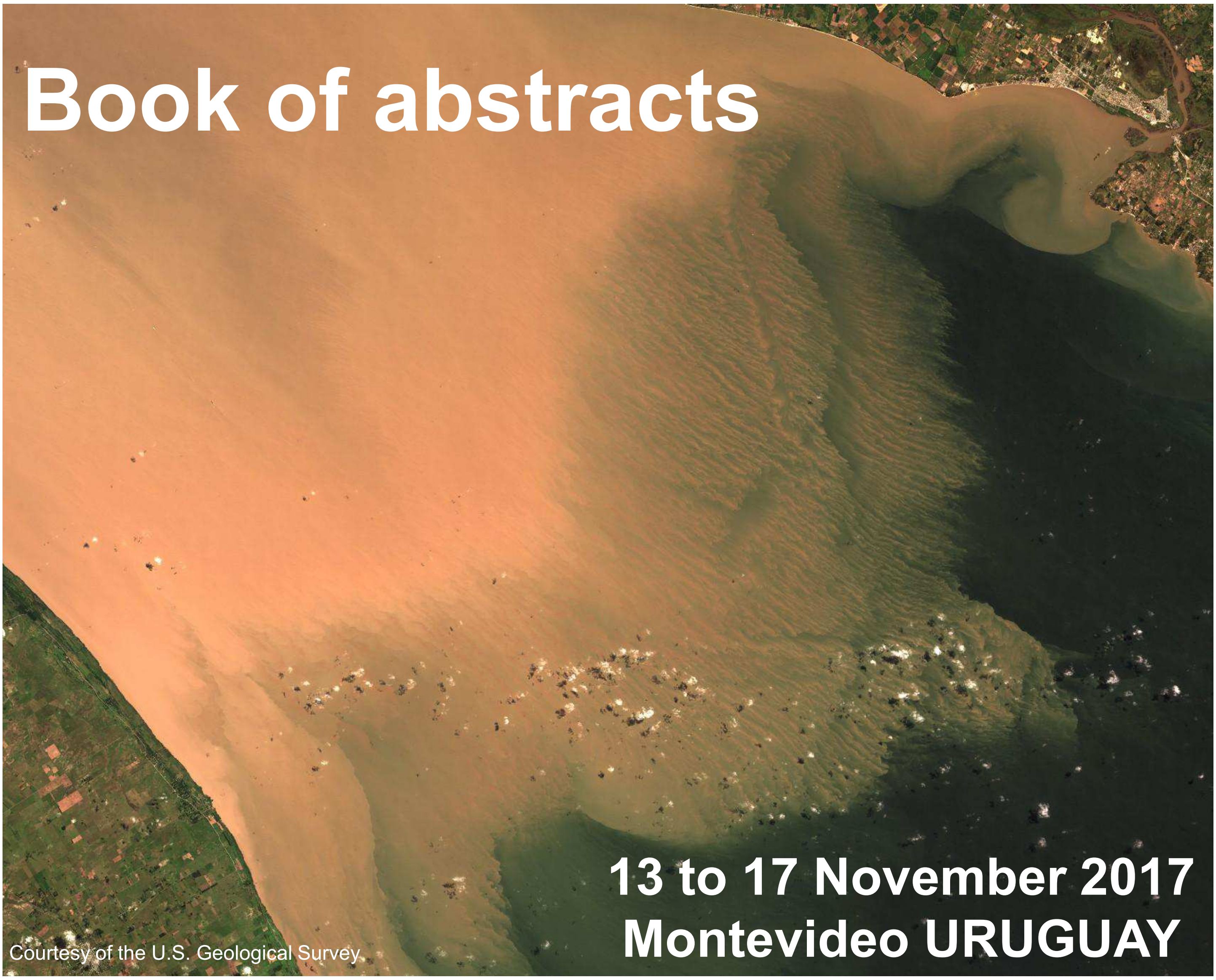

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Equilibria and Evolution of Estuarine Fringing Intertidal Mudflats

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Abstract

Fringing intertidal flats are common features of elongated estuaries. We generalized the geometry of profiles of individual intertidal flats towards a common relationship, based on extensive measurement data of various estuaries. We found a strong linear relation between the width, slope and height of linear intertidal flat profiles, which also yields well for the mild-sloped upper part of convex-up profiles. Deviations of this linear relation at the lower steeper part of the flats are the result of dominating alongshore currents.

Introduction

Elongated estuaries are fringed by tidal flats that consist of bare mudflats and at higher elevations vegetated marshes. These areas form a buffer between the channel and the dike, thereby serving as coastal protection. Furthermore, they provide valuable habitats for various species and are consequently often protected by legislations (e.g. Natura2000). Human interferences have affected and are still affecting these flats. Channel deepening, storm surge barriers and local weirs and groynes are examples of such interferences.

Profile shape (convexity or concavity) has been identified as a predictor for tidal flat development. Convex-up profiles are related to expanding systems dominated by tidal flow and concave-up profiles are linked to retreating wave-dominated systems. The theoretical basis for these relations however lies in analyses of systems dominated by cross-shore tidal flows. Limited evidence is available that supports such relations for systems with predominantly along-shore tidal flows. In this paper, we aim to identify the relations between tidal flat parameters for systems with predominantly along-shore tidal flows in order to determine predictors for future developments of fringing tidal flats.

Data

We consider fringing tidal flats in the meso-tidal systems Westerschelde and Oosterschelde (the Netherlands) and the macro-tidal Seine Estuary (France). All these flats are confined between the shore and a channel. Many of the considered tidal flats in the Oosterschelde and Westerschelde are also confined in streamwise direction by the dyke configuration. For the Oosterschelde and Westerschelde, a data set of 56 transects on 20 fringing tidal flats is available covering a period of 21 years (1993-2014) with annual RTK measurements. Furthermore, LiDAR data in combination with single-beam data is available for various years. For the Seine a local LiDAR database over 12 years is available. Numerical simulations provide the local tidal ranges and characteristic velocities in the channels. The bathymetry, tidal range and average flow magnitudes are indicated in Figure 1.

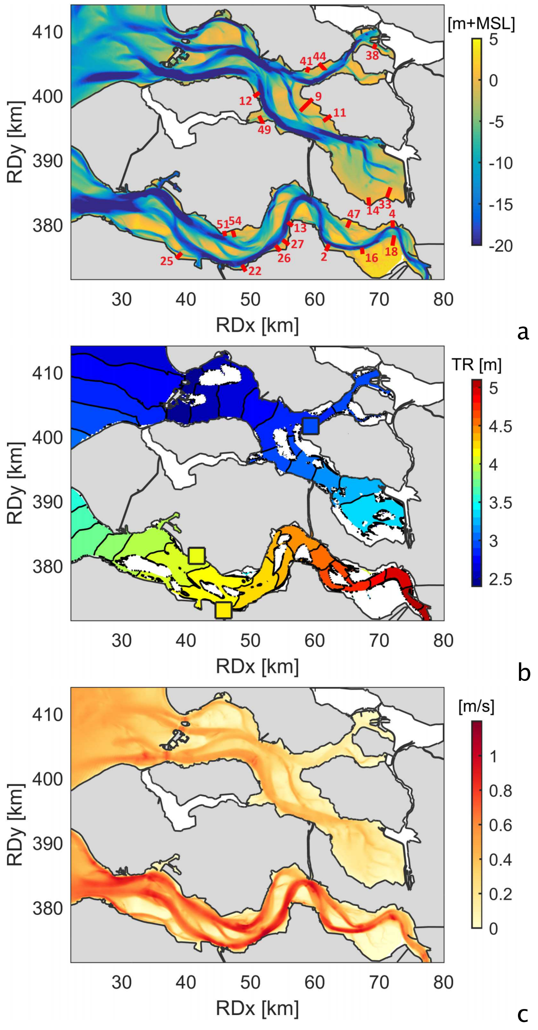

Figure 1: Westerschelde and Oosterschelde: (a) bathymetry and numbering of the tidal flats; (b) averaged tidal range; (c) average magnitude of the velocities.

Results

Oosterschelde. The tidal flats in the Oosterschelde have an S-shaped profile, where the linear part in the middle covers more than 80% of the intertidal area. The flats are therefore characterized as linear. A consistent linear relation is found for the bed level:

$$z = z_0 - s \cdot x \quad \text{with} \quad s = \frac{TR}{L\left(\frac{z_0}{\frac{1}{2}TR}+1\right)} \tag{1}$$

with distance from the shore or marsh x, bed level z (and z_0 at x = 0), tidal range TR, bed slope s and calibrated length scale L=1000 m. High and mild-sloped flats are therefore found when there is sufficient space between the channel and the shore.

Westerschelde. Two types of tidal flat profiles are found in the Westerschelde: (i) linear (partly concave-up) profiles; (ii) convex-up profiles with a mild-sloped upper part and a steep-sloped lower part. Linear and convex-up shapes are found for different widths and heights of the flats. The linear profiles show a similar relation between the height, slope and width as for the Oosterschelde, also with L=1000 m. The convex-up profiles have two distinct slopes. The slope in the upper part follows the relation as found for the linear profiles. The slope in the lower part is significantly larger. Time evolutions of the profiles show that both profiles can be stable, eroding or accreting.

Seine Estuary. The profiles in the Seine Estuary show a distinct double-sloped profile. The upper profiles approximately follow the linear relation with L=1000 m, using a tidal range of TR=6.7m. The transition to the steeper lower part is more distinct than in the Westerschelde.

For all profiles a value of approximately L=1000m was found, despite the significant variation in tidal range. No definite explanation was found yet for this linear profile. It is hypothesized that waves are important drivers. When waves are negligible, it seems that the upper part can become flat and dewatering processes generate creeks.

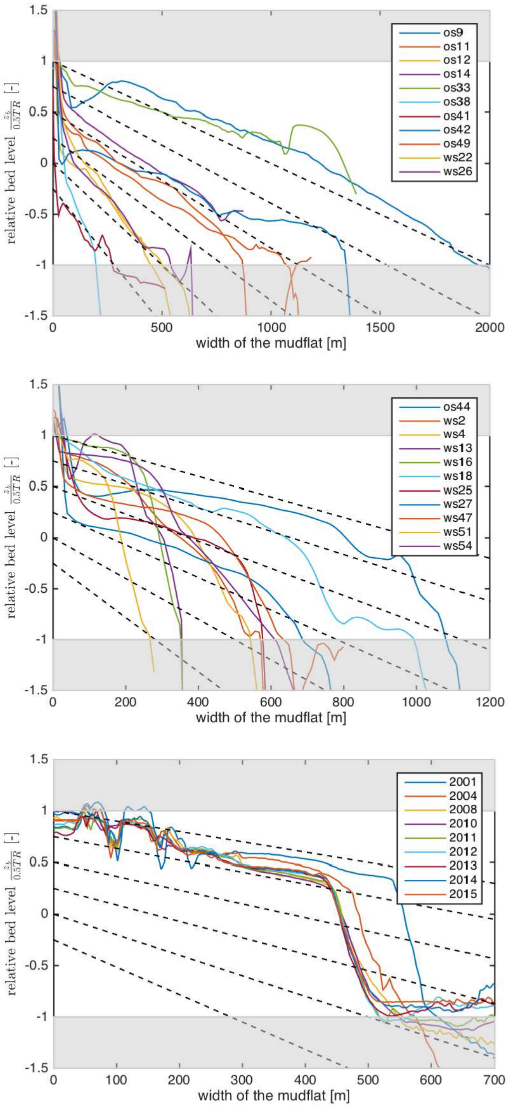

Figure: (a) Linear profiles in the Oosterschelde and Westerschelde. (b) Convex-up profiles in the Westerschelde and Oosterschelde. (c) Profiles in the Seine Estuary for different years. See Figure 1 for the location of the profiles in the Oosterschelde and Westerschelde. The vertical scale is made dimensionless by dividing by $0.5TR$. The dashed lines represent Equation (1) for various values of z_0.

Conclusions and Outlook

The measured transects at the tidal flats in the three estuaries indicate that various (almost) equilibrium profiles exist. The shape itself seems not to be a direct predictor for future development. Linear profiles and convex profiles can prograde, erode or can be in equilibrium. The upper flat follows a linear profile with milder slopes and higher mean bed levels for wider flats. The exact cause for the relation for the upper flat is to be examined. Further steps will focus on determining the influence of the alongshore current and sediment abundance on the width and slope of the steeper lower part of the convex-up profile.

Acknowledgements

Rijkswaterstaat provided the Oosterschelde and Westerschelde data. Jean-Philippe Lemoine, GIP Seine-Aval, provided the Seine data. This study is funded by NWO project EMERGO (850.13.021) and Ifremer is acknowledged for hosting and funding Bram van Prooijen for a two-week stay.