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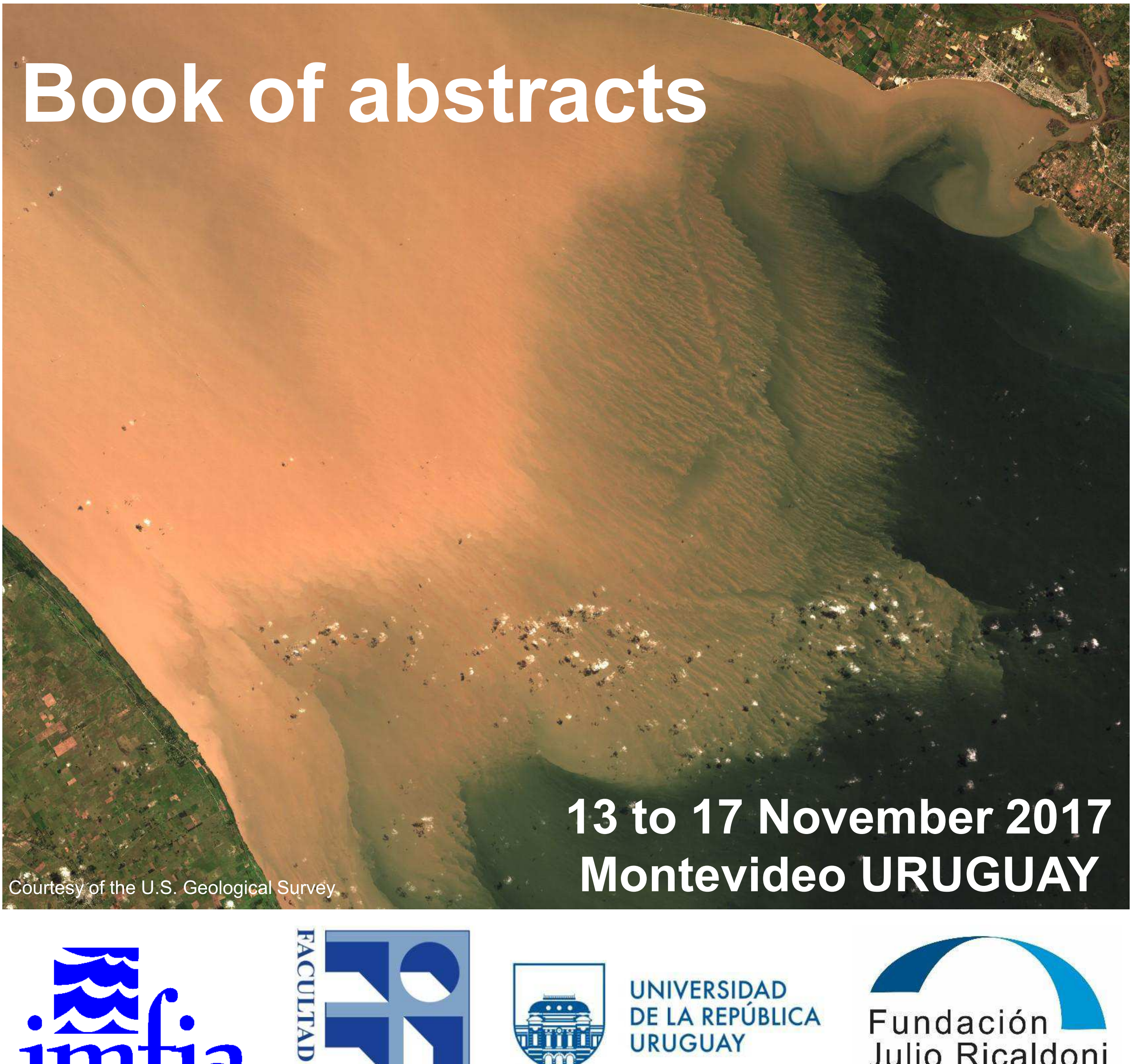

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Mud dynamics in the harbor of Zeebrugge

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Abstract
One year of SPM concentration (SPMC) and Velocity data are analyzed to gain insight in the mud dynamics in the harbor of Zeebrugge. Seasonal dynamics are inferred from satellite images, depth soundings and SPMC data.

Study Site
The harbor of Zeebrugge is situated in the coastal turbidity maximum area along the Belgian coast (southern North Sea). About 5,3 million tons (dry matter) of mainly fine-grained sediments is dredged annually in the port (15.000 TDS/day). The fluid mud inside the port has a mean layer thickness of up to 3m in front of the entrance of the Albert 2 dock (see Figure 4).

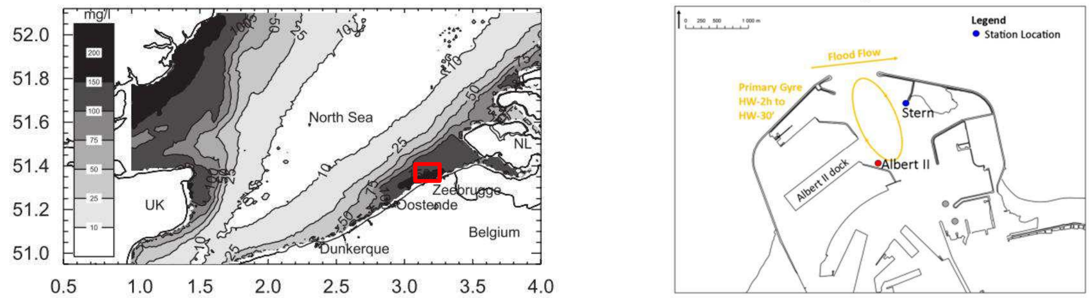

Figure 1 - Depth averaged SPM in Southern North Sea (left, Fettweis, 2007) and harbor of Zeebrugge (right)

Measurements at fixed locations inside the harbor
SPM concentration and current velocity were measured at four locations inside the harbor (see Figure 1) at two depths in the water column. Each measuring point was equipped with a point velocimeter (Aquadopp), an OBS3+ and a CT-probe (Valeport 620). The data were collected every 10 minutes for a measurement campaign lasting 400 days (March 2013 to April 2014).
The time series of SPM concentration are split-up into individual tidal cycles, and grouped according to neap, average and spring tide conditions in an ensemble analysis to study tidal dynamics.

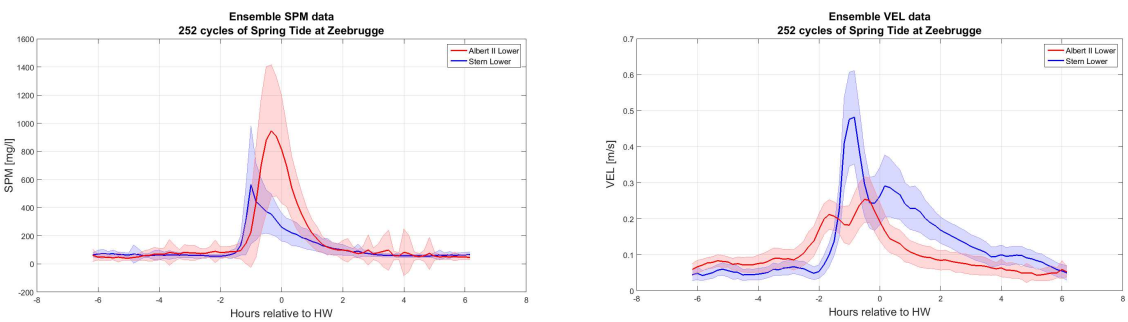

Figure 2 - Ensemble analysis of SPMC (left) and velocity data (right) for the lower set of sensors at locations Stern (in blue) and Albert II (in red) during spring tide conditions

Natural Evolution of the Top of the Mud Layer

The top of the mud layer is measured by the 210 kHz echo sounder reflector. A simple volume balance is set up to decompose the measured depth change Δh^m in the effect of dredging Δh^d and the natural evolution Δh^n.

$$\Delta h^m = \Delta h^n + \Delta h^d$$

$$\Delta h^d = -\frac{m^d(\rho_g - \rho_w)}{A\,\rho_g(\rho_b - \rho_w)}$$

The natural evolution Δh^n of the top of the mud layer corresponds to the cumulative effect of resuspension and consolidation (negative sign) and deposition (positive sign) and is calculated from daily depth soundings in Albert II dock (Figure 3).

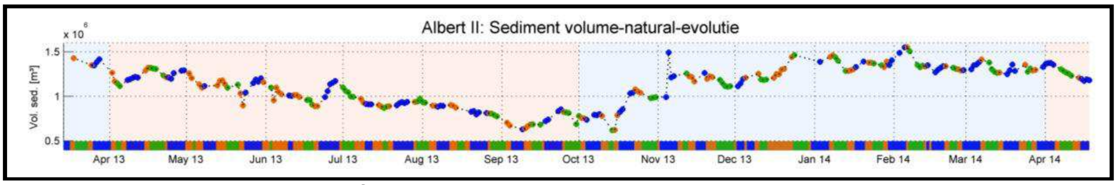

Figure 3 - Natural evolution of the mud volume in Albert II-dock during summer (red background) and winter (green background). Colored dots and (baseline) show tidal conditions: neap tide (green), average tide (orange) and spring tide (blue).

Results and Discussion

Intra-tidal variation

Both SPMC and velocity peaks at location Albert II are 50 minutes delayed to location Stern (Figure 2). The peak concentration at Albert II is higher than at Stern, even though the velocity is lower. This is explained by sediment being advected in the harbor and transported in a primary gyre, and settling out between locations Stern and Albert II. This is consistent with the analysis of Vanlede et al. (2014), who showed that horizontal transport is the most important component of the gross sediment exchange at the harbor mouth of Zeebrugge, and that most horizontal sediment exchange happens from 2h before high water to high water.

Spring-neap variation

Sediment import into the harbor during spring tide is 3 (2 to 4) times higher than during neap tide. This is consistent with the spring-neap variation of SPMC observed at a nearby station in the North Sea and with the spring-neap variation of peak SPMC observed inside the harbor.

Seasonal Variation

The mud volume in the Albert II dock is largest in winter, and reaches a minimum at the beginning of autumn (Figure 3). Density profiles also show that the sediment layers are less consolidated in winter than in summer. Figure 4 shows a striking seasonal pattern in the shape of the mud layer in the Albert II dock. Where the top of the mud layer is flat in winter, it shows a height difference of 1m (max. slope 1/400) in summer. The seasonal variations are believed to be linked to seasonal variations in the floc properties of the SPM (Fettweis & Baeye, 2015) that might influence consolidation and strength properties of the bed.

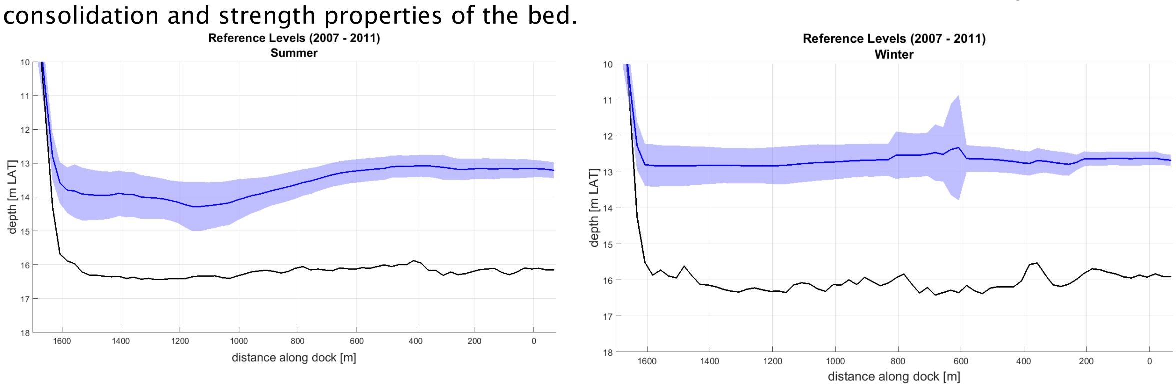

Figure 4 - Seasonal variation of levels in Albert II dock. 210 kHz level (and 1σ) in blue for summer (left) and winter (right). 33 kHz in black.

References

Fettweis, M., Baeye, M., 2015. Seasonal variation in concentration, size and settling velocity of muddy marine flocs in the benthic boundary layer. *J. Geophys. Res.* 120, 5648–5667. doi: 10.1002/2014JC010644

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