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Mud-induced periodic stratification in the hyperconcentrated Ems estuary

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Feedback of stratification on the flow is widely acknowledged to play a significant role in estuarine sediment transport. Recently, attention was drawn to the influence of sediment-induced horizontal density gradients on the location of the estuarine turbidity zone and, in general, on subtidal dynamics in hyper-concentrated estuaries. By contrast to the increasing number of modelling studies, few experimental results were published regarding the actual vertical structure of the water column, or the intratidal dynamics of high concentration layers, such as fluid mud. In this study, we measured tidal variations of stratification due to suspended sediments in the center of the turbidity zone of the Ems estuary, North Sea. The suspended sediment concentration profile was controlled by strong vertical gradients, first, a lutocline on top of a mobile mud layer, and second, an interface that separated the mobile mud from a higher concentrated, stationary mud layer below (> 50 g/l). Entrainment of the mobile mud layer was observed at the beginning of the flood tide. Re-formation of the mobile mud layer occurred at an unexpectedly early stage during flood. This is interpreted to result from super-saturated conditions after entrainment. The exceptionally high concentration of suspended sediments was not sustained during stagnating flow, and the settling flux was increased, inducing a collapse of the vertical concentration profile. Subsequently, the flow was decoupled between the upper and the lower layer and separated by the lutocline approximately in the middle of the water column. Remarkably, the flow was flood directed in the upper layer, while velocities in the lower, mobile mud layer were ebb directed. The mobile mud layer remained unaffected by entrainment for a period of 4.5 h around high water and moved in ebb direction, with a peak velocity of 0.12 m/s. This ebb directed turbidity current is seen as the combined effect of the downstream concentration gradient and the downstream bottom slope, probably supported by low friction between the stationary mud layer and the mobile mud layer. During the collapse of the concentration profile, the region of highest velocity shear shifted vertically from the fluid mud surface to a location above the lutocline. In addition, significant flow deceleration was observed in the lower part of the water column, over the vertical extent of the mobile mud layer before the flow reversal. This indicates a situation of forced convection, driven by the rapid change of the vertical distribution of the horizontal pressure gradient, as induced by the re-formation of the mobile mud layer. Periodically causing flow reversal near the bed, at an early stage during flood, this mud-induced stratification acts against upstream tidal pumping of sediments. In hyperconcentrated estuaries, mud-induced periodic stratification is consequently considered to play an important role in the estuarine circulation.