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The dynamics of bi-directional exchange flows: implication for morphodynamic change within estuaries and sea straits

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Uni or bi-directional flows develop in submerged channels, such as sea straits and estuaries, when two water masses with different densities meet. Earth rotation can affect the flow dynamics by introducing a geostrophic adjustment of the internal fluid flow, with resulting cross channel variations in velocity and density profiles, and by inducing secondary flows. Furthermore, in erodible channels, the interaction of the denser bottom water layer and the sediment bed can alter the channel bed topography with an associated feedback to the flow structure. Due to the complexity of these global rotational effects, the behavior of bi-directional stratified flows within topographically constrained channels warrants further investigation. To this aim, several laboratory experiments have been conducted to determine the effects of both rotation and an erodible bottom boundary on the lateral distribution of density and velocity in the counter-flowing water masses.

The experiments were performed in a trapezoidal cross-section channel in the CNRS Coriolis rotating platform at LEGI Grenoble during a recent Hydralab+ project. Different parametric conditions are considered, by varying both the upper fresh water volume fluxes and the channel rotation rates. The experiments were performed first with a fixed impermeable bed and then repeated over an erodible sediment bed layer. Detailed 2D velocity fields were measured by Particle Image Velocimetry in different vertical planes spanning the width of the channel and high-resolution density profiles are obtained by micro-conductivity probes. Moreover, a laser bed scanning technique was developed and applied to measure changes of the bed morphology due to the evolving bi-directional exchange flows.

The results presented herein consider the exchange flow dynamics at the interface, with particular focus on the observed lateral variations in layer thicknesses and cross-channel pycnocline tilt. As the rotation rate increases, the tilt of the interface between lower salty and upper fresh water flow increases, generating a meandering pattern within the salty layer along the trapezoidal channel. The variations in bi-directional flow distribution across the channel and secondary flow circulations generated in the fixed trapezoidal channels under both rotating and non-rotating conditions, are also presented and discussed. Finally, the exchange flow processes are coupled with the measured bed deformations to discuss the key drivers of morphodynamic change within the erodible channel.