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Adduce, Claudia; De Falco, Maria Chiara; Cuthbertson, Alan; Laanearu, Janek; Malcangio, Daniela; Kaur, Katrin

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The dynamics of bi-directional exchange flows

Claudia ADDUCE[1], Maria Chiara DE FALCO[1], Alan CUTHBERTSON[2], Janek LAANEARU[3], Daniela MALCANGIO[4], Katrin KAUR[3], Eletta NEGRETTI[5], Joel SOMMERIA[5]

[1] Roma Tre University, Italy
email: claudia.adduce@uniroma3.it, mariachiara.defalco@uniroma3.it

[2]University of Dundee, UK
email: a.j.s.cuthbertson@dundee.ac.uk

[3] Tallinn University of Technology, Estonia
email: janek.laanearu@taltech.ee, katrin.kaur@taltech.ee

[4] Polytechnic University of Bari
email: daniela.malcangio@poliba.it

[5] Laboratory of Geophysical and Industrial Flows, France
email: eletta.negretti@legi.cnrs.fr, Joel.sommeria@legi.cnrs.fr

ABSTRACT

Laboratory experiments on uni and bi-directional exchange flows have been conducted at the CNRS Coriolis Rotating Platform at LEGI. Both rotating and non-rotating experiments were performed in a trapezoidal cross section channel and different configurations were considered by varying both the upper fresh water volume fluxes and the channel rotation rates. Detailed 2D velocity fields were measured by Particle Image Velocimetry in different vertical planes spanning the width of the channel. Results show that 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.

1. Introduction

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 (Cossu et al., 2010; Cuthbertson et al. 2011; Maxworthy, 1985). Additionally, the nature of these buoyancy-driven flows depends on strong topographic controls imposed by seafloor bathymetry and channel shape, playing a significant role in flow dynamics (Laanearu et al., 2014, Valle-Levinson et al., 2003). In the present study, the behavior of uni-directional gravity currents and bi-directional exchange flows along a trapezoidal-shaped channel is investigated to determine the relative influence of the channel geometry and Coriolis forces on the lateral distribution of the (counter-) flowing water masses. The experimental apparatus and the exchange flow dynamics at the interface, with particular focus on the observed lateral variations in cross-channel dense interface are discussed.

2. Experimental Apparatus

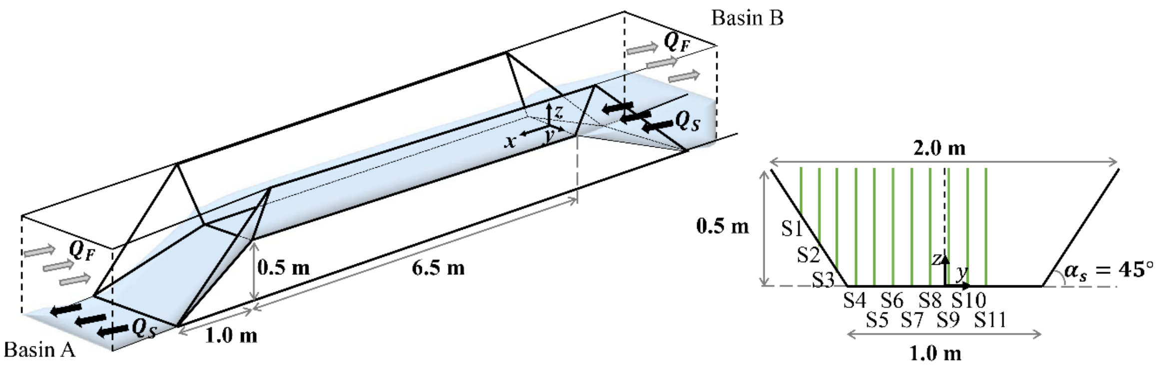

Fig. 1. Schematic representation of the trapezoidal cross section channel placed in the Coriolis Rotating Platform.

The experiments were conducted in the CNRS Coriolis Rotating Platform a 13 m in diameter and 1.2 m deep circular tank with a rotation period that can be set between 30 and 1000 s. Uni and bi-directional exchange flows of a saline solution and fresh water were reproduced in a trapezoidal cross section channel in transparent Plexiglas, 6.5 m long placed in the center of the platform (Figure 1). The channel had a 2.0 m top and 1.0 m bottom width and a total depth of 0.5 m with side slopes of α_s=45°. Two slopes with α_b=26.57° connected the channel to the inlet basin (B), representing the saline water basin and the outlet basin (A) representing the fresh water basin. The circular tank was filled with fresh water at initial density ρ_F to a total water depth H=0.9 m, in order to have in the channel the submergence depth H_{ch}=0.4 m, while the saline outflow at density ρ_S was realized by filling up slowly basin B until to reach the top edge of the entry slope. A constant saline water discharge Q_S=4.4 l/s, was then fed into basin B to establish a stable, uni-directional flow along the trapezoidal channel. To generate a bi-directional exchange flow, two water pumps in the upper part of Basin B were employed to provide a constant fresh water flux Q_F, which was increased over a range of values (Q_F=0,8,20 l/s, i.e. $q^*= Q_F/Q_S$=0, 1.8, 4.5). The rotation of the Coriolis Platform was varied with four angular velocities Ω tested (i.e. Ω= 0,0.05,0.1,0.2 rad/s). Two-dimensional Particle Image Velocimetry (PIV) was used to obtained high temporal and spatial resolution velocity fields across the channel, within a central 1 m-long section of the 6.5 m long trapezoidal channel. In particular the velocity fields were acquired in 11 vertical sections (XZ) at lateral positions ranging between -79.2 cm < y < 20.8 cm (Figure 1), with spatial intervals of 10 cm.

3. Results and Conclusions

PIV measurements were used to obtain detailed information on the spatial flow structure of the upper and lower layers across the channel. In particular, the cross channel variation in the u= 0 cm/s interface elevation is shown in Figure 2 in the measured PIV sections for the three q^* values tested.

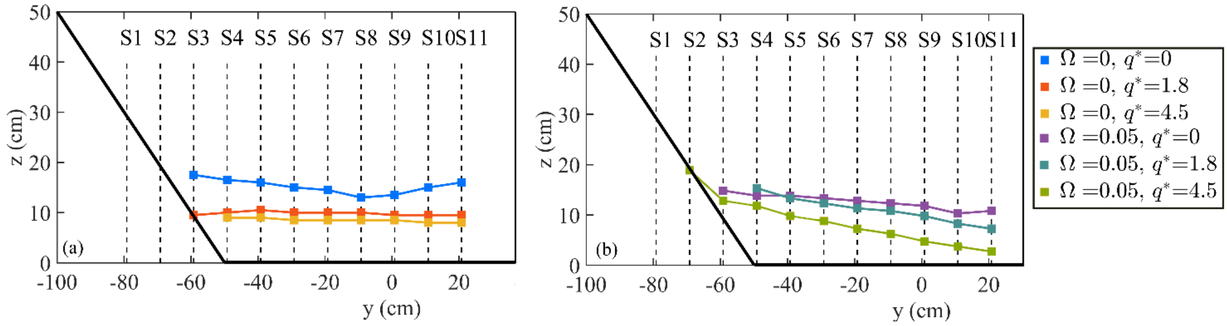

Fig. 2. Cross channel u=0 cm/s velocity interface, for different q* and angular velocity (a) Ω=0 rad/s and (b) Ω=0.05 rad/s.

The non-rotating experiments (Figure 2a) are compared with the experiments with an angular velocity Ω=0.05 rad/s (Figure 2b). In particular, for Ω=0 rad/s, the increasing upper fresh water flow (i.e. increasing q^*) causes the reduction of the lower layer thickness (Figure 2a) defined by u=0 cm/s interface. Whereas, when the angular rotation Ω plays a key role in the counter-flowing water masses (i.e. for Ω =0.05 rad/s, Figure 2b), a tilt in the interface is observed and is coupled with the effect of the increasing q^*, causing a significant deflection of the saline outflow on the right hand side of the trapezoidal channel. In conclusion, the rotation causes the deflection of the current to the right hand side of the trapezoidal channel. As the angular velocity increases, the inclination of the interface between the upper fresh and the lower saline layers increases and a thicker dense current is observed on the sloping sidewall of the channel. In the rotating bi-directional exchange flows, the coupled effect of an increase of both rotation and upper fresh water flow enhances the tilt of the interface up to generate a meandering pattern in the trapezoidal channel.

Acknowledgements

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