

INSTABILITY OF GRAVITY DRIVEN COASTAL CURRENT IN A TURNTABLE EXPERIMENT

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Summary The instability of a current driven by gravity and maintained along a vertical lateral wall by the Coriolis force is investigated in laboratory experiments, performed in the large Coriolis turntable (Grenoble). The current floats over a homogeneous denser layer. It represents for instance the Algerian current, made of the light Atlantic water entering the Mediterranean Sea. This current is unstable, generating meanders and vortices. This is classically attributed to baroclinic instability, but in our case this is forbidden by the absence of potential vorticity gradient in the lower layer. However we find that the instability of the viscous boundary layer initiates the process: the wall vorticity rolls up into vortices, which then interact with the main current potential vorticity as propagating dipoles, mimicking the usual process of baroclinic instability.

INTRODUCTION

Coastal currents are commonly produced by gravity, and maintained along the coast by the Coriolis force. For instance the Atlantic water entering the Mediterranean Sea forms the Algerian current, remaining at the surface by its low density (salinity). Such boundary currents generally become unstable, producing meanders and detachment of vortices away from the coast (see figure 1). Eventually, these instabilities control the horizontal mixing of the current. They play therefore a major role in the distribution of the biogeochemical components and their transfer between different basins.

Boundary currents have been reproduced in various laboratory experiments. They can be obtained by the geostrophic adjustment of a constant volume of light fluid floating on a heavier homogeneous layer. Griffith and Linden ([1]) initially contained a light water ring between two concentric cylinders. The current was rotating around the inner cylinder after the outer cylinder was lifted. In other experiments, the flow is produced by a constant flux of light fluid from a confined source near the free surface. The heavier homogeneous layer is initially at rest in the rotating frame of reference. Obaton et al. ([2]) have studied similar process at higher Reynolds numbers, using the large “Coriolis” rotating platform in Grenoble. We here reproduce some of these experiments, providing a detailed measurement of velocity fields by Particle Imaging Velocimetry (PIV) at different vertical levels. The potential vorticity profiles can be derived from these measurements, leading to a better analysis of the instability process.

The simplest theoretical interpretation of boundary current instability is provided by the classical quasi-geostrophic model of Phillips (1954), considering two layers with uniform velocity. In this model of baroclinic instability, the potential vorticity has a uniform transverse gradient, with opposite sign in each layer. More generally, a necessary condition for instability in quasi-geostrophic models is that the transverse gradient of potential vorticity changes sign somewhere in the flow (Charney & Stern, 1962). This is appropriate for the constant volume case, as potential vorticity anomalies of opposite sign is set in each layer by the initial interface displacement.

However in the constant flux experiments, the lower layer is initially at rest with undisturbed interface, so its potential vorticity is uniform, at least in an initial stage, before the influence of viscous effects. Therefore the usual baroclinic instability is forbidden. This is confirmed by two-layer models beyond the quasi-geostrophic approximation [3] Indeed Obaton et al. ([2]) noticed that the instability first appears in the thin shear layer along the wall, and the baroclinic instability only develop at a later stage, which can be much delayed in time. Our velocity measurements in both layers confirm and clarify such a two-stage process.

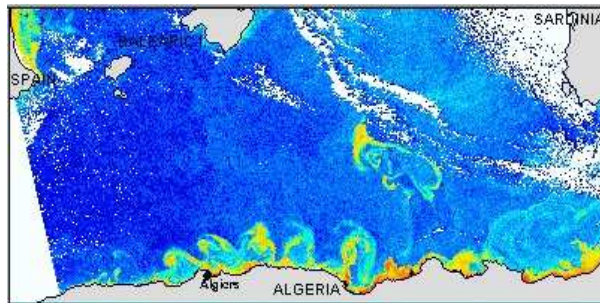


Figure 1. The Algerian current visualized by sea surface temperature: the formation of meanders and vortices is clearly seen along the algerian coast

EXPERIMENTAL SYSTEM

The experiments have been performed in the “Coriolis” rotating tank (LEGI, France), 13 m in diameter. The boundary current is produced along a straight wall on a diameter of the tank.

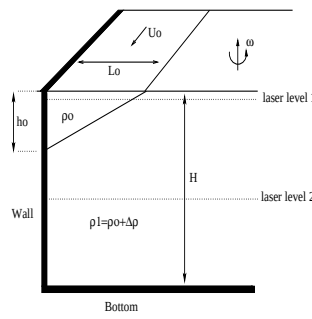


Figure 2. Sketch of the boundary current in the experiments

Initially, an homogeneous water layer, with thickness $H=60$ cm is at rest in the tank. The rotation period is set to $T=50$ s. A steady flow rate Q_0 is imposed, starting at an initial time $t=0$. The density ρ_1 and ρ_0 , respectively in the lower and upper layers, are controlled by salinity. We define $g' = g \frac{\rho_1 - \rho_0}{\rho_1}$ the reduced gravity. The flow is introduced by an injector with a triangular cross section. The height and width of this triangle are adjusted to initiate a geostrophically balanced current. Measurements of horizontal velocity fields have been realized by PIV (Particle Imaging Velocimetry), using a laser sheet illumination at two different levels (1cm and 21 cm from the surface) in a 2.5m x 2.5m domain. The first level provides the velocity field in the upper layer, while the second one remains always inside the lower layer. Density profiles are obtained using translating conductivity probes.

RESULTS

In a first stage, a quasi-parallel boundary current is produced, behind a current head with sharp interface. A weak counter-current is also produced in the lower layer, due to the compression of the material lines, vertically displaced under the upper current. We have checked that this counter-current has a uniform potential vorticity, except in a viscous boundary layer near the vertical wall, 1 cm thick.

As the first stage of the instability process, this thin vorticity layer rolls up forming a chain of small vortices near the wall in the lower layer. In a second stage, these vortices induce transverse displacements in the main current, resulting in vorticity anomalies. Thus vortex pairs are formed, coupling a cyclonic vortex in the lower layer with an anticyclonic vortex with components in both layers. Such vortex pairs (heton) tend to propagate outward, resulting in the development of a jet meander. Experimental vorticity fields showing this process are shown in figure 3.

CONCLUSIONS

In conclusion the jet instability is initiated in the viscous boundary layer: the wall vorticity concentrates into vortices, which then interact with the main current potential vorticity as propagating dipoles. This nonlinear stage mimicks the usual process of baroclinic instability, forbidden here by the uniform potential vorticity in the lower layer. For oceanic modelling, a proper representation of this meander initiation therefore requires a good resolution of the viscous boundary layer. Further studies should analyse the complex meandering jet developing after the initial instability.

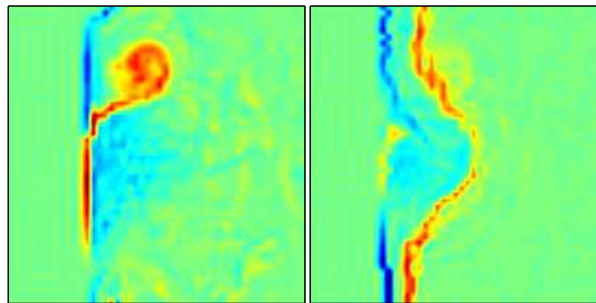


Figure 3. vorticity field at $t=27$ tank periods;(a) in the lower layer (b) in the upper layer (cyclonic vorticity is in red, anticyclonic in blue)

References

- [1] Griffith R.W., Linden : *Dyn. Atmos. Ocean* 5:281-306, 1981.
- [2] Obaton D., Millot C., Chabert d'Hières G., Taupier-Letage, I.: *Deep Sea Res.* **1** 47:2159-2190.
- [3] Killworth P.D., Paldor N., Stern M.E.: *J. Marine Res.* **42**:761-785.