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# MODELING HORIZONTAL COASTAL FLOW MIXING: ASSESSING THE ROLE OF VISCOUS CONTRIBUTIONS.

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### Abstract

Horizontal mixing of shallow coastal flows is studied with specific focus on the role played by large-scale horizontal eddies (macrovortices). Description of macrovortex-induced mixing is given on the basis of numerical solutions of the Nonlinear Shallow Water Equation (NSWE) and sensitivity of the results on viscous-type dissipations is analyzed. This is the first step to determine a suitable framework for Horizontal Large Eddy Simulations (HLES) computations of coastal flows performed by means of depth-averaged NSWE. Statistics of mixing, rather than inspection of the velocity spectra, are used to assess the value of the chosen viscous closure.

## 1 THE PROBLEM

An analysis of macrovortices, based on the depth-averaged NSWE, is proposed and large-scale features of shallow-water turbulence which characterize the flows of near-shore waters are studied. The latters evolve as shallow-water flows and their generation can be seen as due to lateral gradients of shock-type solutions. Computations have been used to describe the evolution of macrovortices generated by topographic forcings in coastal waters, where macrovortices are seen to propagate under the action of self-advection (interaction with the topography), mutual-advection (interaction with other vortices) and interaction with the background flows. Depending on the relative strength of these mechanisms the macrovortices may either propagate towards the shoreline or towards the offshore [1]. Since in a shallow turbulent flow, characterized by large-scale coherent structures, the evolution of tracers and the flow dynamics are so intimately connected that knowledge of the former may give a predictive key for the latter, and, obviously, viceversa, mixing properties of these flows can be used to assess dynamic features of predictive models. Analysis of experimental data of coastal mixing have revealed that typical regimes of 2D turbulence, i.e. enstrophy cascading and turbulence shearing, also characterize the flow induced by submerged breakwaters. Enstrophy cascading is seen to dominate the flow induced by one single structure while rip currents shearing dominates the flow due to arrays of breakwaters [2].

Research is underway to determine a suitable framework for HLES-type computations of coastal flows performed by means of depth-averaged NSWE. The problem, as described by Lesieur [3], is that of modeling a flow which is quasi-2D in the large scales and 3D in the small scales. It is then sensible to assume that the effects of small-scale or sub-grid scale motions on larger scale motions can be accounted for in terms of mass/momentum diffusion more or less heuristically defined and depending on eddy mixing coefficients whose size is many orders of magnitude larger than the molecular values. Much research is being devoted to defining the most suitable form of the diffusive term to be included, for example, in the momentum equation. In general such term is written as $\nu_T(\nabla^2)^n\mathbf{v}$ in which $\nu_T$ is an effective eddy viscosity and $n$ an integer coefficient of order 1. In recent applications of NSWE/HLES models to coastal flows, the choice $n = 1$ is typically made and Laplacian-type operators are most often used in conjunction with algebraic closures for the eddy viscosity.

To evaluate suitability of such an approach and, eventually, to devise alternative strategies, we are analysing the fundamental requirements the diffusive term should obey to. For the sake of simplicity we start with the simplest parameterization, i.e. Laplacian viscous diffusion with constant $\nu_T$ and we are currently evaluating the properties of numerical solutions for which experimental properties of mixing are known [4] as function of $\nu_T$. Comparison in terms of absolute and relative statistics of tracers leads to definition of the most appropriate value of $\nu_T$.

## 2 A SENSITIVITY ANALYSIS FOR $\nu_T$

The benchmark flow for the analysis is that described in [2] and whose bathymetry is illustrated in figure 1, while the solver at hand is that described in [4] and based on the second-order accurate WAF method [5] where intercell fluxes are evaluated by means of an exact Riemann solver which allows, at a limited computational cost, for a very accurate description of the solution.

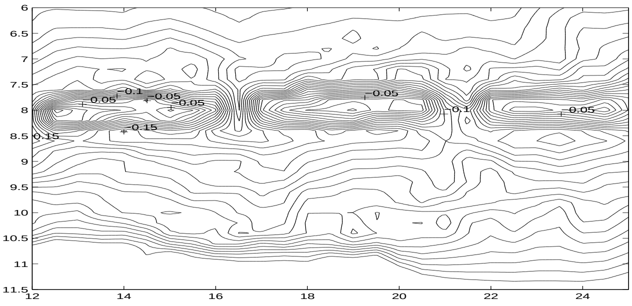

Figure 1: Bathymetry of the benchmark flow.

The mentioned solver has been extended to include the diffusive-type contribution $\nu_t \nabla^2 \mathbf{v}$ by means of a simple explicit scheme and computations run with the flow conditions described in [2] and $\nu_T$ varying in the range $(0 - 10^{-2})\mathrm{m}^2/\mathrm{s}$.

Comparison of the numerical solutions with the benchmark flow has been made in terms of absolute (i.e. absolute diffusivity $K^{(1)}$ of figure 2) and relative (i.e. relative diffusivity $K^{(2)}$ of figure 3) statistics of mixing. To reproduce at best the experimental statistics the initial distribution of the floaters has been chosen to coincide with that used in the experiments (experimental floaters). However this choice, characterized by a relatively small number of particles ($10 \leq N_p \leq 25$), provides noisier statistics than those obtained with a random distribution of $N_p = 64$ particles (random floaters).

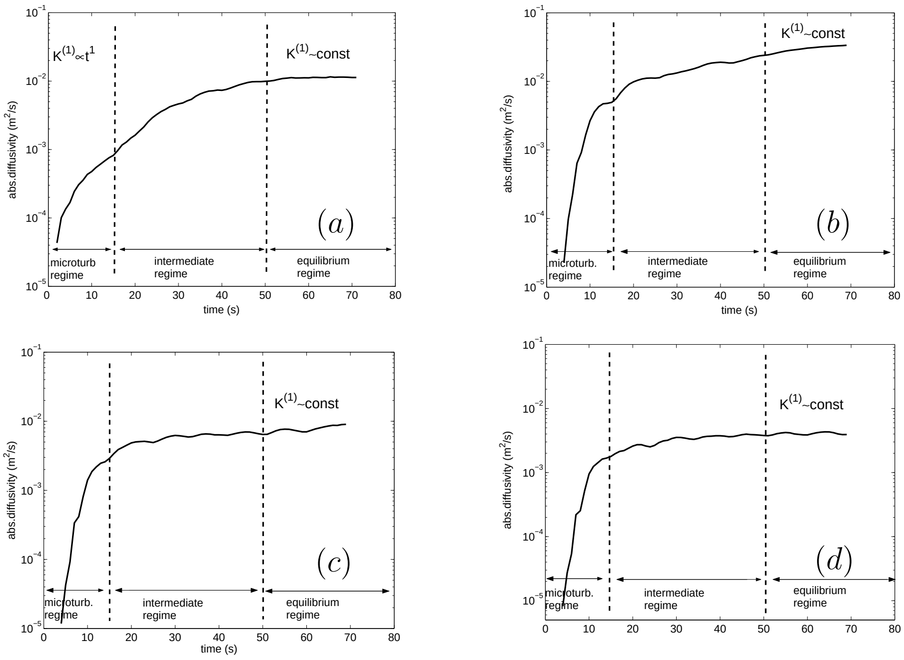

Figure 2: Computation with experimental floaters of the absolute diffusivity for a rip-current configuration: (a) experimental data, (b) numerical solution for $\nu_T$=$10^{-3}$m²/s, (c) numerical solution for $\nu_T$=$5{\times}10^{-3}$m²/s, (d) numerical solution for $\nu_T$=$10^{-2}$m²/s.

Figure 2 shows that $K^{(1)}$ predicted by the numerical computations decreases with increasing $\nu_T$ (trend predicted also using random floaters), overestimates the experimental one for $\nu_T$>$10^{-3}$m²/s, converges to such value for $\nu_T \approx 5 \times 10^{-3}$m²/s while an underestimate is obtained for $\nu_T = 10^{-2}$m²/s which, thus, represents an upper bound for the viscosity. The patterns of $K^{(2)}$ also show an improvement with increasing $\nu_T$.

A detailed analysis is underway to define the most suitable value for $\nu_T$ and evaluate eventual dependencies on the flow characteristics (single vs. array of breakwaters).

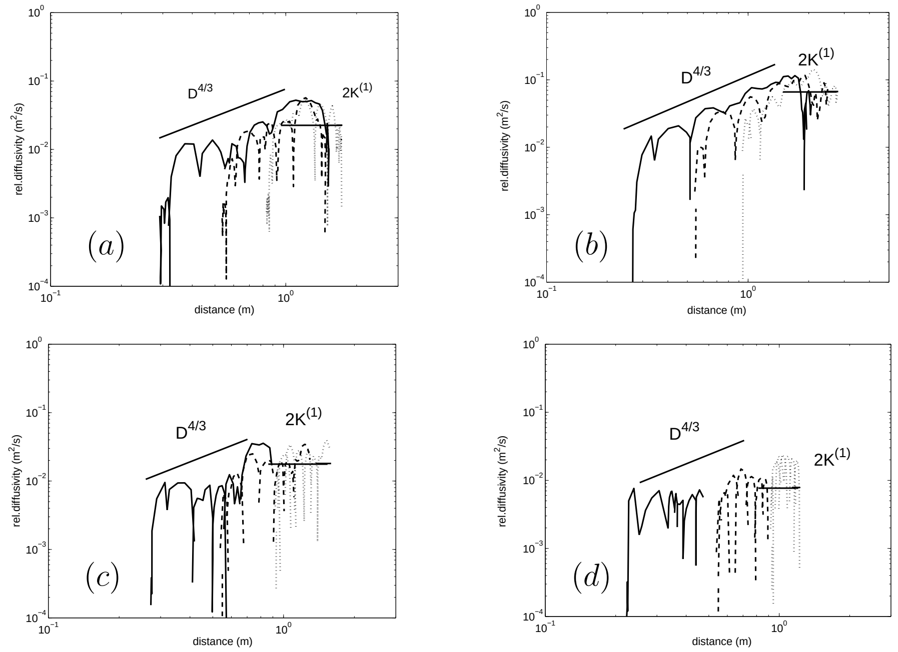

Figure 3: Computation with experimental floaters of the relative diffusivity for a rip-current configuration: (a) experimental data, (b) numerical solution for $\nu_T{=}10^{-3}$m$^2$/s, (c) numerical solution for $\nu_T{=}5{\times}10^{-3}$m$^2$/s, (d) numerical solution for $\nu_T{=}10^{-2}$m$^2$/s.

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