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Turbulent mixing in shallow water basin; parameterization of vertical turbulent exchange coefficient

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Résumé :

La paramétrisation du coefficient d'échange turbulent vertical joue un rôle important dans l'hydrodynamique d'un bassin en eau peu profonde. Les paramètres pertinents sont déterminés sur la base d'expériences d'ADCP. Ils sont mis en œuvre dans le package Azov3D développé au TIT-Russie. Ils sont utilisés pour déterminer les courants dans deux bassins en eau peu profonde: Etang de Berre et étang de Bolmon. Les comparaisons sont effectuées avec les courants calculés à l'aide d'un autre package (MARS3D).

Abstract :

Parameterization of coefficient of vertical turbulent exchange plays an important role in the hydrodynamics of shallow water basin. Relevant parameters are determined on the basis of ADCP experiments. They are implemented in Azov3D package developed at TIT-Russia. They are used to determine the currents in two shallow water basins: Etang de Berre and Etang de Bolmon. Computed currents are compared with those obtained by using another package (MARS3D).

keywords: shallow water hydrodynamics, small-scale turbulence

1. Introduction

Turbulence is an important mechanism in the mixing of heat, salt, momentum and suspended and dissolved matter in the coastal zone. Turbulent fluxes of material occur as a result of correlated, small-scale fluctuations in current velocity and the transported quantity itself. In the coastal zone, mean shear is typically generated by winds and/or tides, but also by surface waves and baroclinic flows. In deep water, the friction has a smaller effect on the tides, as compared with the deflection force of rotation of the Earth, while for shallow water the bottom friction is important and has to be accounting for. Here, we are mainly interested by shallow water basins which can be roughly characterized by the condition [1]: $kh < 1$ ($2\pi h < \lambda$), where k - wave number of the wave, h - height of the water column, λ - wave length.

There exist three main layers in the vertical structure of water column: bottom boundary layer (BBL), surface boundary layer (SBL) and intermediate current zone. Bottom boundary layer (BBL) spans the vertical distance between the no-slip bottom boundary condition and outer, free stream motion. The height of the boundary layer is related to the magnitude of the free-stream velocity, bottom roughness and the time available for boundary layer development. Surface boundary layer (SBL) is a part of the sea that directly exposed to the atmosphere, through which atmospheric properties are transmitted into the water interior. Near-surface turbulence creates a mixed layer immediately below the surface, in which quantities such as temperature and dissolved and particulate material are relatively uniform in the vertical. Between surface and

bottom boundary layers an intermediate current zone is situated. In the deep water all layers are separated, each one has different properties and different turbulent parametrizations [2].

In shallow water, the influence of surface waves may penetrate right to the bed and create a wave bottom boundary layer that can interact with the mean tidal (pressure-gradient-driven [2]. That is why we can't separate for every layer turbulent approximation, and have only one universal approach for determining effects of vertical turbulent exchange for all parts of water column.

Because of their statistical character, turbulent fluxes are difficult to be measured, and must usually be quantified by indirect strategies. Numerical models usually incorporate parameterizations for quantifying turbulent fluxes. The validity of these parameterizations is checked by their ability to reproduce certain observable turbulent behavior.

In modern numerical models, the coefficient of vertical turbulent exchange is often mentioned as a fitting parameter, a choice, which can be achieved fairly good agreement of the observations and numerical modelling. But its value is often chosen for reasons of computational stability of the account for long periods, and may, at the orders surpass him physically reasonable estimates for the real sea. There are various strategies for modeling turbulence, each of them resolving a different interval of the type of the flow dynamics: 1) Direct numerical simulation (DNS); 2) Large eddy simulation (LES); 3) Statistical turbulence modeling and 4) Empirical turbulence modeling [2,3]. Each one strategy has a good application for exact problem. We concentrated on the problem of parameterization of vertical exchange in shallow water reservoirs, where chaotic fluctuations of velocities in vertical direction are significant and define all hydrodynamic processes in the sea. Subgrid scale techniques (analog of LES) are designed for simulating the impact of turbulence and small-scale mixing on the larger scales with reasonable computer effort. These methods are based on the definition of turbulent flow as averaged in space or time (correlation) of products of deviations of flow velocity and portability of a physical quantity. For subgrid methods of assessment of characteristics of vertical turbulence, there is a problem which is associated with the need for large amounts of data in long and expensive *in situ* measurements.

The main difficulty is thus to determine an approach which will give us agreement between results of model simulations and experimental data measured in situ. The present work consists of two parts: (1) experimental part: the calculation of turbulence parameters using expedition data by different approaches and the choice of the approach which shall give more realistic results according to physics of the process; (2) simulation part: the computation of currents with the chosen approach to be included in the hydrodynamic model developed in TIT-Russia, and also the comparison of results with MARS3D developed by Ifremer. The computations of turbulence coefficients were performed in two shallow water basins: Etang de Berre, Etang de Bolmon.

2. Two approaches of parameterization of vertical turbulent exchange coefficient

Several subgrid scales and statistical approaches were used for calculation of the coefficient of vertical turbulent exchange in the water column, $\nu(z)$, in two adjacent shallow water basins: Etang de Berre and Etang de Bolmon. In this work we shall consider two approaches to determine $\nu(z)$:

1. The Monin [4] approach:

$$\nu(z) = \sqrt{\nu_{xz}(z)^2 + \nu_{yz}(z)^2}, \text{ where } \nu_{xz}(z) = -\frac{\overline{u'w'}}{\frac{\partial \overline{U}}{\partial z}} \text{ and } \nu_{yz}(z) = -\frac{\overline{v'w'}}{\frac{\partial \overline{V}}{\partial z}}$$

$\nu(z)$ - coefficient of turbulent exchange for the fixed point in the plane (x,y).

u', v', w' - velocity fluctuations, \bar{U}, \bar{V} - horizontal components of velocity averaged in time.

2. The Belotserkovsky [5] approach:

$$v(z) = (C\Delta z)^2 \left[\left(\frac{\partial \bar{U}}{\partial z} \right)^2 + \left(\frac{\partial \bar{V}}{\partial z} \right)^2 \right]^{1/2}, \text{ where } C=0.1-0.2$$

Both lagoons can be considered as shallow water basins, in particular near the coastline. For the deeper lagoon, Etang de Berre, the mean depth is about 6m, and the wavelength of the order of 10m [6].

3. Measurement in situ

In September 2006 and in July 2008, field campaigns took place in the two lagoons: Etang de Berre and Etang de Bolmon, separated by a sandspit (lido du Jaï). During these campaigns, the velocity fluctuations have been measured in some mooring points with an Acoustic Doppler Profiler (ADCP RDI 600Khz); see the scheme in Fig. 1.

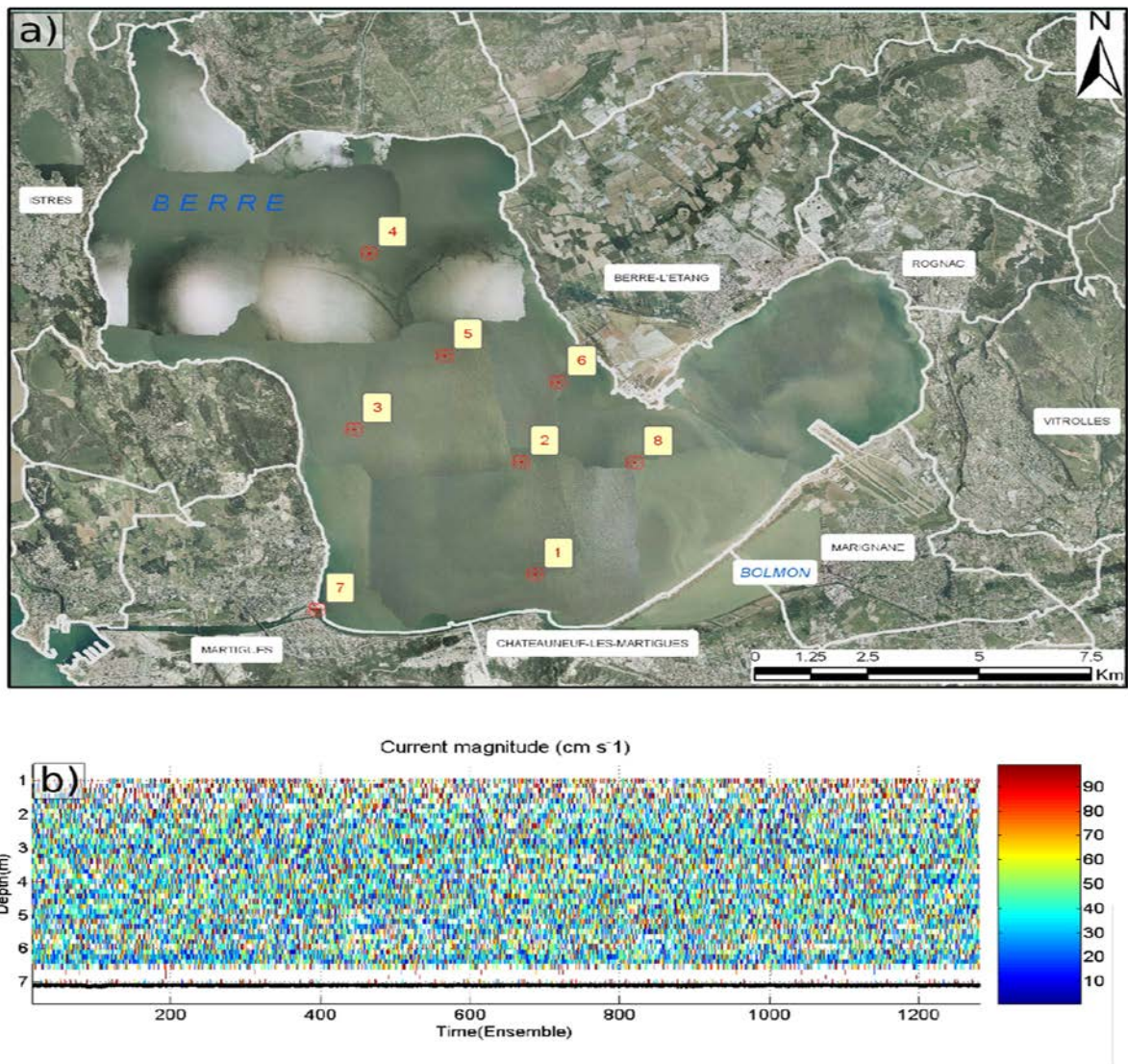


FIG.1. (a) Scheme of the field campaign in September 2006 in Etang de Berre;
 (b) Ensemble of measured current magnitude, at exact point, as a function of depth (vertical coordinate) and time (horizontal coordinate)

Computation of vertical turbulent coefficient was done on the basis of each approach using ADCP data; distributions coefficients of vertical turbulent exchange for two lagoons Berre and Bolmon were obtained. The analysis of the obtained distributions has shown that subgrid scale methods allow similar distributions (order of values and locations of points of maximum and minimum) of coefficient of a vertical turbulent exchange. However, the Belotserkovsky [5] method yields to the results which are the most physically relevant for shallow water bassins (the method 2 doesn't give strong increasing of coefficient value near the bottom layer).

4. Numerical simulation and comparison

The Belotserkovsky approach was included as a module for parameterization of the coefficients of vertical turbulent exchange in the software Azov3D [7-8] developed in the TIT SFU for modeling currents in shallow water bassins. In Fig. 2, the non-uniform vertical distributions of the coefficient of vertical turbulent exchange are shown; the numerical results obtained by using Azov3D package are compared with the ADCP experiments performed in Etang de Berre.

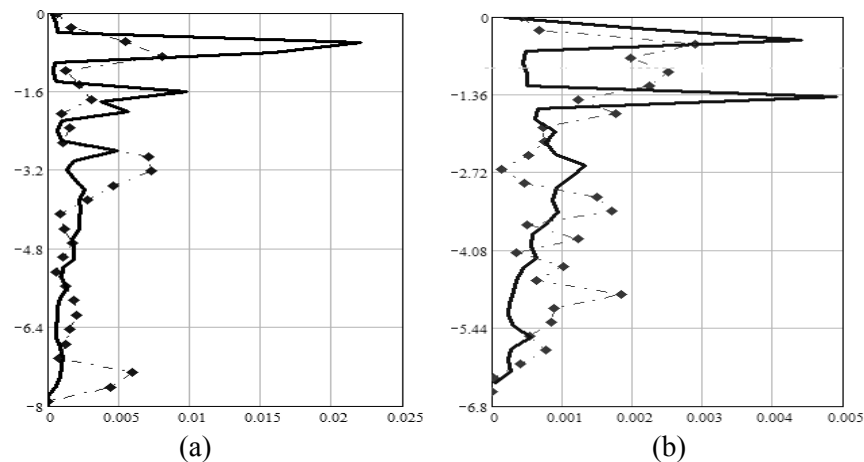


Fig.2. Coefficient of a vertical turbulent exchange on levels of depth (m^2/s), received using Azov3D numerical modeling (the Belotserkovsky [5] approach- continuous line) in comparison with data of field campaign (dashed line); (a) in station 3 and (b) in station 4 in Berre (see Fig. 1)

The idea was to implement the same boundary conditions and the same meteo data as in the field campaign of September 2006. In Fig. 3, barotropic currents calculated by Azov3D package [7-9] by using the Belotserkovsky parameterization are shown for a western wind of 5m/s.

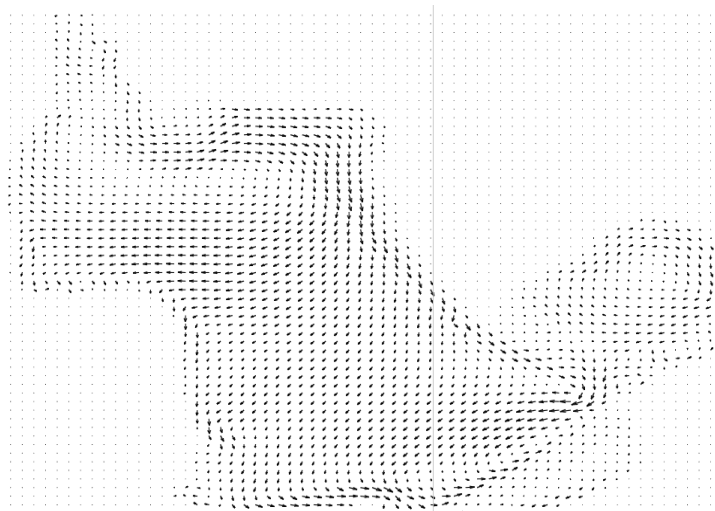


FIG.3 Barotropic currents for the western wind 5m/s. (meteorological data in September 2006)

Consider also the vector field obtained by well-known software MARS3D, developed in the Ifremer [10-12], and adopted to shallow water basins, like Etang de Berre and Etang de Bolmon. Also computations of currents were done using software MARS3D for different meteorological data (dominate winds and different inflows of fresh water in rivers and channels, different turbulent closures). For structure of currents in the lagoon Etang de Berre streams of fresh water and strong NW wind are significant and dominate during all year, so for the case with these parameters (NW wind 5 m/s and inflow of EDF channel 200 m³/s) we obtained stable currents (vortexes in the middle of the lagoon which are not changing in time after period of stabilization – 72 hours, see Fig. 4)

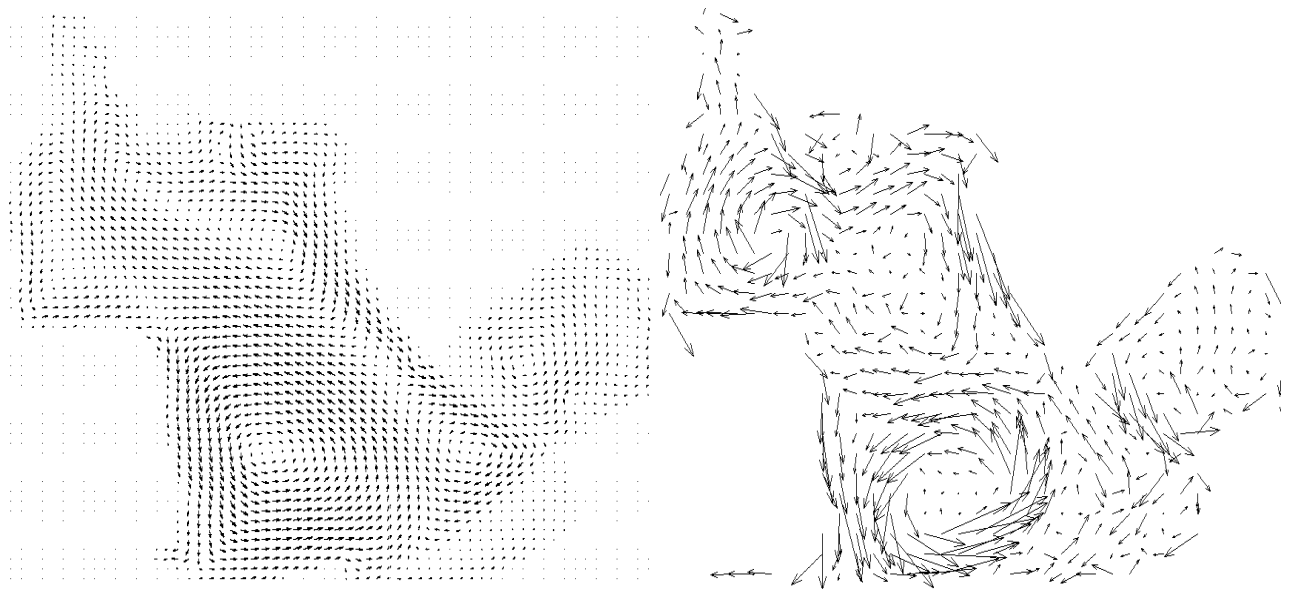


FIG.4 Barotropic vector fields of Azov3D(left picture) and Mars3D (right picture) 72 hours after the beginning of simulations; N-W wind of 5 m/s

5. Conclusions

An adequate parameterization of coefficient of vertical turbulent mixing is crucial for realistic simulations of hydrodynamics in shallow water basin. We have implemented the two most used methods in the hydrodynamic simulation models and found the Belotserkovsky method to be better appropriate in capturing the dynamics in lagoon of Etang de Berre.

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