Two-layer model for the numerical simulation of oil spills over coastal flows

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Abstract

A one-dimensional (1D) numerical model for the simulation of oil spills in coastal flows is studied. A two-layer eulerian model is implemented. The main advantage of this model is the capability of solving the evolution of the oil layer, computing the oil depth and the velocity field.

Introduction

The final extension of oil spills can be estimated empirically by analyzing separately the four acting forces: gravity, inertia, viscous stress and surface tension [1]. However, numerical methods improved oil spills behavior simulation by means of kinematics. Nowadays, the vast majority of models are based on Lagrangian methods focused on particle tracking algorithms to represent the oil slick [3]. There also exist some Eulerian models to solve the oil slick thickness and dynamics. However, they take the water column velocity field as an input [2]. In this work, a complete model for the simulation of oil spills over water is implemented by means of a particular two-layer shallow water model.

Methodology

Equations and numerical scheme

Figure 1 shows a layout of the simulated problem. The upper layer (1) represents oil slick, while lower layer (2) stands for the water column.

A complete model for the simulation of oil spills over water is implemented by means of a particular two-layer shallow water model. A 1D finite volume upwind scheme with a Roe solver is used to discretize the computational domain and carry out the simulation of the oil spills, solving both oil slick and water column.

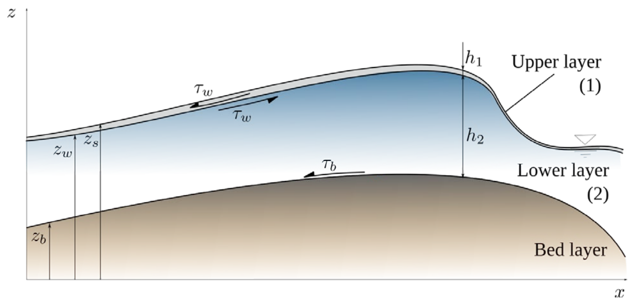

Figure 1. Scheme of the studied problem

By assuming a very thin layer of oil floating and being transported over a huge volume of water, the pressure term that the upper layer exerts over the lower layer can be neglected. However, friction terms between layer are considered so that the oil flows over a movable water volume being transported by friction stresses. The main advantage of this model is the capability of solving the evolution of the oil layer, computing the oil depth and the velocity field. Special emphasis is placed on the treatment of the two-layer wet-dry mechanisms following [4].

The system of equation is based on mass continuity and momentum conservation equation for both layer, as

$$\frac{\partial h_L}{\partial t} + \frac{\partial (h_L u_L)}{\partial x} = 0$$

$$\frac{\partial (h_L u_L)}{\partial t} + \frac{\partial}{\partial x}\left(h_L {u_L}^2 + \frac{1}{2} g {h_L}^2\right) = -g h_L \frac{\partial z_{bL}}{\partial x} + \frac{\tau_b}{\rho_2} \pm \frac{\tau_w}{\rho_L}$$

where L represents one of the layers (1 or 2), τ_b only acts on layer 2, standing for bottom stress, while τ_w acts in both layers representing the friction between them. The conserved variables h and hu represent depth and unit discharge, respectively and the bottom z_{bL} is only the solid bottom for layer 1, while is $(h_2 + z_{bL})$ for layer 1.

Model Application

The model is applied to common numerical test such as lake at rest with irregular bottom or dambreak to validate the model. Then, real cases that represent an eventual oil spill on the sea are computed to demonstrate the usefulness of the model.

Assuming a lake-at-rest condition on the lower layer, a very thin oil spot spreading is computed. The initial condition is performed by an oil column that produces a spill over the water.

The initial condition of the simulated test case can be seen in the upper picture of Figure 2 and is described in Table 1. A constant distribution of water depth can be seen, while a spot of oil is located in the middle of the domain. When the simulation starts, the oil column spreads over the water volume, provoking some perturbation on the water due to friction stresses, as pressure exerted by oil into water is neglected in this model.

Table 1. Initial layer characteristics

Layer	Density	Initial depth	Initial vel.
Oil	800 kg/m^3	1 m	0 m/s
Water	1000 kg/m^3	10 m	0 m/s

Figure 2 shows how the evolution of the oil slick at the beginning is pure inertial, provoking higher discharges, as reported by [1]. After that, the inertial spreading mechanism has a lower effect and the oil slick does not propagates far away. It is seen how the model deals with wet-dry fronts properly without generating numerical instabilities and providing logical results.

Conclusiones

A model for the simulation of oil spills over a water volume has been implemented by means of a two-layer shallow water system.

Traditional two-layer systems must include the pressure that upper layer exerts over the lower layer. However, this model is based on the hypotheses that the oil layer (upper) is always much thinner than the water layer (lower), so that term can be neglected on the equations. This does not provoke instabilities as seen on the results.

The lack of real data does not allow to calibrate the model. However, it is also important that the numerical scheme behaves properly with the typical numerical test cases.

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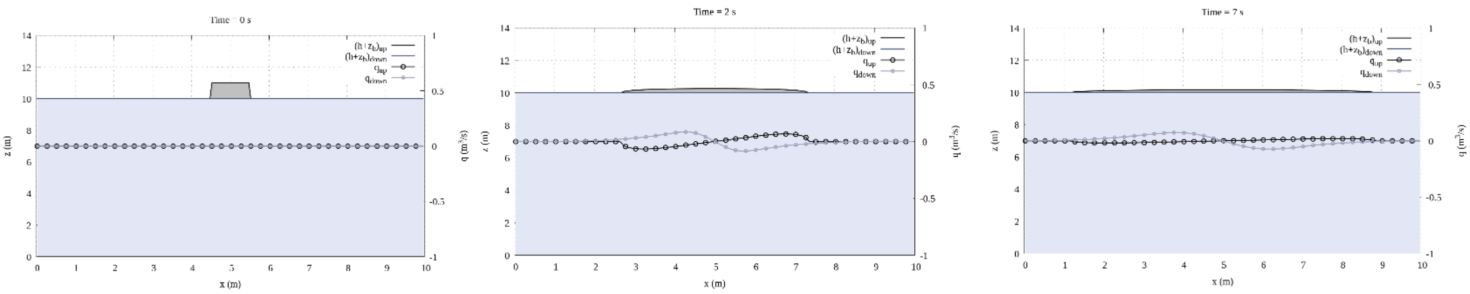

Figure 2. Spatial distribution of water column and oil depth and discharges for both layers for two different moments: t = 0 s (left picture), t = 2 s (middle picture) and t = 7 s (right picture).