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On topographic and wind vorticity effects in bora driven circulation in the North Adriatic

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The effects of the bottom topography and input of the atmospheric vorticity to the sea for the NE (bora) wind driven circulation in the North Adriatic was studied from the numerical solutions of the vertically integrated Ekman's equations. The numerical results for the vertically integrated current show that the effects of bottom topography and input of the atmospheric vorticity to the sea are of the same importance in the formation of the characteristic flow pattern and neither can be neglected.

Efekti topografije dna i vrtložnosti u polju vjetra za struje uzrokovane burom u sjevernom Jadranu

U radu je studiran značaj topografije dna i vrtložnosti u polju vjetra za struje uzrokovane NE vjetrom (bura) u području sjevernog Jadrana. Iz rezultata numeričkih rješenja vertikalno integriranih Ekmanovih jednadžbi pokazano je da ne možemo zanemariti ni jedan od dva navedena činioca.

1. Introduction

The input of the atmospheric vorticity to the sea was considered by Stravisi (1977) in the numerical solution for the NE (bora) wind driven circulation in the North Adriatic. The importance of the vorticity input was observed by Zore-Armanda and Gačić (in press) from the experimental results. The importance of bottom topography in formation of characteristic flow pattern for the NE (bora) wind driven currents in the North Adriatic was observed by Kuzmić at al. (1985) from numerical experiments. These two effects have not been compared to find which is more important, and the results of the numerical model for the vertically integrated current are used in this article for their comparison.

2. Methods

The basis of numerical modelling of flow pattern is the model of vertically integrated velocity (e. g. Nihoul et al., 1979, discussion of $2D + 1D$ type of three-dimensional model). Here the model of vertically integrated velocity was used to illustrate the importance of bottom topography and vorticity in the wind field in the evolution of characteristic flow pattern in the North Adriatic for the NE (bora) wind.

The hydrodynamic equations are

$$\frac{\partial u}{\partial t} - fv = -g\frac{\partial h}{\partial x} - \frac{c}{H}\sqrt{u^2 + v^2}\,u + \frac{T_x}{H} \tag{1}$$

$$\frac{\partial v}{\partial t} + fu = -g\frac{\partial h}{\partial y} - \frac{c}{H}\sqrt{u^2 + v^2}\,v + \frac{T_y}{H} \tag{2}$$

$$\frac{\partial h}{\partial t} + \frac{\partial Hu}{\partial x} + \frac{\partial Hv}{\partial y} = 0 \tag{3}$$

where t is the time, (x, y) are the spatial coordinates, (u, v) are vertically integrated velocity components, f is the Coriolis parameter, g is the acceleration of gravity, h is the sea level denivelation, (T_x, T_y) are the components of wind drift forcing, H is the bottom depth and c is the de Chezy friction constant.

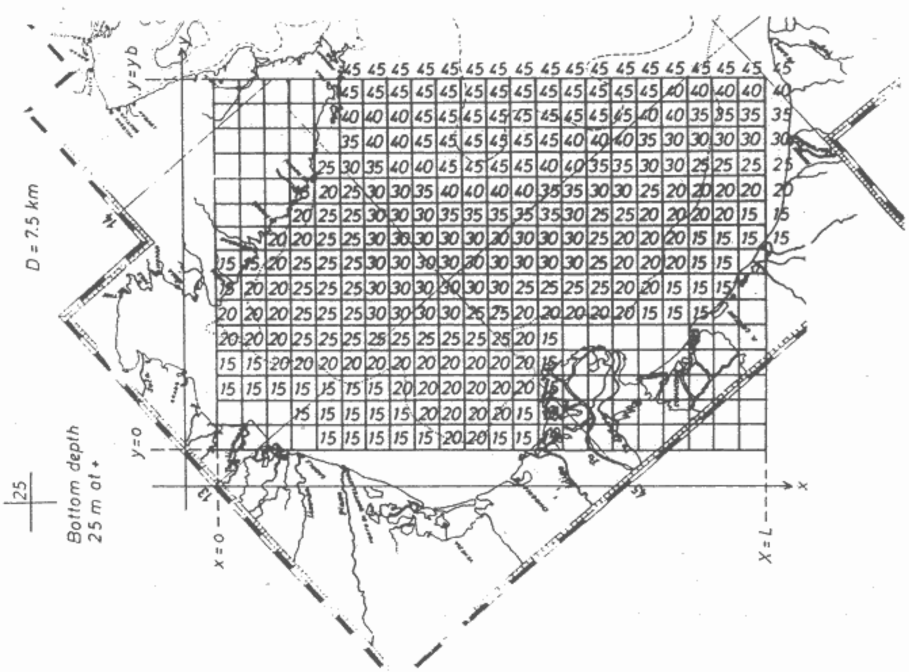

Figure 1. Domain of numerical integration, coordinate system and bottom topography.

The kinematic condition is assumed on the rigid boundary and the conservation of mass in the considered basin, i. e. the zero total mass transport through the open boundary, is assumed on the open boundary. In the case considered here where the output transport is defined by v velocity component (see Fig. 1) it is

$$\int_{x_o}^{x_o + D} H\, v\, dx = 0 \tag{4}$$

In the open boundary area ($x \epsilon [x_o, x_o + D]$ and $y \approx y_b$) some simplifications have to be made to allow the introduction of equation (4) in the model. For example Stravisi (1977) assumed $v \equiv 0$ on the open boundary line in order to introduce equation (4) in the model. Here the following assumptions are made:

$u\,(x = x_o, y = y_b) = u\,(x = x_o + D, y = y_b) = 0$ (from kinematic boundary conditions, see Fig. 1.), $H = H(y)$, $T_x = T_x(y)$, $T_y = T_y(y)$, bottom friction is linear, $\left.\frac{\partial h}{\partial x}\right|_{y=y_b}$ = const = $= [h\,(x = x_o + D, y = y_b) - h\,(x = x_o, y = y_b]/D$. By integrating the equations (1) – (3) from x_o to $x_o + D$ for $y = y_b$ and using equation (4) without restrictive assumptions in the boundary region it follows for the sea level denivelation on the open boundary line that

$$h\,(x, y = y_b) = (T_x - \frac{c_m T_y}{fH})\, \frac{x - x_o - D/2}{g H} \tag{5}$$

where c_m is linear bottom friction coefficient ($c_m = 3 \cdot 10^{-4}$ m/s).

The equations are numercally solved in C grid (according to Arakawa and Winninghoff) and leap-frog time scheme (e. g. Mesinger, 1976). An uniform network of grid points has been used, with a 7,5 km square mesh (Fig. 1.). The other parameters are: $g = 9{,}81$ M/s^2, $f = 10^{-4}$ 1/s and $c = 0.003$.

3. Results

In the case of flat bottom H = const = 30 m and homogeneous wind field from NE, the vertically integrated velocity components equal zero and the gradient force in the equations (1) – (2) is in equilibrium with the wind drift force.

The flow pattern for the homogeneous wind from NE (bora), T_x = 5 dyn cm/g, T_y = 0, with real bottom topography is given in Fig. 2. In this case the current field is well developed.

Fig. 3. presents the current field for assumed flat bottom H = 30 m and the NE wind (bora) having the vorticity: $T_x = \alpha\,[1 + (\frac{2y - y_b}{y_b})^2]$, α = 5 dyn cm/g, T_y = 0. There is a well developed current field.

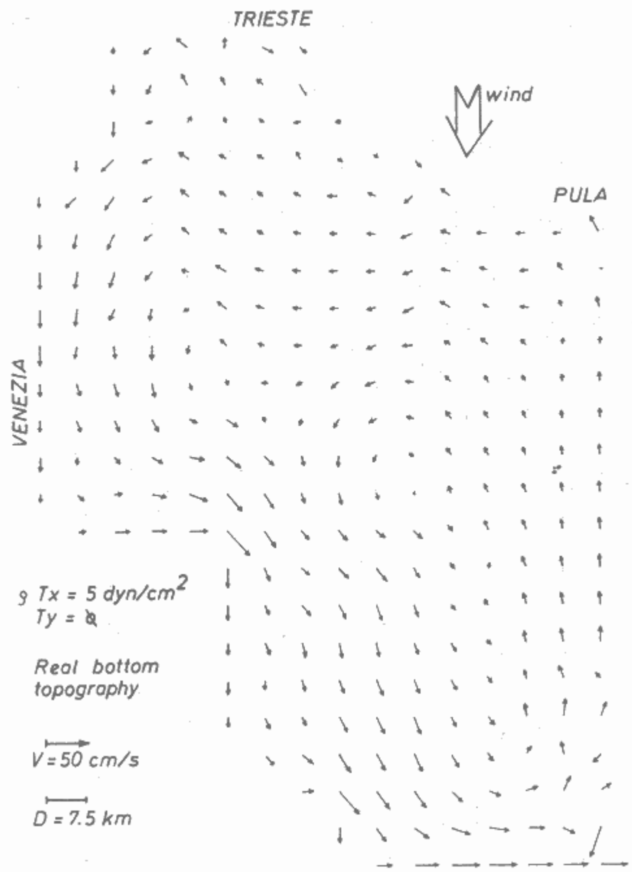

Figure 2. Flow in the case of the real bottom topography and homogeneous bora wind.

Fig. 4 presents the current field for real bottom topography and wind from NE (bora) having vorticity.

The simple balance is obtained only in the case of flat bottom and homogeneous wind and it is destroyed by introducing bottom topography or wind having vorticity. The resultant flow for the case of the real bottom topography and homogeneous NE (bora) wind which is comparable with the flow for the case of the flat bottom and NE (bora) wind having vorticity demonstrates that the two effects are similar, i. e. neither of the considered effects is negligible. The resultant flow, with the real bottom topography and the NE (bora) wind having vorticity, is given in Fig. 4. and it agrees with the empirical knowledge (Zore-Armanda and Gačić, in press).

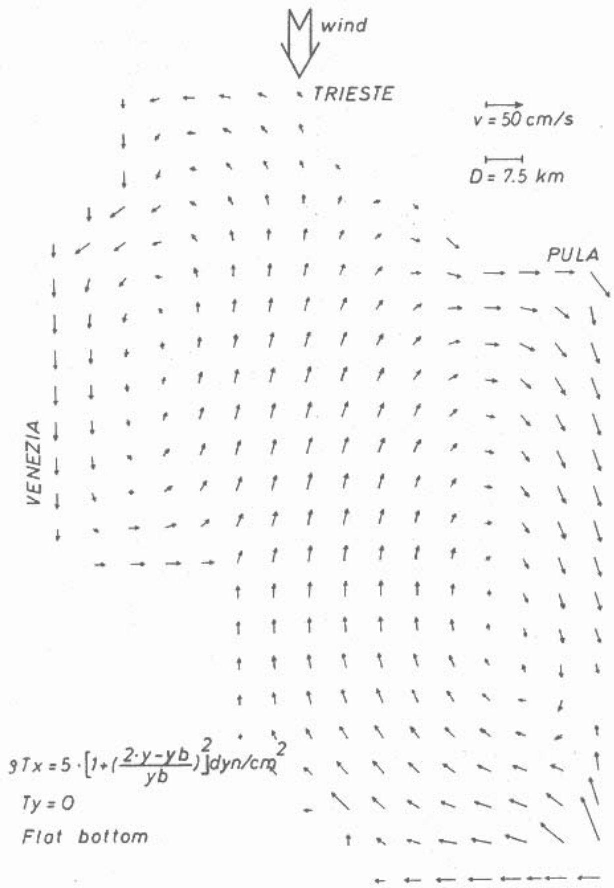

Figure 3. Flow in the case of the flat bottom and bora wind having vorticity.

4. Conclusion

From the presented numerical solutions it follows that a simple balance between the gradient and wind drift force in the equations (1) – (2), obtained in the case of flat bottom and homogeneous NE (bora) wind, is destroyed by introducing either the bottom topography or the wind having vorticity in the model. Comparing the numerical solutions for the latter two cases it is not possible to neglect either of them. This means that the bottom as well as the wind vorticity should be introduced in the model for the NE (bora) wind driven circulation in the North Adriatic. The numerical results for the case of real bottom topography and the NE (bora) wind having vorticity are consistent with the empirical results, and they demonstrate the frontal zone offshore from Pula as well.

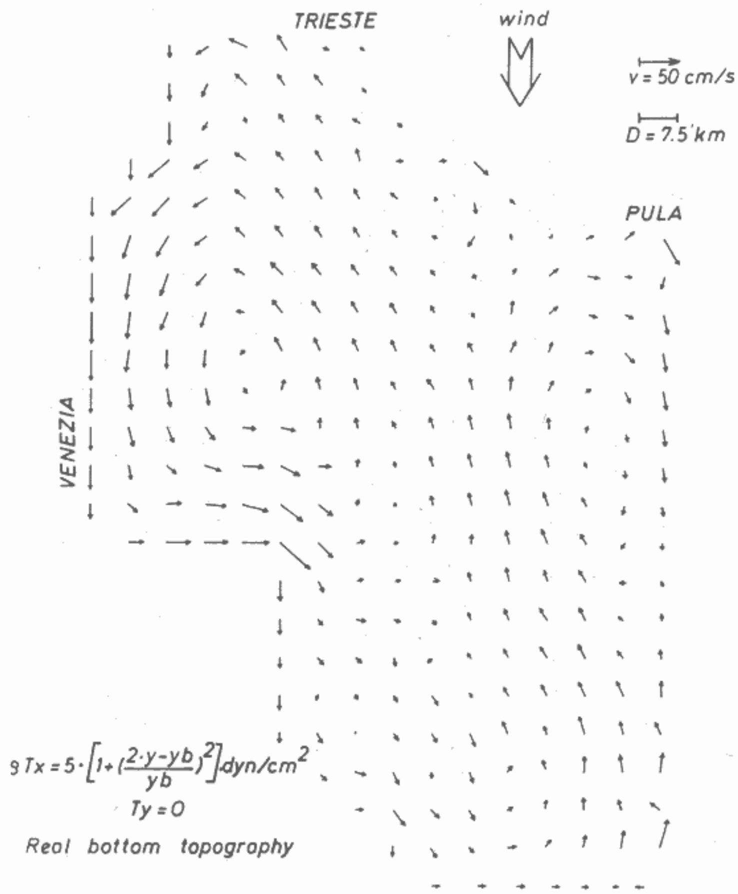

Figure 4. Flow in the case of the real bottom topography and bora wind having vorticity.

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