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Ecological study of gas fields in the northern Adriatic

5. Numerical modelling of the Bora and Scirocco driven currents

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The results of the numerical integration using a non-linear levels model are presented. In the model the vertical turbulent exchange is defined with the Level II closure model. The Nihoul form for the vertical turbulent length-scale is accepted in order to describe surface and bottom turbulent layer. For the horizontal exchange of momentum the non-linear Smagorinsky diffusion is assumed. The sea-level distribution after longer integration time has the known general features as well as vertically averaged current field. However, it is understood from the presented results that finer structure of the flow without decreasing the horizontal grid step is obtained. The current intensities are lower than in some previous numerical experiments. It is discussed considering the results of the analysis of the current-meter data and the integration time. Some preliminary results of stratification impact on the wind induced current has been considered too. The main difference in current fields between stratified and homogeneous sea is observable in the surface layer. The heat exchange between sea and atmosphere has not been taken into account. In this case the well-mixed surface layer with the very sharp pycnocline is formed. The Richardson number at the pycnocline is near the critical value and the momentum exchange with the deeper layers is very slow. However, after longer integration time, this does not affect essentially the fields of the vertically averaged current and sea-level distribution.

5.1. INTRODUCTION

The numerical experiments using the non-linear levels model, which is described in the BONE (1993) paper, are presented. Some modifications of the model have been introduced regarding the turbulence and the numerical integration technique. The model is shortly described below. The results of the numerical integration with this model give the known general features of the fields in the case of the Bora-driven circulation. This feature is also obtained with the linear spectral model (KUZMIĆ and ORLIĆ, 1987) and is experimentally confirmed (ZORE-ARMANDA and GAČIĆ, 1987; KUZMIĆ, 1991). However, in the presented results current filed structure is finer than in the linear case (ORLIĆ et al., 1994) and the earlier version of this model (BONE, 1993). The current intensities are lower than in some previous numerical experiment and this is shortly discussed below. The impact of stratification is considered running the model with simple initial conditions and excluding the heat exchange with the atmosphere.

5.2. Hydrodynamics

The BUSSINESQ approximation is introduced in the momentum equations. To filter the sound waves (HOLTON, 1972) hydrostatic equation is assumed. The traditional approximation (ECKART, 1960) for the CORIOLIS force is used. The non-divergent motion is considered because the motion is quasi-adiabatic and velocities are small compared to the velocity of sound, (LANDAU and LIFŠIC, 1965). The horizontal turbulent exchange of momentum is described with non-linear SMAGORINSKY (1993) diffusion. The cutoff wave-number length is the two horizontal grid steps and the value of the constant that enters into equations is according to SMAGORINSKY (1993). The vertical turbulent exchange is described with the Level II closure model (MELLOR and YAMADA, 1974; 1982). In order to describe surface and bottom boundary layer the NIHOUL (1984) form for the vertical turbulent length-scale is used. The density field is calculated assuming no-heat transport at sea surface. At the surface and bottom, the non-liner stress is used with the constant drag coefficient. At the close boundary, no-slip boundary conditions are taken. The radiation conditions are introduced at the open boundary. In the mass continuity equation the JOSEPH and SENDNER (1958) diffusion is applied for the horizontal turbulent exchange. The equivalent radius of diffusion is defined according to the horizontal grid step. The diffusion velocity is 1 cm/s as proposed by JOSEPH and SENDNER (1958). The integration area is shown in Fig. 5.1. It has been discussed in the BONE (1993) paper. In comparison to the width, the integration area is very long. Bora blows normal to the Adriatic axis. The results of the integration depend on the vorticity in Bora field (STRAVISI, 1977). The Bora weight function in the northern Adriatic, considering as referent the intensity at Pula, has been described in the KUZMIĆ and ORLIĆ (1987) paper. The extension on the whole Adriatic Shelf is as presented in the BONE (1993) paper. In this paper the stress with the moderate wind of 10 m/s at Pula has been considered. The Scirocco blows along the Adriatic axis and due to the form of the integration area and small width could be considered as the homogeneous wind field. The moderate value for the wind intensity of 10 m/s, as in the case of the Bora, is taken into account. For the stratification, the simplest case is to consider initially horizontally uniform stratification. The summer stratification in the Jabuka Pit is taken as characteristic. The initial conditions are hydrostatic. In order to avoid the initially induced inertial oscillation the longer integration time was taken into account. According to the BONE (1993) paper the integration time was 144 hours.

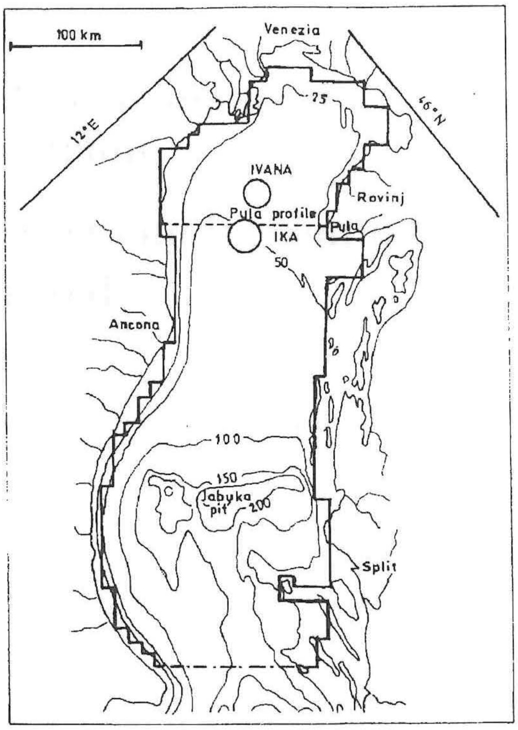

Fig. 5.1. The integration area

5.3. Numerical scheme

The semi-implicit modification of the explicit forward-backward time scheme is used in the numerical integration. The implicit schemes were used only for some terms affecting the stability in the calculation of the three-dimensional fields. The CORIOLIS terms are introduced using trapezoidal scheme (JANJIĆ and WIIN-NIELSEN, 1977). The model is defined on the semi-staggered grid. In the plane, the E-grid is used. The two-interval wave noise in the sea-level field is filtered using the modified MESINGER AM method (JANJIĆ, 1979). In the computation the two-dimensional model (external mode) is considered separately from the three-dimensional model (internal modes) according to BLUMBERG and MELLOR (1987) in order to save computational time. The two-dimensional model is stable according to the CFL criteria.

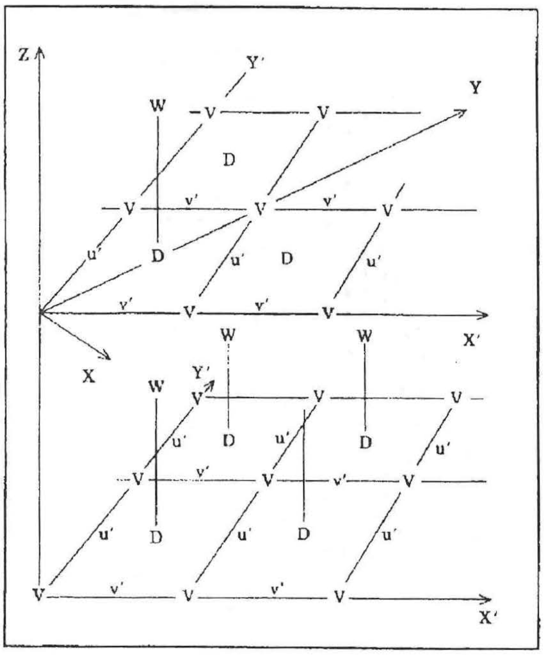

Fig. 5.2. Semi-staggered grid with E-grid axes (x,y.z), auxiliary C-grid axes (x',y',z), horizontal velocity points V, vertical velocity W and divergence, pressure and density points D

The time step for the three-dimensional model is sufficiently short to describe inertial oscillations. To obtain the stability for the longer time step it was necessary to use the implicit scheme for the vertical turbulent exchange. The horizontal advection terms are treated with the JANJIĆ (1983) scheme. The scheme conserves energy and enstrophy as for the ARAKAWA scheme on the C-grid and, in addition, it conserves E-grid energy and momentum. This provides an efficient control over the non-linear energy cascade (JANJIĆ, 1983). The SMOLARKIEWICZ (1983) scheme is used for the terms of the vertical advection. It is a positive definite advection scheme with correction for the numerical implicit diffusion. The used semi-staggered E-grid and the auxiliary C-grid are shown in Fig. 5.2. The horizontal grid step in the integration area is 10 km and the vertical step is 5 m.

5.4. RESULTS

5.4.1. Homogeneous sea — Bora

The vertically averaged currents and the sea-levels forced by Bora are shown in Figs. 5.4a and 5.4b. The surface and the bottom currents are shown in Figs. 5.3a and 5.3b. The well-known general feature is obtained. In the northern Adriatic the anti-clock-wise vortex is formed along to southward clock-wise vortex. The flow along the Italian coast to south and from Pula toward Italian coast is well visible.

The recent modelling results obtained by a linear spectral model and a more simple closure model (ORLIĆ et al., 1994) than the one used here, gives larger current's intensities. This is at first the question on the parametrization of the models. The model used here involves more physics and is not linear, i.e., the results presented here should be qualitatively different from the results obtained considering the linear case. Let's shortly discuss these facts. The results presented in Fig. 5.3 are zoomed in the northern part and given in Fig. 5.15. The results accepted here agree with the observed values referring to the ZORE-ARMANDA et al. (1995) paper and the F. MOSETTI and P. MOSETTI (1990) analysis in the Gulf of Trieste. The results also agree with the KUZMIĆ and ORLIĆ (1987) analysis of the current-meter data for Panon. In the considered period March-April 1982 the data analysis is in accordance with the results related to the numerical solutions presented in the same paper. The present results are not in accordance with the current intensities of the current-meter data analysis taken into account

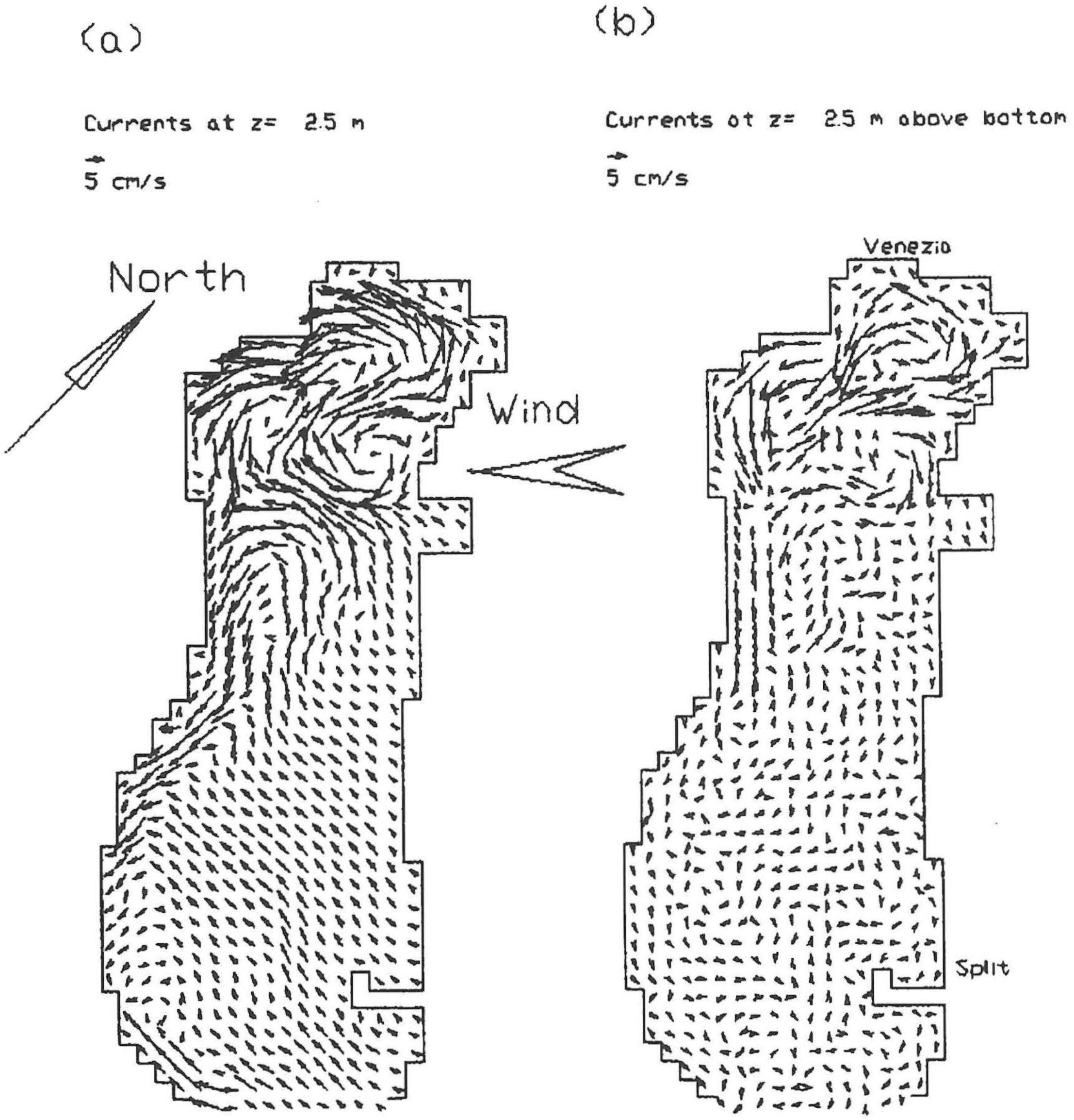

Fig. 5.3. Surface (a) and bottom current (b) for the homogeneous sea forced by Bora

in the ORLIĆ et al. (1986) paper for Panon in the period November-December 1978. To illustrate the qualitative differences the time series of the mean kinetic energy per unit mass of the water column at Jabuka Pit obtained during integration is given in Fig. 5.13. Long period oscillation is obtained. It is obvious that the current intensities are dependent on the integration time too. The obtained long-time oscillation results from the non-linearity of the model. This, comparing with the previously results do not change much the geometry of the flow field. The known general feature is conserved, but finer structure of the current field, comparing with the earlier numerical experiment (BONE, 1993; ORLIĆ et al., 1994), is evident. For example, it could be noted that the vortex in front of Rovinj is more enhanced in the presented results. Considering the sea-level distribution the geometry of the field is similar to the earlier numerical experiments. In some cases the amplitudes of the sea-level distribution are smaller compared with the previous numerical experiments. This may be explained

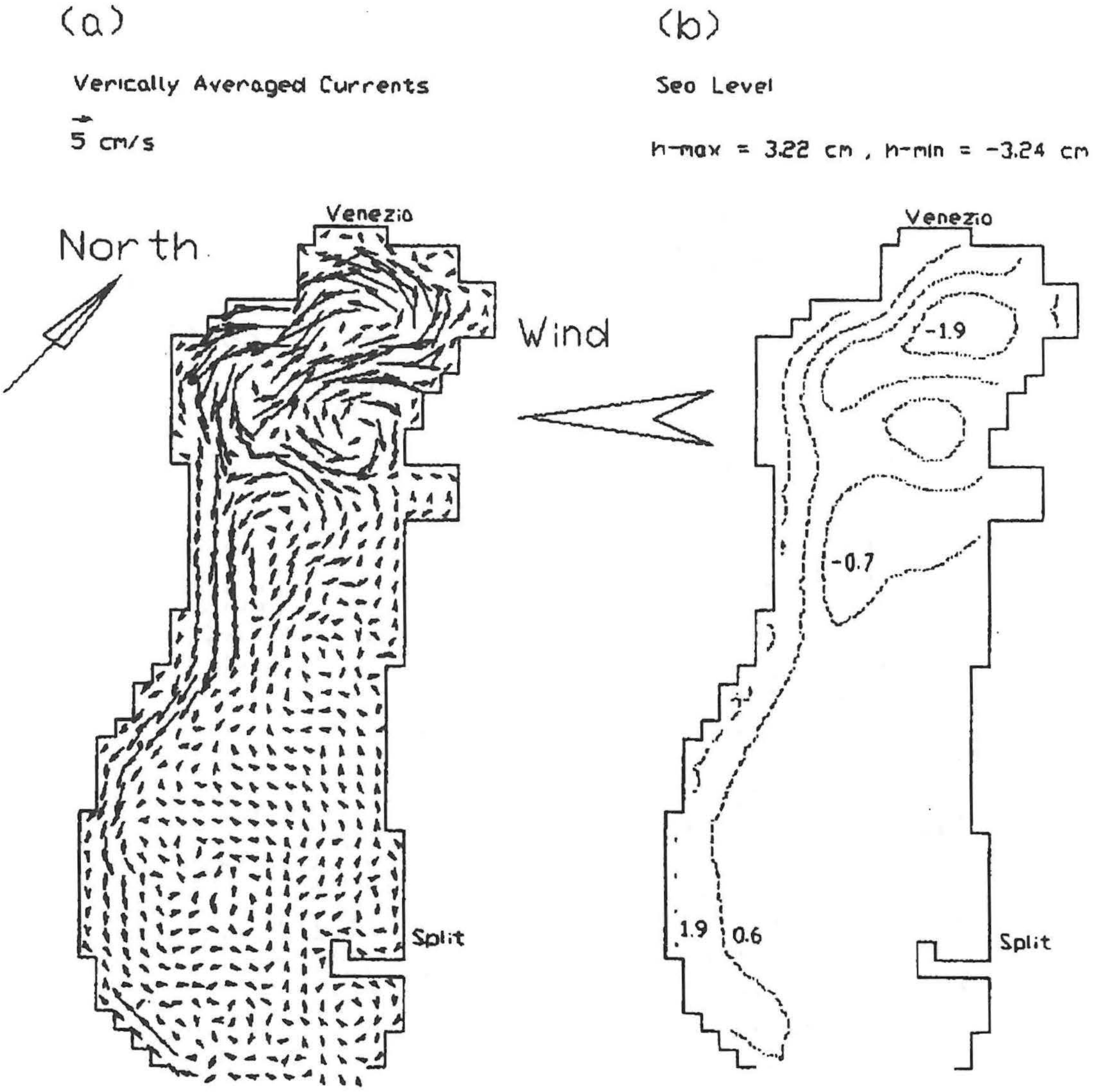

Fig. 5.4.Vertically averaged currents (a) and sea-level (b) for the homogeneous sea forced by Bora

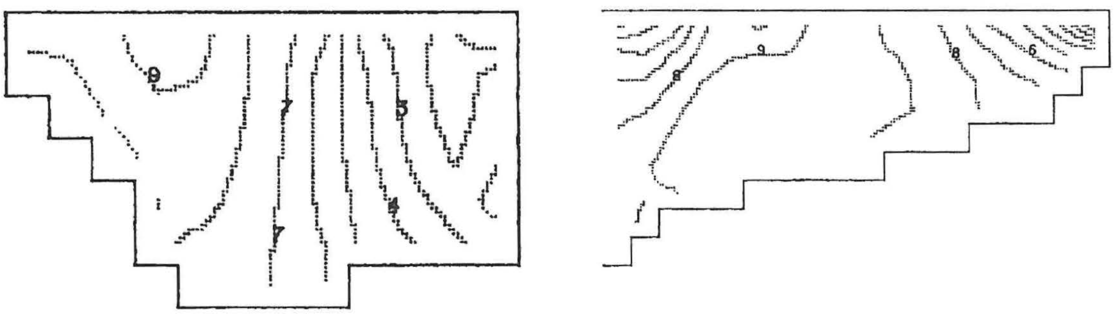

Fig. 5.5. Water transport forced by Bora for the homogeneous sea through (a) thePula-Rimini transect and (b) along the Adriatic axis in cm/s

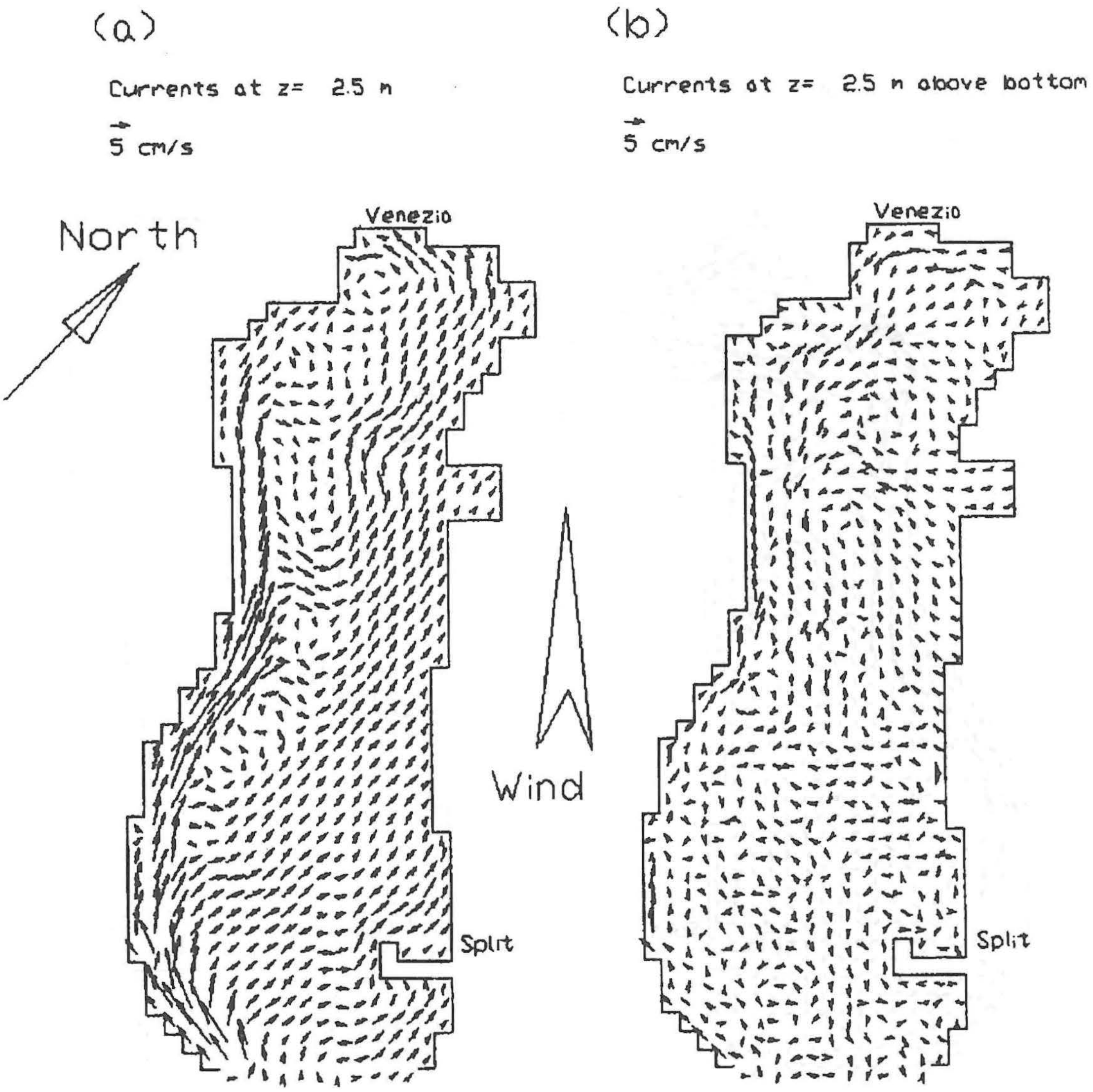

Fig. 5.6. Surface (a) and bottom current (b) for the homogeneous sea forced by Scirocco

by the longer integration time and non-linearity of the model. At present time this will be not discussed theoretically. Let's illustrate only the numerical evolution of the process. The free oscillation of the water over the Adriatic Shelf described in the BONE (1993) is decreasing during the integration without disappearing, as seen in Fig. 5.14. Long time changes due to the non-linearity of the model may be also observed. The shape of the vortex in front of the Rovinj differs from that obtained from the linearized equations. Taking into account all these facts some differences in the obtained numerical results describing sea-level distribution could be expected. However, the result for the sea-level distribution follows simple from the volume continuity equation.

To describe the Bora induced water transport profiles from Pula towards the Italian coast and along the Adriatic axis are considered. The cross section transports are shown in Figs. 5.5a and 5.5b.

5.4.2. Homogeneous sea — Scirocco

The surface and bottom currents forced by Scirocco are given in Fig. 5.6a. and 5.6b. The vertically averaged current and sea-level fields are shown in Fig. 5.7a and 5.7b. The cross section transports are shown in Fig. 5.8a and 5.8b. The transports generally are towards north, i.e., diagonally to the basin axis. Exceptions are the Gulf of Trieste, where the transport is directed towards Venezia, and the coast from the Gargano to Ancona where there is larger current along shore towards north. The discussion given for the case of Bora regarding the non-linearity of the model may be extended on this case too.

5.4.3. Stratified sea

The results for the stratified sea, initially horizontally homogeneous and without heat transport at sea surface, are given in Figs. 5.9a. to 5.12b. The main differences between current field in the cases of homogeneous and stratified sea are visible in the surface current field. In the case of the stratified sea the surface cur-

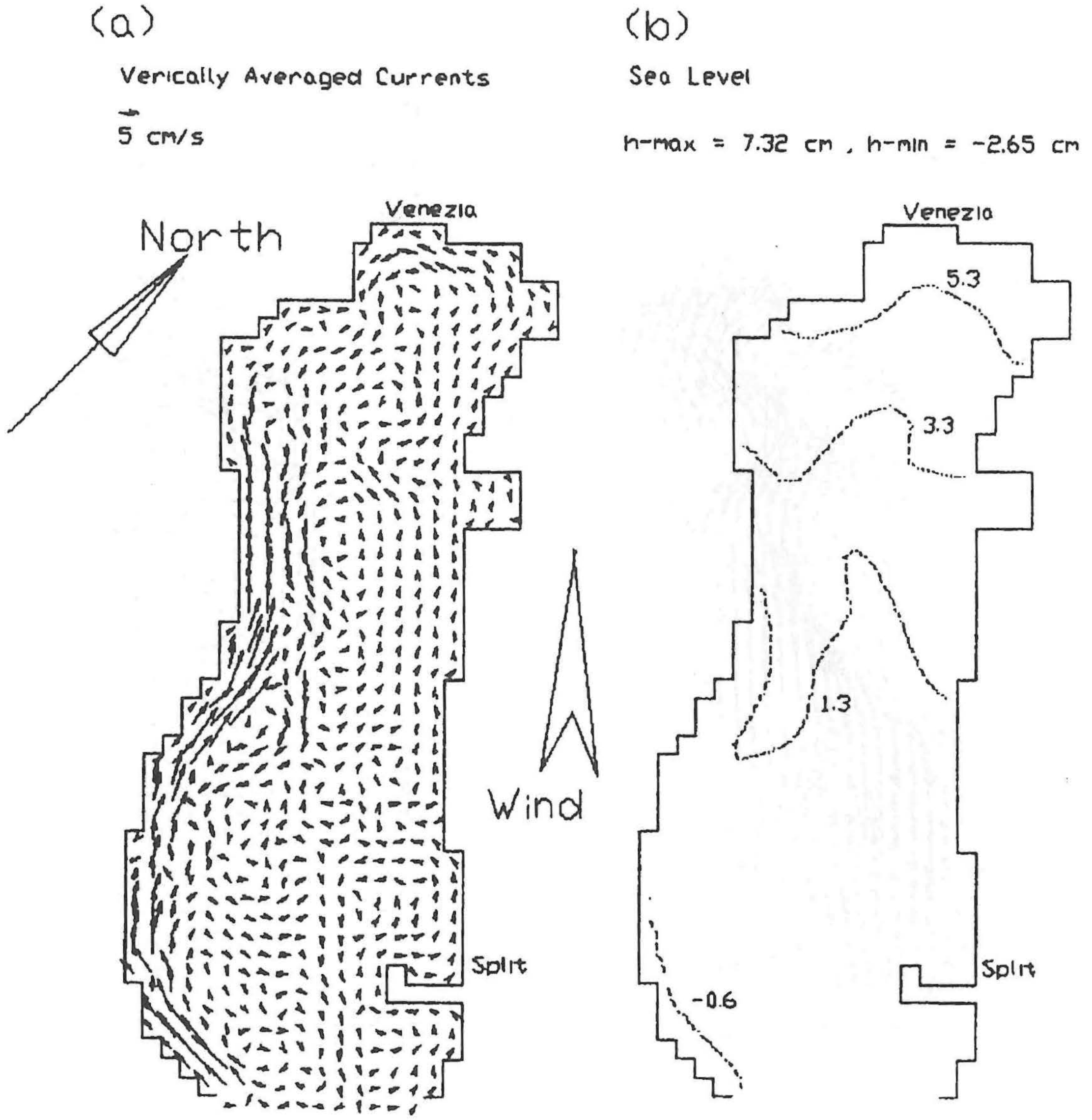

Fig. 5.7. Vertically averaged currents (a) and sea-level (b) for the homogeneous sea forced by Scirocco

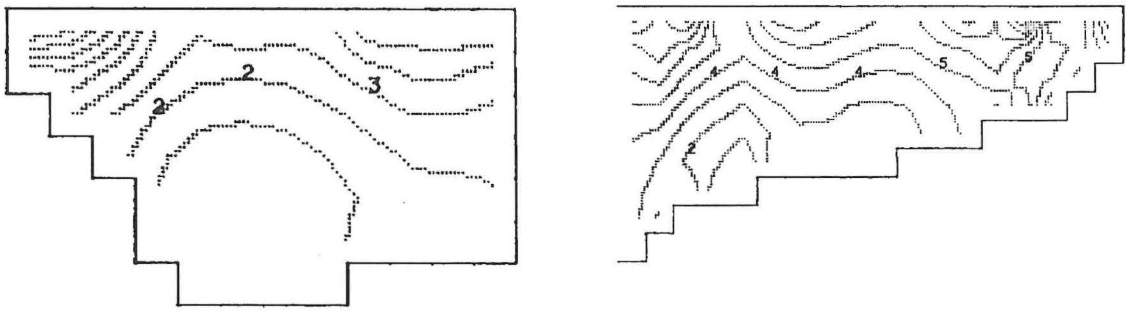

Fig. 5.8. Water transport forced by Scirocco for the homogeneous sea through (a) the Pula-Rimini transect and (b) along Adriatic axis in cm/s

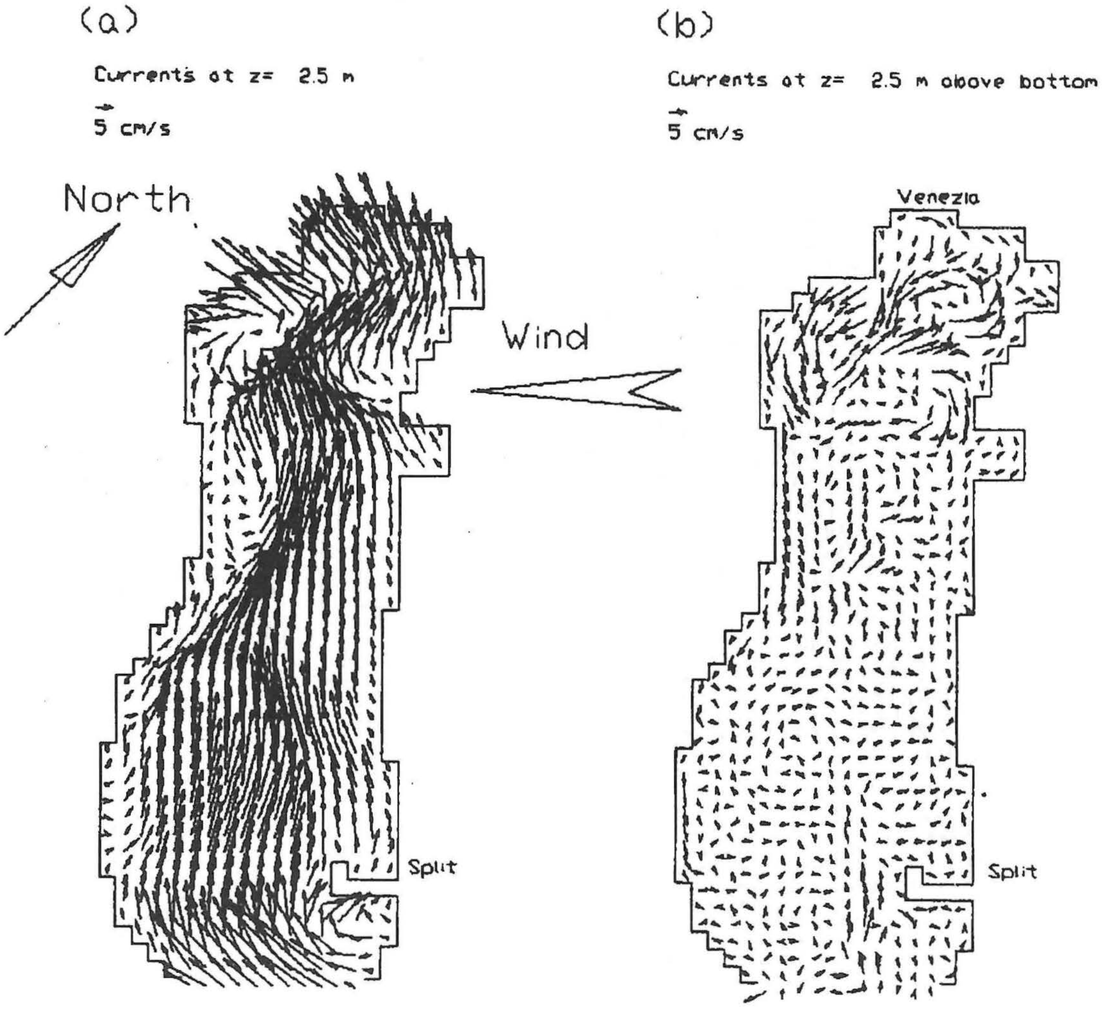

Fig. 5.9. Surface (a) and bottom current (b) for the stratified sea forced by Bora

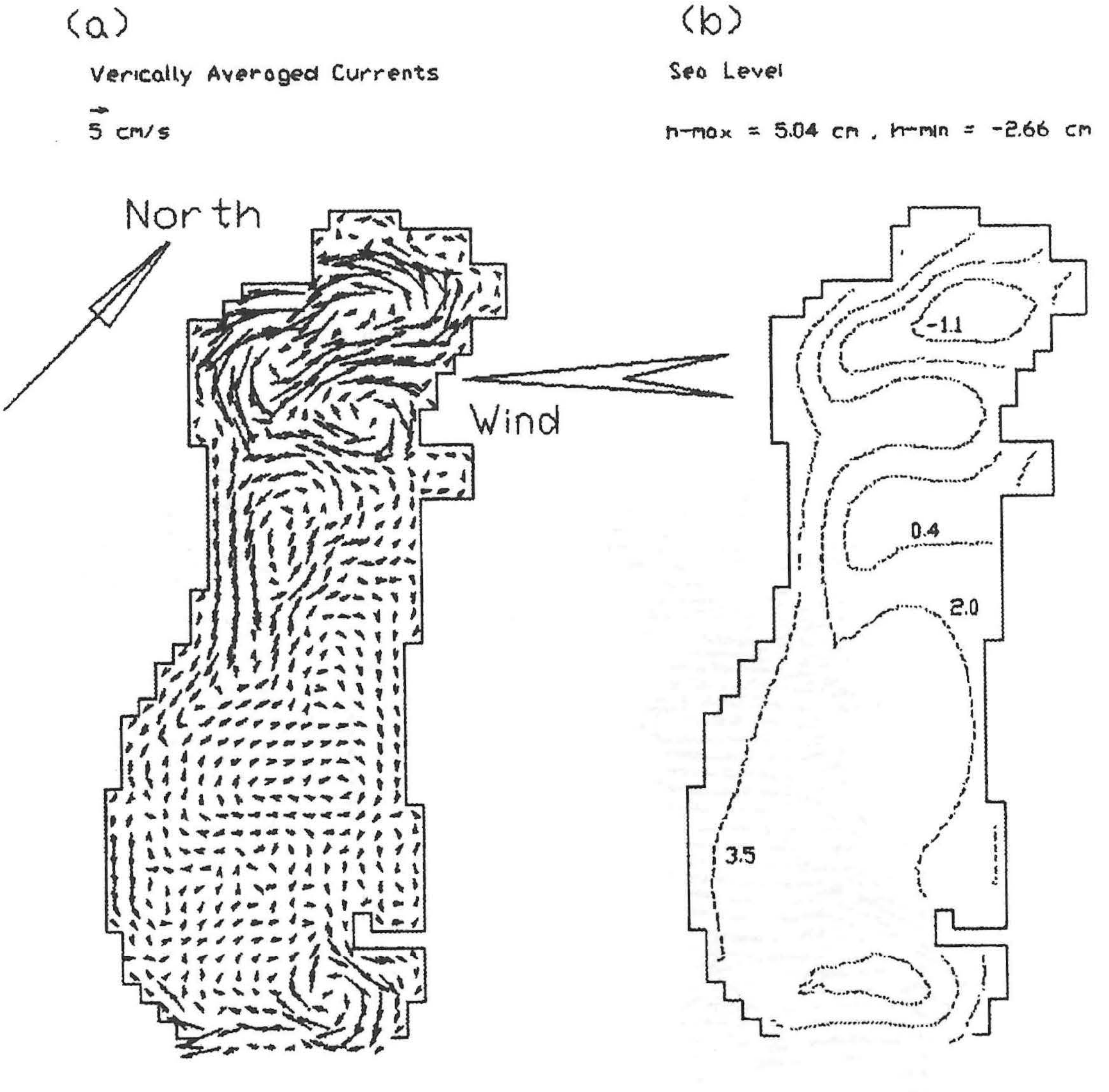

Fig. 5.10. Vertically averaged currents (a) and sea-level (b) for the stratified sea forced by Bora

rents change in the direction and the intensities are larger than in the case of the homogeneous sea.. This difference may be explained considering formation of the well-mixed surface layer and sharp pycnocline due to the lack of heat exchange at sea surface. The RICHARDSON number at pycnocline is near the critical value and the turbulent transfer of momentum towards the lower layers is very slow. That can explain the obtained differences. All these affects are of little impact on the vertically averaged current field and the sea-level distribution after a longer integration time. It should be necessary to introduce the heat fluxes at the sea surface before getting some deeper understanding on the impact of stratification on the wind induced current system.

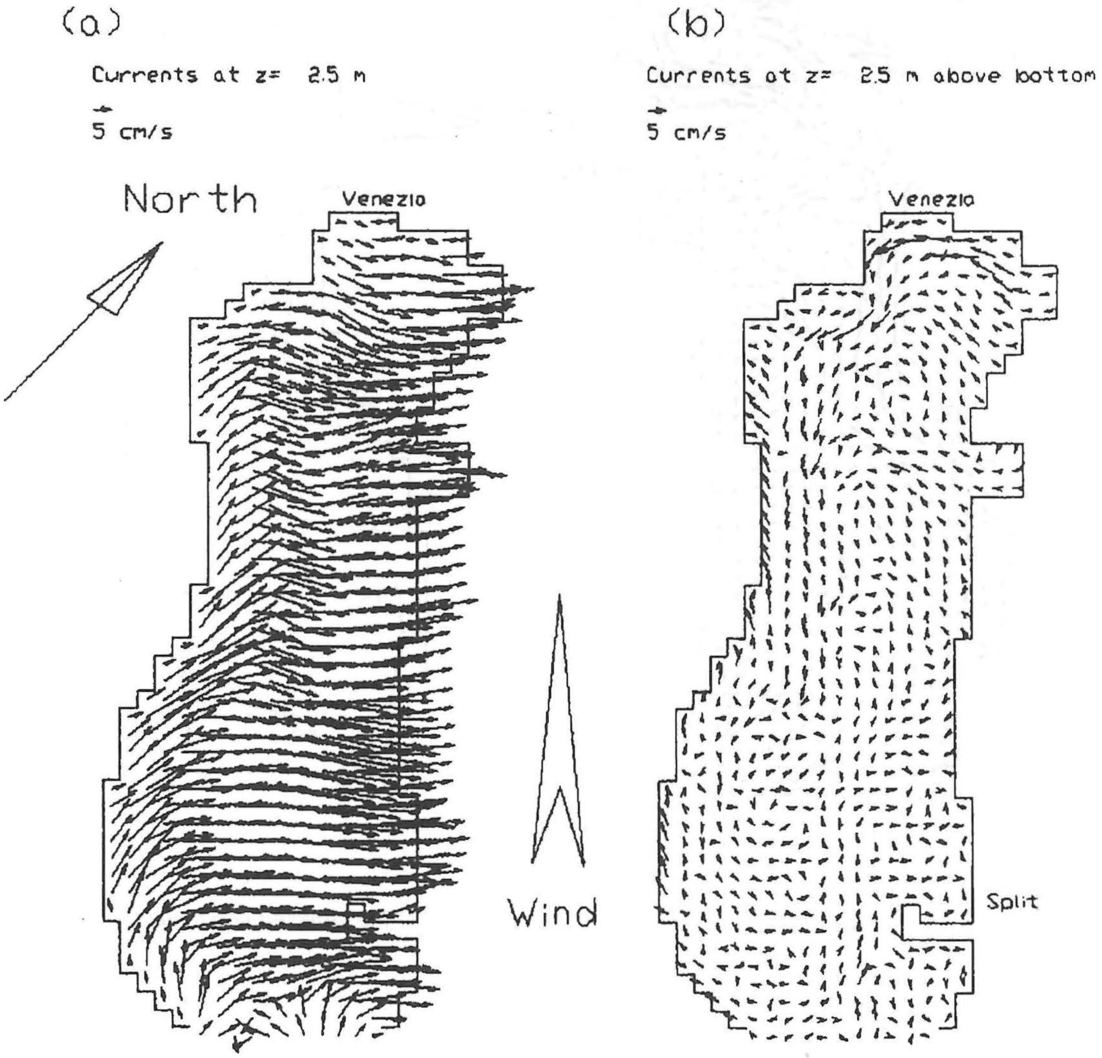

Fig. 5.11. Surface (a) and bottom current (b) for the stratified sea forced by Scirocco

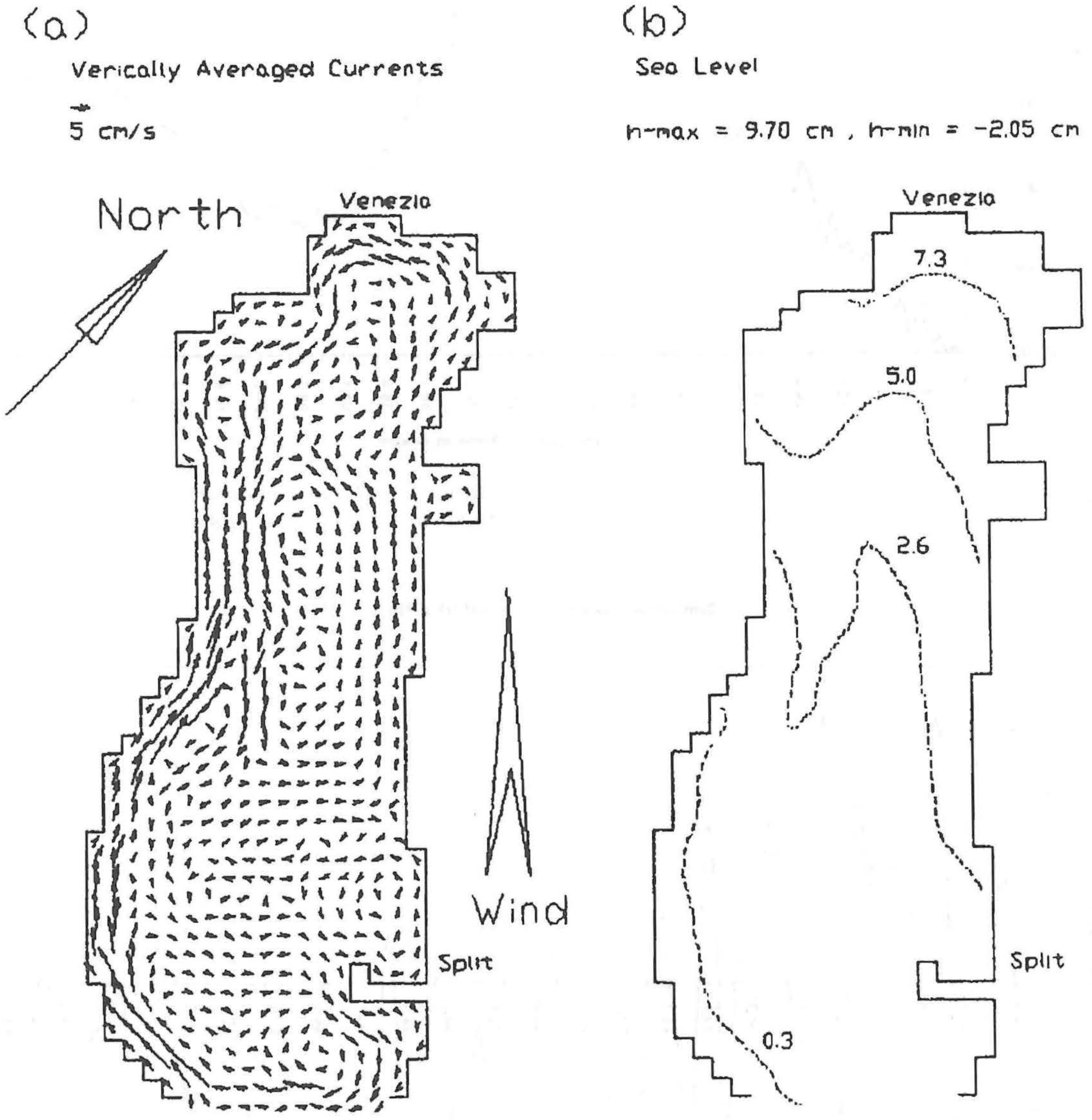

Fig. 5.12. Vertically averaged currents (a) and sea-level (b) for the stratified sea forced by Scirocco

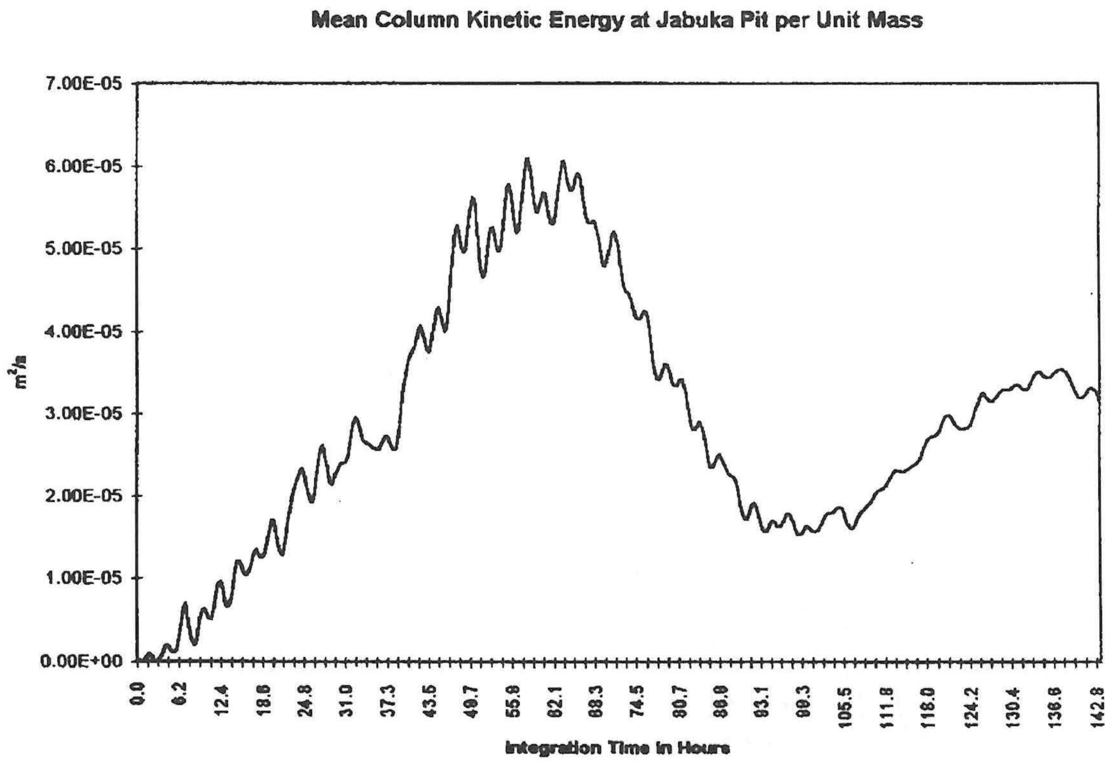

Fig. 5.13. Time series of the mean water column kinetic energy per unit mass at Jabuka Pit obtained during the numerical experiment for Bora induced currents in the homogeneous sea

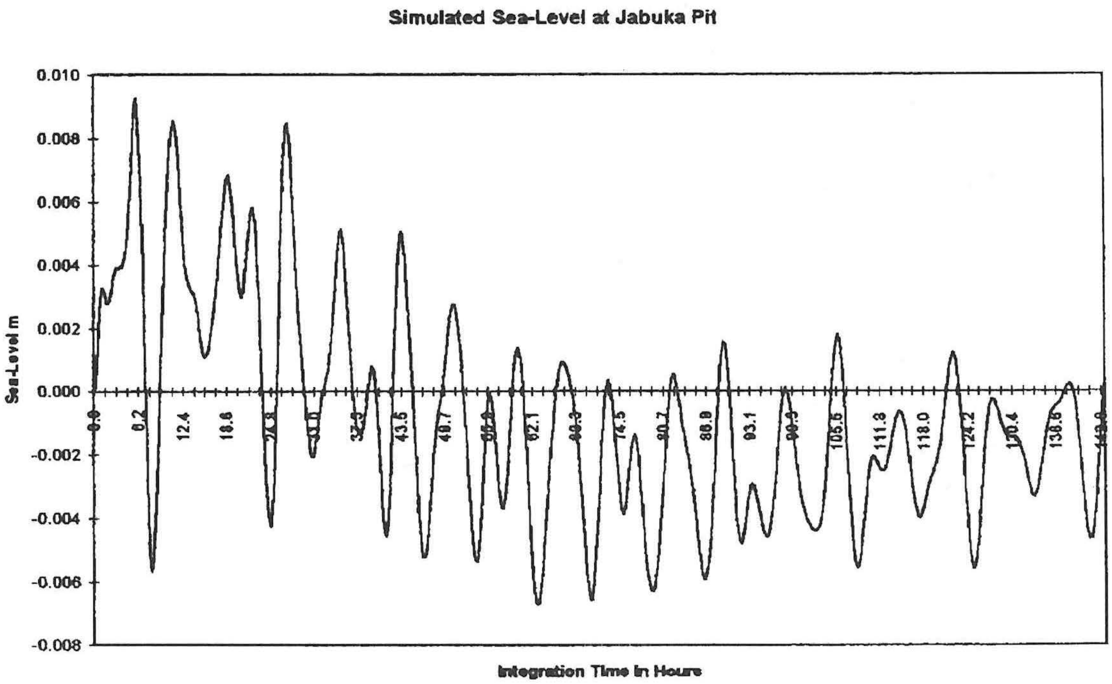

Fig. 5.14. Time series of the sea-level at Jabuka Pit obtained during the numerical experiment for Bora induced currents in the homogeneous sea

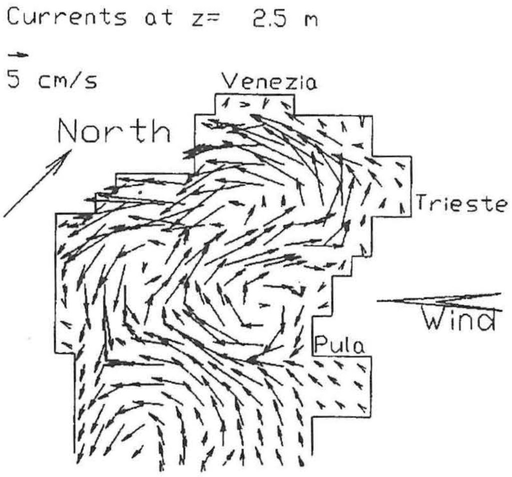

Fig. 5.15. Zoomed the northern part of the Fig. 5.3 (a) where the surface currents of Bora induced currents in the homogeneous sea are presented

5.5. CONCLUSIONS

In the obtained numerical results for the homogeneous sea the vertically averaged current field induced by Bora show the known general features as well as the sea-level distribution. Comparing the results of these numerical experiments with earlier the finer structure of the current fields is obtained without decreasing horizontal grid step. In the case of the Bora the vortex in front of Rovinj is more clear in the present results. This may be explained with the non-linear advection and horizontal diffusion terms used. The obtained intensities are in good agreement with the recently analyzed current data.

The closure defining the vertical turbulence exchange in the present model has not been used in the earlier numerical experiments. Here, the Level II closure model is applied according to the newer MELLOR and YAMADA data for the parameters and NIHOUL form for the turbulent length scale describing surface and bottom turbulent layers. The bottom currents in this case are clearly different

The initial conditions in the considered case of the stratified sea are too simple. The model should be started with the more realistic initial density field. Also, it is obvious that some main processes as heat fluxes at sea surface and heating by solar radiation are not considered. Due to lack of excluded fluxes the well-mixed surface layer with very sharp pycnocline is formed. The RICHARDSON number is near the critical value. In this case, due to slower momentum exchange with the deeper layers, the surface current intensity is larger and the direction of the current is changed too. However, after longer integration time, this does not affects very much the vertically averaged current fields and sea-level distributions.

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Ekološka studija plinskih polja u sjevernom Jadranu

Numeričko modeliranje struja uzrokovanih burom i jugom

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KRATKI SADRŽAJ

Numerička integracija je izvršena nelinearnim višerazinskim modelom sa Level II modelom zatvaranja. Oblik zavisnosti dužinske skale turbulencije uzet je prema Nihoulu kako bi se bolje opisao pridneni i površinski turbulentni sloj. Horizontalna turbulentna izmjena momenta opisana je nelinearnom difuzijom Smagorinskog. Rezultati numeričke integracije sukladni su već poznatoj slici raspodjele nivoa mora i vertikalno osrednjenog strujanja. Uspoređujući strujna polja, vidljivo je da je ovim modelom dobivena finija struktura ne mijenjajući horizontalni korak mreže. Dobiveni inteziteti struja nešto su niži nego u nekim ranijim numeričkim eksperimentima, a time se i amplitude promjene morske razine razlikuju. To je posebno diskutirano razmatrajući rezultate analiza mjerenja i dužine integracije. Razmatran je utjecaj stratifikacije na struje inducirane vjetrom. Razlika u rezultatima dobijenim za homogeno more i onih u slučaju stratifikacije uočljiva je kod površinskog strujanja. Nisu razmatrani toplotni fluksevi na površini te se dobijene razlike mogu objasniti formiranjem vrlo oštre piknokline gdje je Richardsonov broj blizu svoje kritične vrijednosti, pa je izmjena količine kretanja sa dubljim slojevima vrlo slaba. Time je intezitet strujanja u površinskom sloju veći nego u slučaju homogenog mora, a znatne su razlike i u smjeru strujanja. To, ipak, bitno ne utječe na sliku vertikalno osrednjenog strujanja kao ni na raspodjelu morske razine, nakon nešto duže vremenske integracije .