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A MULTILEVEL MODEL FOR THE STUDY OF THE DYNAMICS OF THE NORTH ADRIATIC SEA

VIŠESLOJNI MODEL ZA IZUČAVANJE DINAMIKE SJEVERNOG JADRANA

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A method which can be applied to describe, understand and forecast phenomena characterizing a semi-enclosed basin will be discussed.

A numerical multilevel model that can be used as a basic structure in biological, geological and chemical research will be presented. In particular its application has been made in the North Adriatic Sea because this area offers the opportunity to study a variety of interesting phenomena.

Different numerical experiments were carried out, using 7 km regular grid, 10 vertical levels with different thickness, different boundary conditions, different wind fields; the Po runoff and subsequent advection diffusion of a passive scalar was taken into account.

The results of the IBM-3090/VF implementation of the model will be shown.

INTRODUCTION

After an initial period of intense exploitation of the environment, essentially seen as a store of almost unlimited capacity for human wastes, man has begun to realize the serious damages that, with time, are caused by this way of thinking. It is only in the last few years that man has begun to consider "the environment"as a field in which the scientific and technical knowledge can be applied, not only to understand the processes that regulate the dynamics, but also to minimize the impact of many human activities.

Models and numerical simulation using powerful and sophisticated computers, are the key to understanding the phenomena that characterize the behaviour of a complex system as a marine basin or, more generally, an ecosystem in which the physical, chemical and biological processes are so interrelated that it is impossible to study them separately.

Any integrated study of the "Adriatic System" requires a knowledge of its hydrodynamics and the factors which govern it. The aim of this paper is to present a simulation model of the dynamics of this basin.

PHENOMENOLOGY

The Adriatic Sea is a rectangle-like elongated basin surrounded by the Italian and Croatian coasts, and communicates, in the South, with the Inonian Sea through the Otranto Strait. The northern and shallow part is constituted of a continental shelf with the isobaths running parallel to the coastline (Fig. 1).

From a phenomenological point of view it is possible to distinguish two different seasonal situations. The first one, typical of the autumn-winter period, is characterized by an almost complete homogeneity of the vertical distribution of physical parameters (salinity, temperature). This vertical homogeneity of the water column is present down to 200 m depth (T r o t t i , 1970; F r a n c o , 1970; M a l a n o t t e R i z z o l i , 1977).

In this season the dominant wind blows from the South-East (sirocco) and some time from the North-East (bura).

During the summer periods there is a strong vertical stratification caused by the formation of a pronounced thermocline (due to the cooling of the sea surface). The wind, less intense than in winter, blows prevalently from the North-West.

A fundamental characteristic of the basin is the lighter, fresh water brought by the river outflow, especially from the Po. The intense horizontal gradient produced by this influx of fresh water, concentrated along the Italian coast, is one of the forces that regulate the basin circulation.

Other interesting phenomena that characterize the basin and render it a particularly interesting test area are the intense winter evaporation that, with the simultaneous cooling, produce the formation of dense water and the geometrical configuration that cause important resonant phenomena (seiches) in correspondence with particular wind conditions. Moreover, two distinct biological phenomena have taken place in the north Adriatic region during the recent years. The first one, shows itself as an abnormal algal bloom (in particular of Diatoms and Dinoflagellates) and is an indication of the increase of eutrophication along the coast. During the 1989 summer, instead, a large amount of jelly mucus was observed that was produced, for some unknown reason, on the sea bottom, surfacing detained inside sediments, phytoplankton and zooplankton. Due to this phenomenon the sea surface was covered by a jelly layer, at times ten centimetres thick,

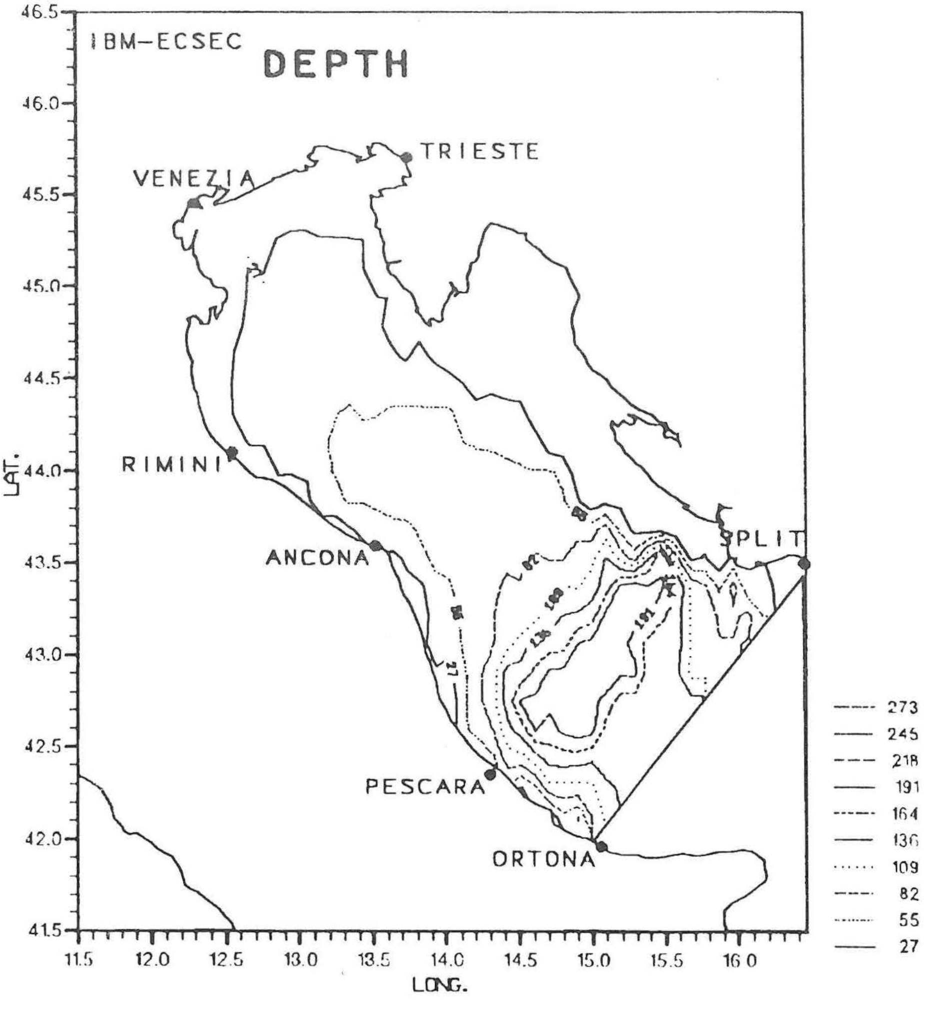

Fig. 1. North Adriatic sea bottom topography

making the water impossible to swim in, with obvious consequences for the tourist industry.

The description of the Adriatic Sea phenomenology is fully reported in B u l j a n and Z o r e - A r m a n d a (1976) and G i l m a r t i n and D a v i d s o n (1971).

DESCRIPTION OF THE MODEL

System of equations

To simulate the dynamics of the North Adriatic Sea a model developed by Malanotte Rizzoli and Bergamasco (1983), based on the previous work of Simons (1980), has been generalized. The equations of the motion are well known Navier-Stokes equations simplified according to Boussinesq, hydrostatic and shallow water approximations, which, together with the assumption of small Rossby number lead to:

$$\frac{\partial u}{\partial t}=fv-\frac{\partial}{\partial x}\left(\frac{\psi+\phi}{\rho_0}\right)+\frac{\partial}{\partial x}\left(A_H\frac{\partial u}{\partial x}\right)+\frac{\partial}{\partial y}\left(A_H\frac{\partial u}{\partial y}\right)+\frac{\partial}{\partial z}\left(A_V\frac{\partial u}{\partial z}\right)$$

$$\frac{\partial v}{\partial t}=-fu-\frac{\partial}{\partial x}\left(\frac{\psi+\phi}{\rho_0}\right)+\frac{\partial}{\partial x}\left(A_H\frac{\partial v}{\partial x}\right)+\frac{\partial}{\partial y}\left(A_H\frac{\partial v}{\partial y}\right)+\frac{\partial}{\partial z}\left(A_V\frac{\partial v}{\partial z}\right. \tag{1}$$

where (u,v) are the horizontal components of the velocity along the transversal and longitudinal basin direction, A_H, A_V are the horizontal and vertical coefficients used to simulate the phenomena of turbulent viscosity and ρ_0 is the average water density. In the previous expression the baroclinic ϕ and the barotropic pressure ψ are defined as:

$$\phi=\int_z^{\xi}(\rho-\rho_0)\,dz$$

$$\psi=p_s+\rho_0 g\xi \tag{2}$$

where p_s is the atmospheric pressure, ζ is the elevation from sea surface; the water density ρ, a function of the temperature and salinity, is calculated using a polynomial expression (Cox *et al.*, 1970).

Coupling between equations (1) and (2) is achieved through the advection-convection equations for temperature and salinity:

$$\frac{\partial\phi}{\partial t}+\frac{\partial(u\phi)}{\partial x}+\frac{\partial(v\phi)}{\partial y}+\frac{\partial(w\phi)}{\partial z}=\frac{\partial}{\partial x}(K_H\frac{\partial\phi}{\partial x})+\frac{\partial}{\partial y}(K_H\frac{\partial\phi}{\partial y})+\frac{\partial}{\partial z}$$

(3)

where K_H, K_V are the horizontal and vertical coefficients of eddy diffusivity and Φ denotes temperature, salinity or any passive tracer.

The continuity equation for an incompressible fluid closes the system of equations and allows the calculation of free surface evolution:

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}=0$$

(4)

Vertical discretization and boundary condition

To simulate a typical winter situation it would be sufficient to consider the water column as composed of a single layer in which all the physical parameters have a constant value. On the contrary, due to the stratification that starts during the summer period, it is necessary to divide the water column into different levels. Through a generalization of the code, based on the model (Malanotte Rizzoli and Bergamasco, 1983), it is then possible to subdivide the water column into arbitrary numbers of levels; results shown in this paper have been obtained using ten levels of different thickness but constant in time.

The dynamic action of the wind over the free sea surface was taken into account through the expression:

$$\tau=K_w\rho_a|\vec{W}|\vec{W}$$

(5)

where W is the wind velocity, ρ_a the air density and K_w the drag coefficient at the air-sea interface.

For the bottom friction a quadratic expression has been used:

$$\tau_b=k\rho|\vec{v}_b|\vec{v}_b$$

(6)

where v_b is the bottom fluid velocity, ρ is the water density and k the drag bottom coefficient. Moreover a no-slip condition for the velocity was taken into account. To simulate the tide effect, the level of the free surface (ζ) was assigned, in the open southern part, to the two opposite coastal stations of Split (Croatia) and Ortona (Italy):

$$\xi(t) = \sum_{n=1}^{7} A_n \cos(\omega_n - \phi_n) \qquad (7)$$

where the frequencies, amplitudes and phases of the first seven harmonic tide components were taken from experimental data (M o s e t t i). A linear interpolation was used for the points of the open boundary situated between the two coastal stations. For the numerical experiments carried out, only the first two tide components (M_2 S_2) were used.

For the open boundary conditions in the southern basin between Split and Ortona, due to the unavailability of the experimental value of the influx and outflows, the radiation condition (O r l a n s k i , 1976) was implemented for all the physical variables.
For the moment, to simulate the effect of the rivers on the dynamics only the Po River was taken into account and the outflow fixed at 4000 m^3/s, the salinity at 25 ppm and the temperature at 15°C.

Numerical resolution and IBM 3090-600E VF implementation

The equations previously shown were numerically resolved by the finite difference method on a 7 km wide regular grid (total of 1600 points for each level).

In particular the velocity equations were integrated using staggered grids rotated for 45°; for the advection-convection equation (3) an Arakawa "B-grid" scheme was used; the temporal integration was performed by a 120-second time step according to the Courant stability condition.

Further details on numerical resolution of the equations system are reported in the paper by S i m o n s (1980).

Generalizing the implementation of the equation and making this independent of the level number an attempt was made to adapt the algorithms to exploit the vector features present in the IBM-3090-600E VF system. The results of this work, achieved in a test case which simulated the dynamics of one day using 3200 grid points, are shown in the table:

CPU TIME	
Original version	40.8 s
Vector version	16.7 s

The table shows a speed-up of about 2.5 with respect to the original version. We are now developing a parallel version of the code in order to best exploit the features offered by the multiprocessor system IBM 3090-600E VF, using at the same time six processor units with a considerable saving in elapsed time.

MODEL RESULTS

Due to the great difficulty in finding available and extensive data, it was preferred to use ideal field conditions for our tests. The wind fields used were considered constant in direction over the whole basin. The source of a hypothetical conservative tracer was used in correspondence with the Po River, whose diffusion is governed by equation (3).

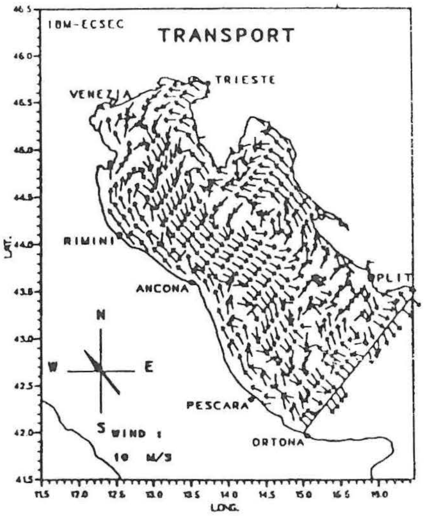

Fig. 2. Mean total transport (30-day simulation) (southeast wind)

Fig. 2 shows the mean total transport of the water column after a 30-day simulation with a southeast wind. In Figs. 3, 4 and 5 the concentration in tracer carried by currents is shown for the second (3-6 metres), third (6-9 metres) and fourth level (9-15 metres). The same numerical experiment was performed using a northeastern wind (Fig.6 & 7).

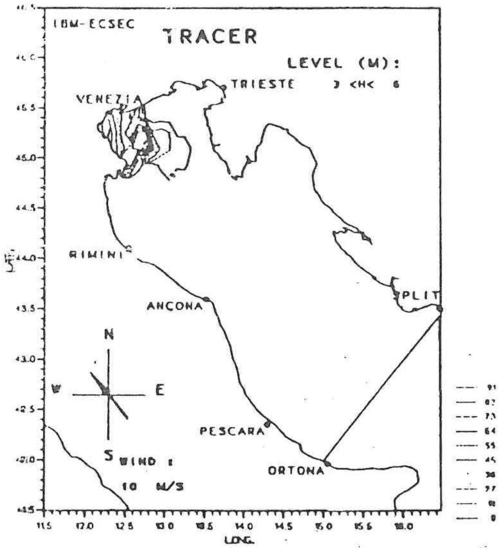

Fig. 3. Diffusion of a passive tracer after 30 days (southeast wind, second level)

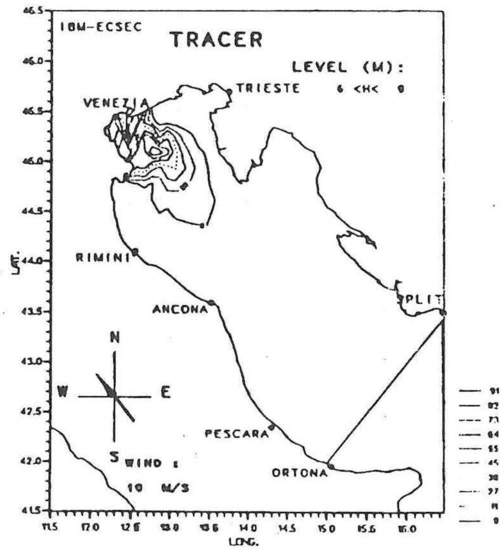

Fig. 4. Diffusion of a passive tracer after 30 days (southeast wind, third level)

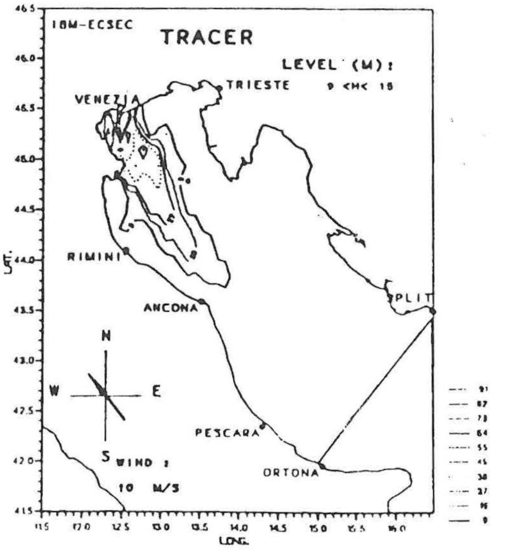

Fig. 5. Diffusion of a passive tracer after 30 days (southeast wind, fourth level)

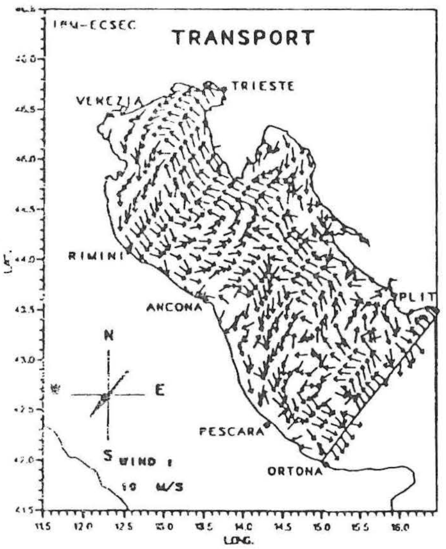

Fig. 6. Mean total transport (30-day simulation) (northeast wind)

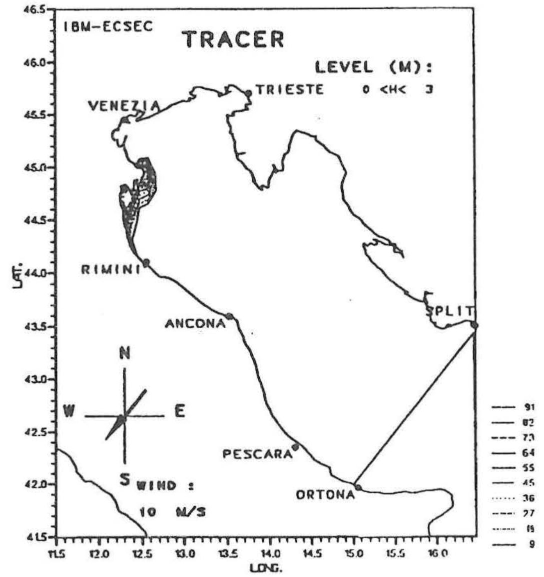

Fig. 7. Diffusion of a passive tracer after 30 days (northeast wind, first level)

Figs. 1 and 6 show that a general cyclonic circulation is observed in both cases. A large area of re-circulation along the Italian coast is present only in Fig. 1 while in Fig. 6 there is a strong southward current along this coast. These differences are associated with the different response of the basin to the action of the wind dynamics.

The analysis of the horizontal distribution of tracer concentration at different level depths shows again a general cyclonic circulation. We are, however, able to discriminate, with greater accuracy than in the past, the vertical dynamic behaviour. We observe that the surface layer is driven in the same direction as the wind, while the underlying layers are joined to the general circulation.

From these first simulations it is apparent that both the knowledge of meteorology and climate (wind field, thermal fluxes, evaporation, etc.) and of salinity and temperature is needed to get a realistic simulation of the influence of the Po River, and more generally, of the relevant factors involved in biological processes.

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VIŠESLOJNI MODEL ZA IZUČAVANJE DINAMIKE SJEVERNOG JADRANA

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KRATKI SADRŽAJ

Prezentiran je numerički višeslojni model koji se može primijeniti kao osnovna struktura u biološkim, geološkim and kemijskim istraživanjima. Primijenjen je na sjeverni Jadran budući da to područje nudi izuzetne pogodnosti za izučavanje niza zanimljivih pojava.

Različiti numerički eksperimenti su radjeni upotrebom sedamkilometarske pravilne mreže, 10 vertikalnih nivoa različite debljine, različitih graničnih vrijednosti, različitih polja vjetra.

Ustanovljeno je da se površinski sloj kreće u smjeru vjetra dok se niži slojevi nadovezuju na generalnu cirkulaciju.

Prva simulacija pokazuje da su kako poznavanje meteorologije tako i poznavanje saliniteta i temperature neophodni da bi se dobila stvarna simulacija utjecaja rijeke Pad kao i relevantni čimbenici važni za biološke procese.