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Modelling basic physical parameters in the Adriatic Sea as the basis for marine benthic habitats mapping

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ABSTRACT

There is a great challenge for marine ecologists to explain and map benthic marine habitats by developing new methods that identify and link environmental processes responsible for those map patterns. Methods that use single factors such as sediment type or water depth for predicting and explaining marine benthic habitats are generally inadequate when applied on a broad scale. Using a combination of factors such as near bottom velocity (tidal and wind induced), temperature and salinity fields in conjunction with sediment type and depth those habitats may be more clearly characterized. In the frame of the project "Mapping the habitats of the Republic of Croatia" (financed by the Ministry of Environmental Protection and Physical Planning of the Republic of Croatia) specific oceanographic variables (sea bottom temperature, sea bottom salinity, sea bottom currents) have to be modelled as an input parameters for neural network models developed for spatial prediction of infralittoral habitat types. The physical model used in this study is based on a three-dimensional finite element method and unstructured grid. By running the model on the high resolution finite element mesh we were able to include the main features of the very complex East Adriatic coast, representing a domain with 77 islands and many narrow channels as well as varied bathymetry. To our knowledge, this study is making the first step in gaining better knowledge and understanding of the complicated relationships of specific bottom variables (model estimates), that are playing a key role for infralittoral habitat distributions, for the whole Adriatic Sea.

1. Introduction

The challenge for marine ecologists is to map and explain marine benthic habitats by developing new cost-effective approaches that identify and link the driving environmental processes and with subsequent reconstruction of these patterns by a predictive model. Our global strategy was to include the physical parameters as input factors, among others, into a complex neural network scheme used to predict and explain recurrent patterns of marine benthic habitats. Physical parameters of the environment are an important issue in modelling and predicting marine habitat patterns and their spatial distributions (Freeman and Rogers, 2003; Rosenberg, 1995). In 1980s, the association between benthic organisms and the seafloor

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have been the subject of studies of seabed sediments. These studies found that the influence of sediments is the key factor controlling the occurrence and spatial distribution of benthic organisms (Flint and Holland, 1980; Gray, 1974; Thorson, 1957). Several recently published studies addressed the importance of other physical factors such as tidal velocity and depth on the occurrence of benthic flora and fauna (Freeman et al., 2001; Gibson and Robb, 1992).

Despite the fact that only the infralittoral zone of the eastern Adriatic benthos was required to be covered with modelled spatial distributions of chosen oceanographic variables (sea bottom temperatures, sea bottom salinity, sea bottom currents), modelling of these variables had to be carried out for the entire Adriatic Sea due to the chosen methodology (by using a 3D finite element diagnostic model with open boundary at the Otranto Strait, minimising open boundary length).

As a study area, the Adriatic Sea is a long (approx. 800 km) and narrow epicontinental basin that is shallowest at its northern part and gently sloping in the south-east direction to about a 100 m isobath. An abrupt bathymetry change toward the Jabuka Pit marks the beginning of the Middle Adriatic, which extends down to the Palagruža Sill. In the Southern Adriatic the relief deepens steeply to the South Adriatic Pit to rise again in the Otranto Strait (40 N), as seen in Fig. 1. Such a domain, with more than 1000 islands and great bio-complexity, is a big challenge for modelling.

2. Data and method

To accomplish the aim we used a high resolution 3D finite element diagnostic model based on three-dimensional shallow water equations (Lynch and Werner, 1987; Lynch et al., 1992). The model was used in similar fashion for solving a problem of summer circulation in the Canadian Artic Archipelago (Kliem and Greenberg, 2003) and spring climatological circulation of the Gulf of Maine (Lynch et al., 1997). The model solves for the dynamic variables, elevation and current and forced by density gradients, boundary conditions and wind stress. The time dependence is based on the assumption that all model variables are oscillating with frequency ω as in spectral models (for the stationary case we set $\omega = 0$ and for tidal ω = tidal frequency). The equations for continuity and horizontal momentum are:

$$i\omega\zeta = -\vec{\nabla}_H(h\bar{v}) \quad (1)$$

$$i\omega\vec{v} + \vec{f} \times \vec{v} = -g\vec{\nabla}_H\zeta - \frac{g}{\rho_0}\int_z^0 \vec{\nabla}_H\rho \, dz + \frac{\partial}{\partial z}\left(N\frac{\partial\vec{v}}{\partial z}\right) \quad (2)$$

where ω is the frequency, ζ the surface elevation, v the velocity (with bar is depth averaged velocity), i the imaginary unit ($\sqrt{(-1)}$), h the depth, f the Corriolis parameter, g the gravitational constant, ρ the density, N is the vertical turbulent mixing coefficient and ∇ is horizontal divergence operator.

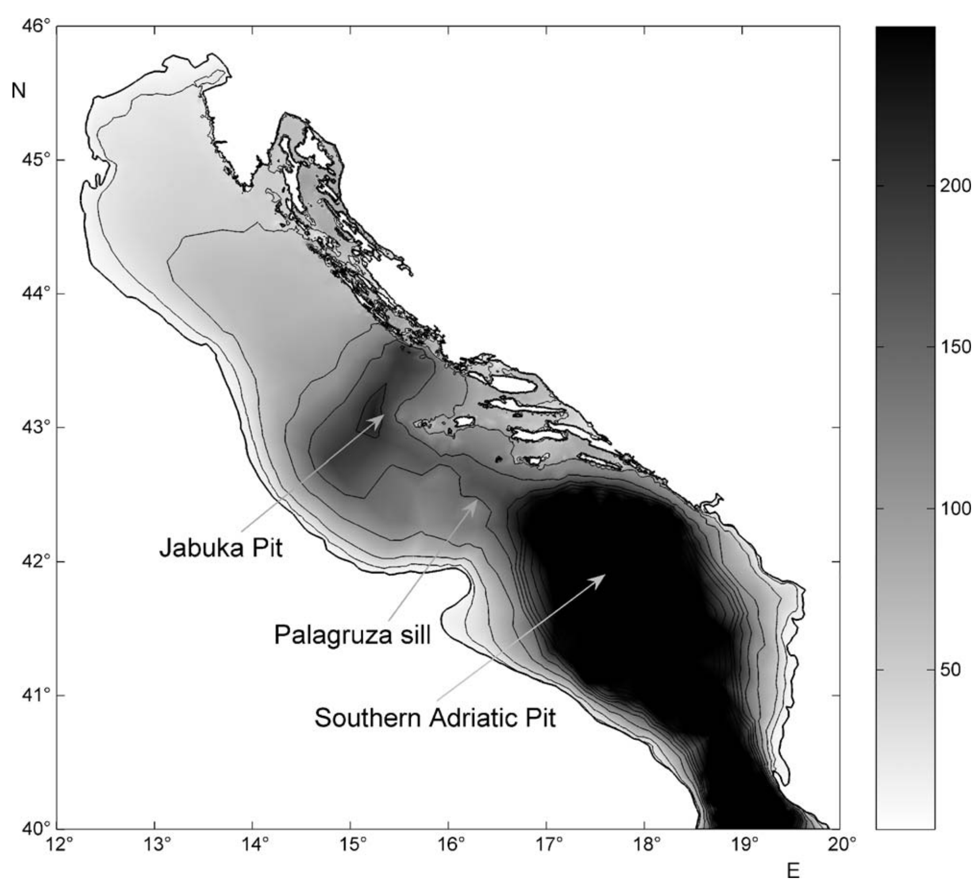

Fig. 1 – Bathymetry and coastline of the Adriatic Sea used in the finite element model. Isobaths are drawn for 20, 50, 100, 150, 200, 250 m, while after 250 m with 100 m spacing down to deepest depth of 1200 m.

The well-known “sigma” coordinate system is used in the vertical, with 21 non-uniformly placed nodes whose sinusoidal vertical spacing provides an increased resolution in the surface and bottom layers (of our direct interest). This high resolution vertical grid is necessary for adequate simulations of turbulent dissipation and details of the currents, especially along the complex Croatian coast. The horizontal finite element grid used in the study consists of 23 055 nodes and 37 200 elements.

The size of triangle areas varies from 0.02 to 757 km^2, with the length of nodal distances varying from about 500 m in coastal areas up to 44 km in the largest triangle (deep off-shore part of the domain). With this mesh (Fig. 2) we have been able to include in our simulations 77 major islands and recognize realistic topography with lateral geometry capable of representing in a realistic way the varied Croatian coast (many islands and narrow channels). Magnification of the northern part of the Adriatic Sea (Fig. 3) shows the capability of the model to resolve small-scale features important for detailed infralittoral marine habitat mapping.

The model was forced with temperature and salinity (used to calculate density gradients in model Eq. (2)) fields obtained from available datasets (MEDATLAS database) using optimal analysis. In short, the model produces a velocity field which is in dynamical balance to the forcing density field. We grouped all data into four seasons (winter = December–February, spring = March–May, summer = June–August, autumn = October–November) because of a low temporal and spatial distribution. Data were interpolated on 21 model sigma levels in order to have seasonal three-dimensional temperature-salinity (TS) fields. In that way, we obtained climatological density fields that are in good agreement with previously published results for the Adriatic Sea (Artegiani et al., 1997; Gačić et al., 1997).

Spatial distributions of original observation data are shown in Fig. 4 and temporal distribution in Fig. 5.

It is evident that for winter and autumn periods we had the least, and for summer the most, number of observations. In addition, there is a gap in the data between 1915 and 1947, probably because of the First and Second World Wars. The total number of observations used in optimal data interpolation and preparing TS model fields was 151 023 for all seasons and depths. In Fig. 5 values on the y-scale represent only the number of horizontal locations (of observations), not the total number of depths multiplied by positions.

We also probed for currents, generated with tidal forcing of the two main harmonics (M2 and K1), for contributions to the previously obtained current fields in order to have “the worst

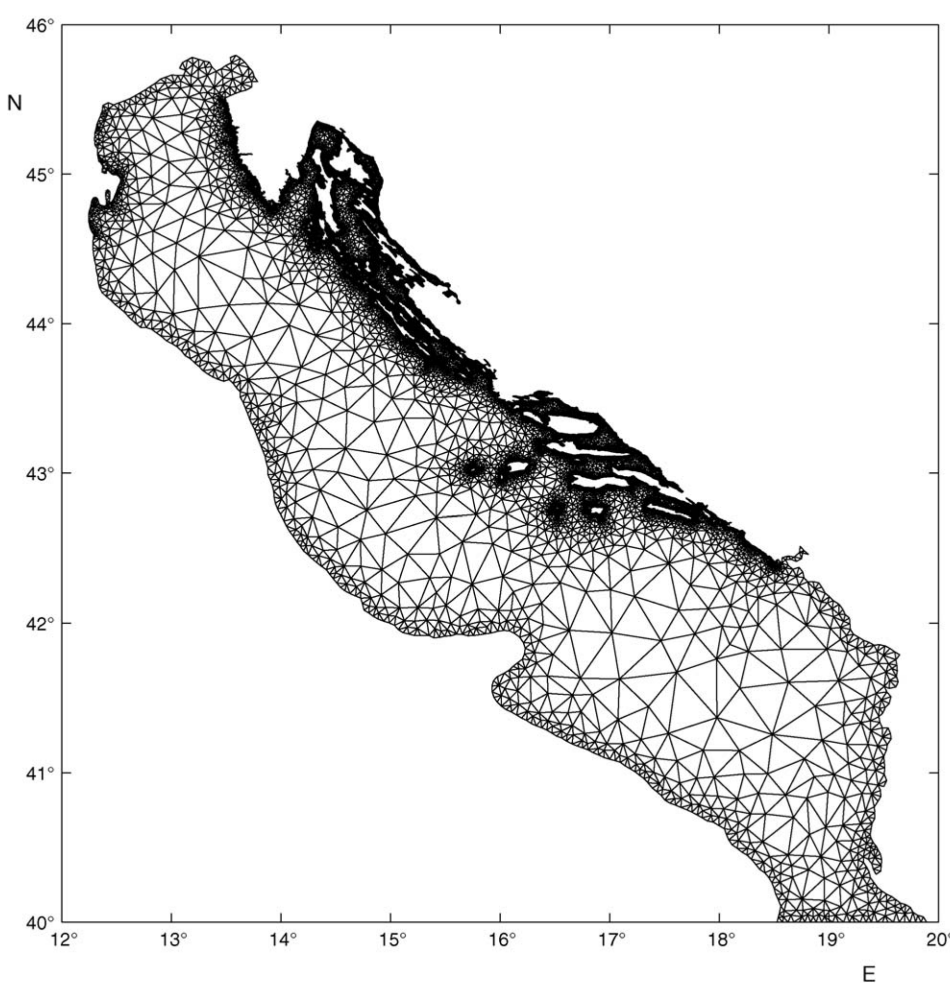

Fig. 2 – Finite element mesh of the Adriatic Sea.

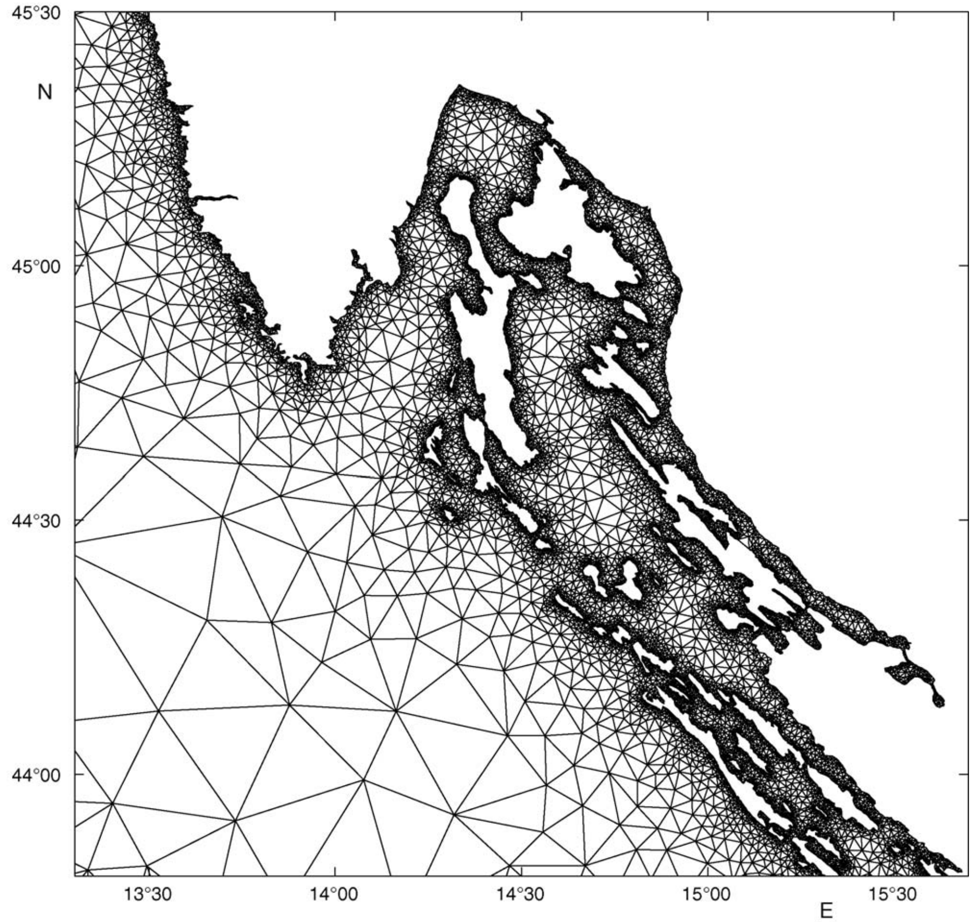

Fig. 3 – Magnification of the finite element mesh on the northern Adriatic (Kvarner region).

case scenario" for minimal bottom velocities. The tidal part of the study was carried out previously using a similar model (prognostic) and data assimilation technique (Janeković et al., 2003). The particular topography of the Adriatic Sea and resonance frequency of the first two Adriatic modes, close to the tidal frequency of diurnal and semidiurnal harmonics, result in stronger tidal dynamics in the otherwise weak Mediterranean Sea tidal response. Combining those two sets, presuming that tidal dynamics are manly barotropic phenomena that are invariant through the seasons, we computed minimum bottom current magnitude as a measure of bottom kinetic energy.

Another possible limiting factor for particular marine habitats, apart from minimum bottom velocities, is the opposite – i.e. maximal bottom velocities. This type of circulation can occur in cases of strong wind which transfers momentum through the sea surface down to the bottom. Wind-driven circulation was obtained using typical strong wind stress (0.2 Pa) blowing along the basin from the south-east (sirocco) and across the basin from the north-east direction (bora) giving possible high values of current magnitude at the bottom. The effect of wind-induced sea bottom currents is more pronounced in the shallow northern part, rather than in the middle and southern deep parts of the Adriatic Sea. In deeper parts of the domain, there is a well-known compensation current due to conservation of volume with nearly the opposite bottom current direction of wind forcing. On the other hand, in very shallow areas, like those close to the Italian coast, current is directed, along with wind direction, through the entire vertical profile which is in agreement with previously published results (Orlić et al., 1994). Fig. 6 shows the magnitude of bottom velocity induced by wind blowing from a south-east direction, along the Adriatic Sea. Intensification of bottom currents is evident in narrow channels (northern Adriatic) and along the southern East Adriatic where it has a maximum value of about 20 cm/s.

3. Results and discussion

Using the data fields and methodology previously described, we succeeded in producing temperature and salinity seasonal mean fields which, while never happening in nature, are most likely to occur. It is therefore necessary to be aware of the limitations of the physics, as well as the numerics, of the model with those types of forcing fields. Numerical simulations can never replace reliable observations, in fact, the simulations rely on the observations. However, models can help in the interpretation of the data and in the understanding of the physical processes taking place. Those fields were used in the

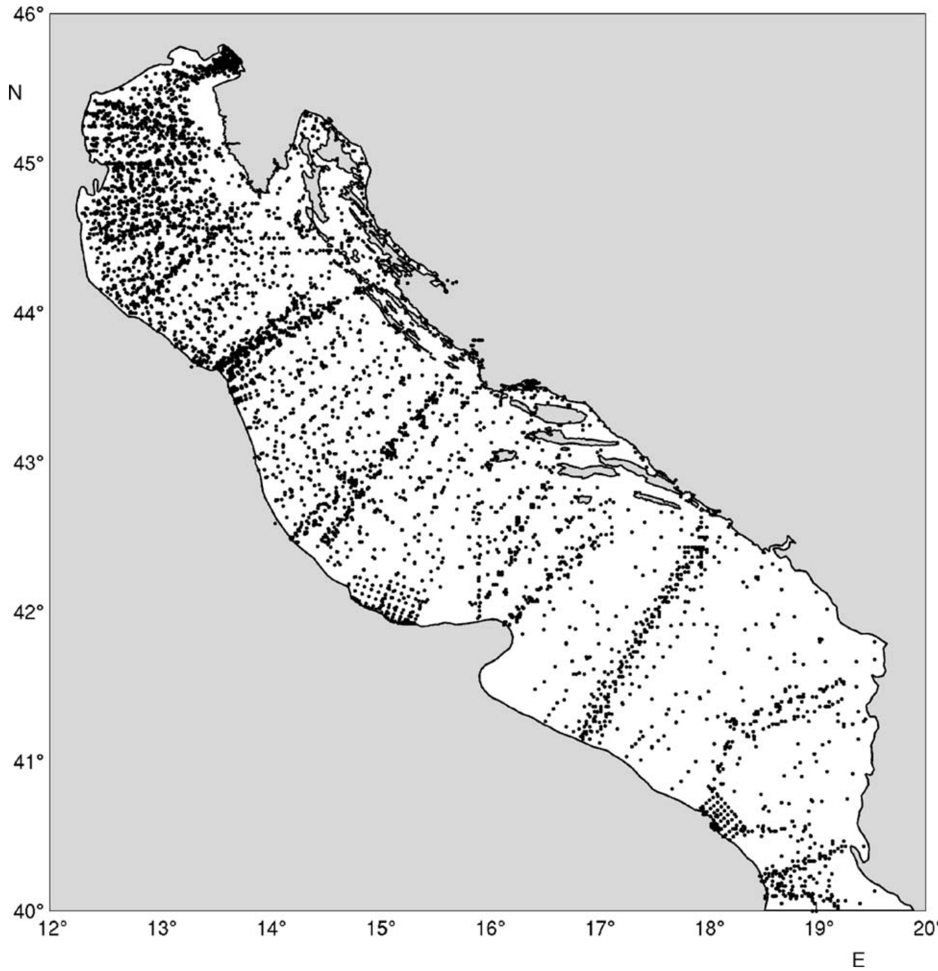

Fig. 4 – Location map of temperature and salinity observations used in optimal analysis procedure.

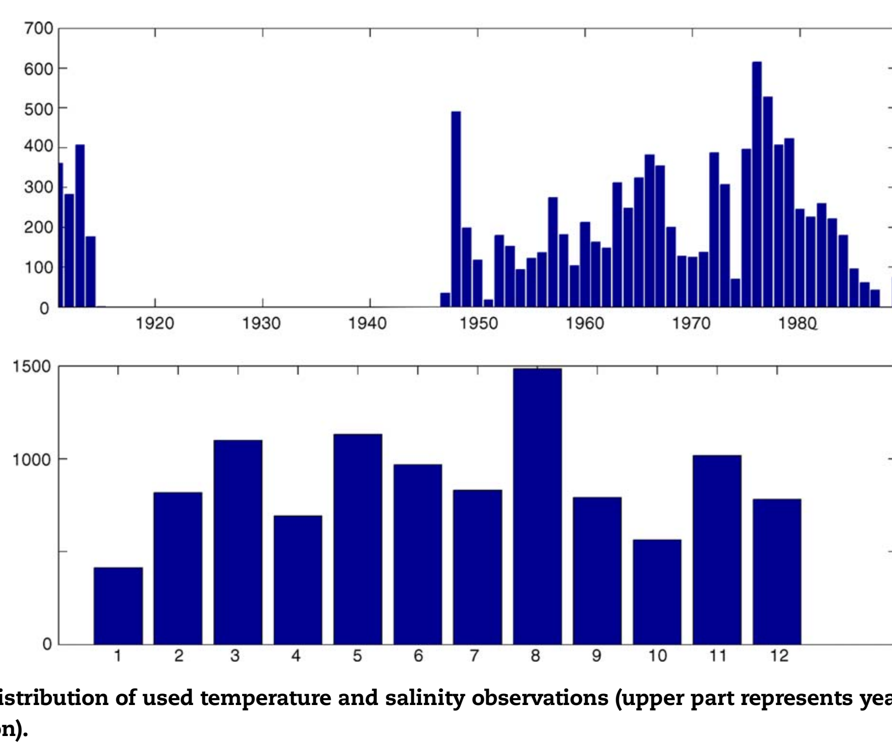

Fig. 5 – Temporal distribution of used temperature and salinity observations (upper part represents yearly and lower part monthly distribution).

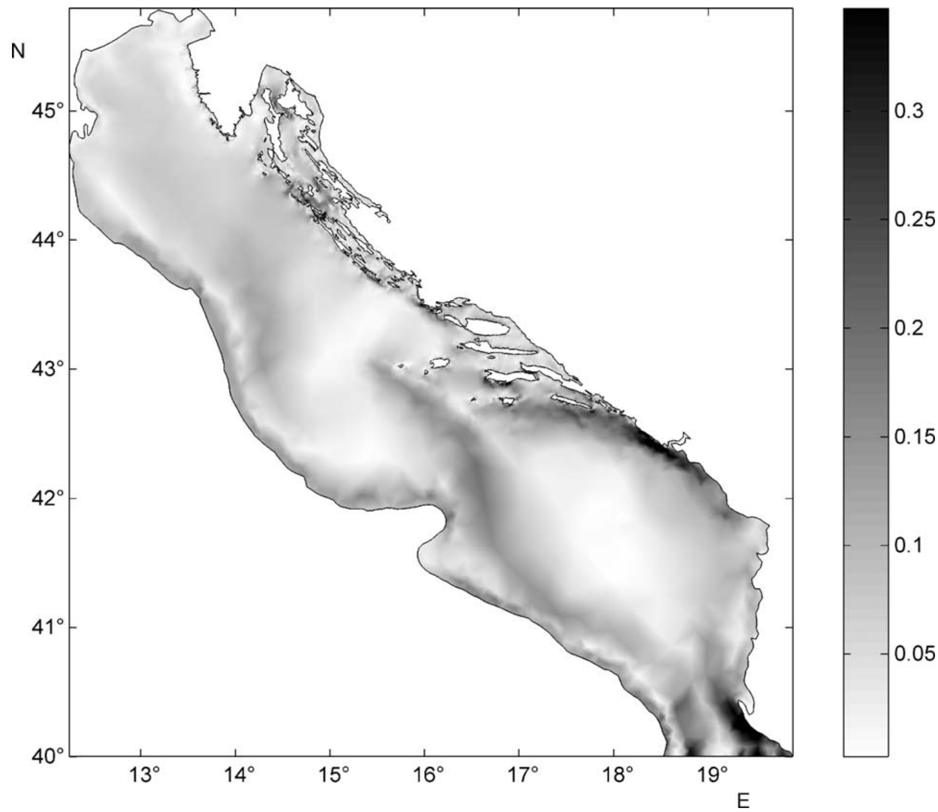

Fig. 6 – Magnitude of bottom currents (in m/s) induced by wind stress of 0.2 Pa blowing along the basin from the south-east direction.

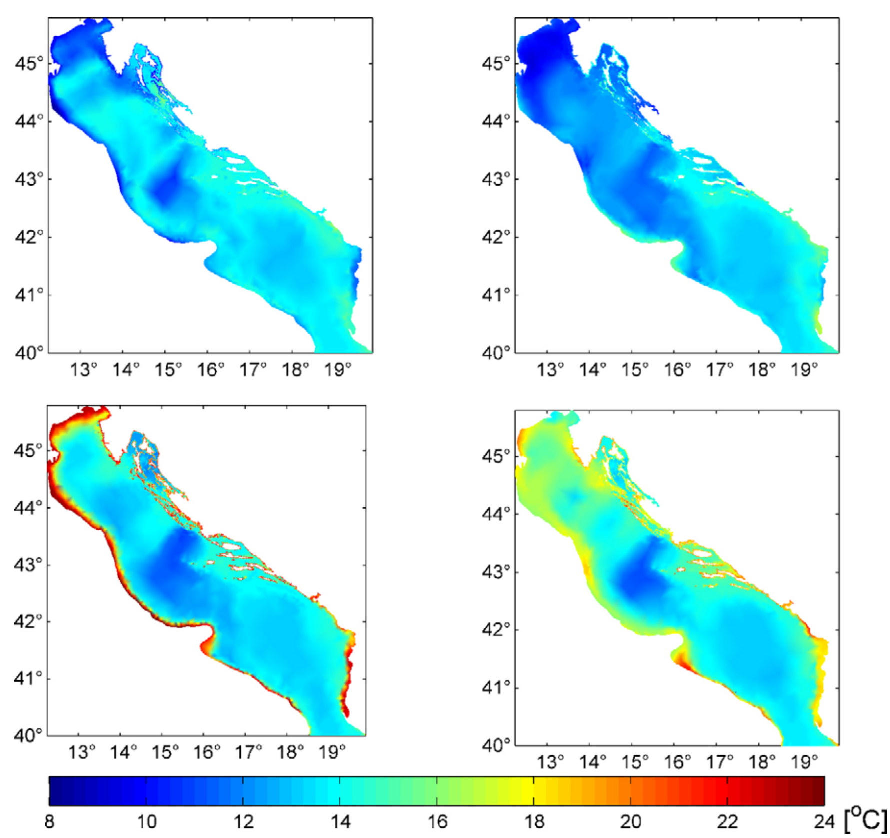

Fig. 7 – Seasonal climatological temperature fields at the last sigma model level (one meter above true bottom). Upper-left part indicates horizontal distribution in winter, upper-right in spring, lower-left in summer and lower-right in autumn.

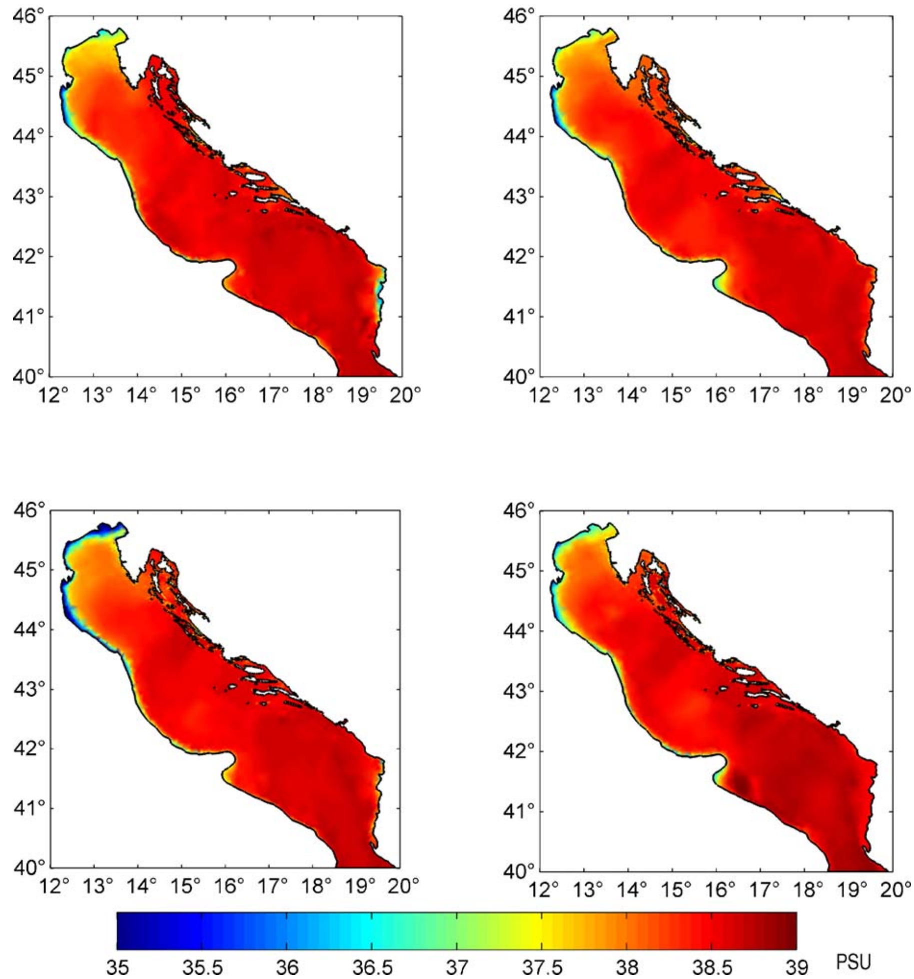

Fig. 8 – Seasonal climatological fields same as in Fig. 7 but for salinity (in PSU).

model to generate a dynamical response in the corresponding current fields that were used as the worst case scenario of minimum bottom current criteria.

It appears that, in addition to bottom currents, sea bottom temperature and salinity are very important physical parameters that control and bound specific benthic organisms. Seasonal bottom temperature fields are shown in Fig. 7, showing the temperature spatial and temporal distribution in the Adriatic Sea. All those fields are similar to those published although have better spatial resolution as needed by a high resolution finite element model mesh.

It is worth mentioning that those are not temperature fields at certain constant depth but are fields on the last sigma level in the model mesh, following basin topography. Minimum values are found in the winter period around February–March with values around 9 °C in the most of northern Adriatic which is shallow (depth <50 m) and where cooling takes place in the whole water column. In the deepest part of the Adriatic Sea (Southern Adriatic Pit), at about 1200 m, temperature is constant in time with values around 13–14 °C, which is again in good agreement with previously published results (Artegiani et al., 1997). In summer, the temperature reaches a maximum value of around 24 °C in shallow water, while in the deeper parts there is still cold water which is not affected by summer heating. With respect to salinity distribution (Fig. 8) there are values with lower salinity around river runoff regions, especially around the river Po whose signal of fresh water propagates along the Italian coast of the Adriatic Sea. On the eastern side of the Adriatic there are a few significant river runoffs including Neretva, Krka and Zrmanja, but are small compared to river Po. What is worth mentioning that our objective analyses give correct values of temperature and salinity around major river runoff on the eastern side of Adriatic Sea (around the Neretva river) by preventing propagation of information through the narrow Peninsula of Peljesac. This is due to a correct correlation scale imposed on the objective analyse algorithm, in contrast to the previously published results. In the rest of the basin, there are values between 38 and 39 PSU and are nearly constant through the seasons.

The results obtained in this study are general and available for the whole Adriatic Sea, while only part of it is used in the accompanying study of Bakran-Petricioli et al. (2005) as independent variables in a sophisticated neural network training and validation scheme, not described here. That makes this study and results useful for a broad audience and, although presenting only bottom values here, we have also made estimates for the entire water column.

4. Conclusions

Modelling basic physical properties with a special focus on the bottom of the Adriatic Sea was not goal in itself but as part of a robust effort for mapping benthic marine habitats in the Adriatic Sea. To our knowledge this is done for the first time for the entire Adriatic Sea at such a space–time resolution, and the results obtained are more general and are possibly attractive to a broader academic audience. Results from this study are closely linked to the contribution of Bakran-Petricioli et al. (2005), which is using only part of our study in order to estimate input parameters for their neural network procedure. Constructing and using a high resolution finite element mesh with a resolution ranging in coastal regions from about 500 m or less, we were able to represent in a realistic way the Adriatic Sea basin, important for high resolution benthic marine habitat mapping. Careful checking of historical observational data for temperature and salinity and using optimal analysis we computed 3D seasonal fields from which we calculated corresponding density fields. Moreover, using adequate covariance fields for temperature and salinity around major eastern Adriatic river runoff we gain more realistic results than previously available (Artegiani et al., 1997). Current fields were taken into account as the magnitude of bottom velocity (at the last sigma level – one meter above true bottom) for two different scenarios; that based on density fields (geostrophic currents) and tidal (two main tidal harmonics – M2 and K1) acting as a permanent source of motion at the sea bed and secondly strong bottom current induced by strong wind storms. The latter type can be seen as the worst case scenario, which may occur rarely but can cause permanent damage to benthic habitats. Taking into account both types, as well as temperature and salinity fields separately, we have covered major physical parameters that control benthic marine habitats distributions.

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