Modelling the circulation off Iberian Peninsula

Ramiro Neves[1], Henrique Coelho[2], Aires dos Santos[1], Hélder Martins[1] and Paulo Leitão[1]

1 – Instituto Superior Técnico
2 – Universidade do Algarve

Introduction

The major task of IST in OMEX is the implementation and validation of a 3-D ocean model for the study area, in order to determine relevant water fluxes. To achieve this objective IST uses the 3-D ocean model, MOHID3D (Santos, 1995), previously implemented during OMEX I and OMEX II-I. The model was upgraded to a finite volume spatial discretization method that uses a generic vertical coordinate (Martins *et al., in press*). Coupled to MOHID3D there is an eulerian transport module of able to compute advective and diffusive fluxes of any property. There is also a lagrangian transport module capable to simulate the dispersion of particles/water masses containing a large number of properties such as volume, phytoplankton concentration, nutrient concentration, *etc.*

Circulation in the Atlantic Iberian continental margin is markedly seasonal being dominated by a southward surface current driven by the wind during the upwelling season and by a poleward density driven current during the winter. The poleward current extends from about the depth of Mediterranean Water to 200 m during the upwelling season and reaches the surface when the upwelling favorable wind relax. In this context the major task for physicists is to determine the volume transport across OMEX boundary boxes. This seasonal variability and other features related to a very complex bottom topography make the circulation around Galicia very difficult to understand and simulate. Thus it needs some previous understanding of some isolated processes. IST is conducting numerical experiments to investigate discrepancies between simulated and observed currents (see also **Task II.3**).

Results from 3-D ocean circulation model

IST is involved in several tasks both in WP I, WP II and WP IV. However all the work already done and to be done by IST in OMEX is based in the 3-D Ocean Circulation model, MOHID3D. For that reason it is appropriate to describe model results obtained during the second year of the project and then link them to each task.

Model Domain

MOHID3D was implemented in a domain covering the entire West Coast of Iberia. It is a box of 10 by 10 degrees located between 36ºN and 46ºN in the N/S direction and between 16ºW and 6ºW in the W/E direction (Figure 1). The horizontal spatial step is 8 km. In the vertical 22 layers were used. The vertical coordinate is a double sigma coordinate with the interface between the two domains located at 300 m. Bottom topography was derived from ETOPO5 database.

Initial Conditions

Initial conditions were derived from the World Ocean Atlas (WOA94) based on Levitus (1982). Spring climatological temperature and salinity were used to initialize the model. The original fields were interpolated to the model grid using an inverse square weighting method. After interpolation the obtained fields were spatially filtered. The ocean was assumed to be at rest with a horizontal sea surface.

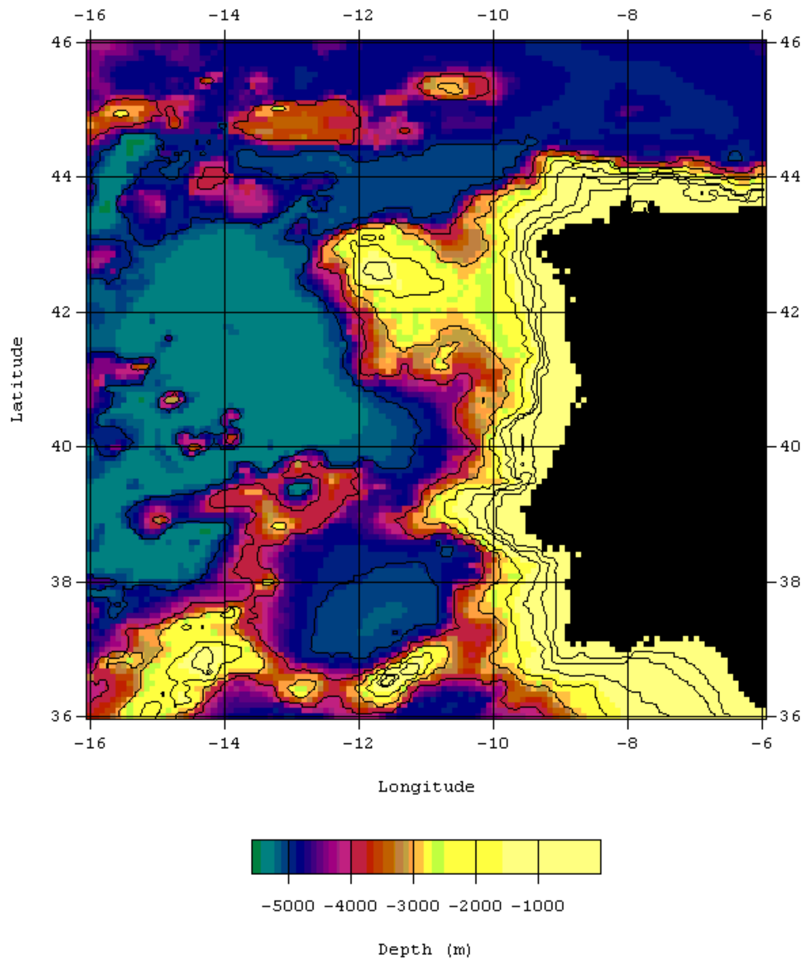

Figure 1. Model bathymetry. Contours are for 200, 500, 1000, 2000, 3000, 4000 and 5000 m

Boundary Conditions

Boundary conditions at lateral boundaries and at the bottom are described in Santos (1995). At the air-sea interface momentum, heat and mass fluxes made available by ECMWF were used. These fields are supplied every 12 hour and are then interpolated in time in order to have a value every 5 minute.

Other Run Conditions

The model is initialized with high horizontal viscosity and diffusivities O(10^4 m^2 s^{-1}). In this initial phase of the run no atmospheric forcing is considered and the model is only driven by density distribution, which in turn is frozen. After 1 month the model is reinitialized using the same density field, and the velocity and surface elevations previously obtained. Horizontal viscosity and diffusivities are calculated using the Smagorinsky formula. Vertical diffusion coefficients are obtained from a turbulence closure that solves the turbulent kinetic energy equation. Atmospheric forcing for summer months of 1994 is used.

Results

In general we can say that results obtained for current field show the expected patterns. On the surface layers the flow is southward with a significant offshore component. This represents the ocean response to the equatorward-prevailing winds in Summer. Below the surface layer (about 80 m) the flow is reversed over the shelf (the flow is poleward) corresponding to the baroclinic adjustment to upwelling. Over the slope the flow is poleward and intensifies with depth until near 1000 m (more than 20 cm s^{-1}). This represents the signature of the slope current. The slope current reaches maximum intensity near Nazaré Canyon and decreases consistently to north. Figures 2 to 5 show some of the described features. In some locations cyclonic and anticyclonic eddies are seen. Usually these eddies seem associated with irregularities in topography as it is the case in front of Lisbon (Cabo da Roca), at the Nazaré Canyon (where a cyclonic eddy develops) or around Vigo mountain.

Specific results for tasks

Task I.6
A nested model module was implemented in MOHID3D. The utility of this module is the ability to simulate small specific areas without diminishing spatial step in the all modeled area. The kind of model implemented for now is a 1 way, meaning that information is passed only from the large-scale model to the small-scale model. In this implementation it is allowed that a run for the nested model is done separately from the regional model. This represents a considerable reduction in CPU and makes possible that another different team use the results of the regional model to run the nested model for is own purposes. In particular the nested model is available for SINTEF to run it coupled with biochemical model.

A Lagrangian particle-tracking model was coupled to the hydrodynamic model. Particles to be tracked can have a large number of properties (*e.g.*, volume, nitrate concentration, phytoplankton concentration, *etc.*). During the second year of OMEX a non-dimensional biochemical model was coupled to the particle-tracking model using a prototype interface developed during OMEX I.

The system of coupled models (hydrodynamic, particle tracking and ecological) was run for summer months. We present here results for August 1994. On the Figures 6 and 7, positions of particles and concentrations of ammonia, nitrate and phytoplankton are shown. Although this represents a very preliminary application of the coupled system of models there are some interesting features that are reproduced. Upwelling near Rias is reproduced and identified by relatively high primary production (0.05 mgC l^{-1} after 15 days, 0.18 mgC l^{-1} after 30 days). In this area, where higher phytoplankton concentration is found, nitrate values are minimal and ammonia reaches maximum concentrations. It is also possible to identify a filament near 42ºN that seems to be topographically controlled. Inside that filament we found high phytoplankton values corresponding to exportation of material from the shelf to the open ocean.

On future we will try to compare results with available data to have an idea of the accuracy of the model. After that phase of “validation”, estimations of export of material by the filament can de undertaken.

Task II.1
Historical currents processed by NUI-Galway were compared with virtual time series of currents produced by the model in the same locations and for the same period. Locations and periods to do the comparisons were choose having in mind available atmospheric data to drive 3-D ocean circulation model. Virtual time series were analyzed as if they are real (computation of mean, standard deviation, *etc.*) and comparison was made in that way.
Comparisons are shown in Table 1.

					OBSERVATIONS			MODEL		Direction	
Month	Latitude	Longitude	Depth	CM Depth	East	North	Stability	East	North	Obs.	Model
8	42.218	-9.803	2337	2037	**-0.53**	**1.14**	0.86	**-3.6**	**7.7**	**114.9**	**115.0**
8	42.218	-9.803	2337	837	**-1.22**	**2**	0.88	**-11**	**29**	**121.4**	**110.7**
8	42.218	-9.803	2337	1237	**-0.69**	**2.66**	0.9	**-8**	**24**	**104.5**	**108.4**
8	42.218	-9.803	2337	337	**-1.23**	**-0.86**	0.59	**-3**	**3.1**	**215.0**	**134.0**
8	42.218	-9.509	1338	1238	**0.02**	**-0.12**	0.1				
8	42.218	-9.509	1338	338	**-0.54**	**4.33**	0.83	**1.9**	**2.4**	**97.1**	**51.7**
8	42.218	-9.509	1338	838	**0.53**	**2.1**	0.83	**1.6**	**0.74**	**75.9**	**24.8**
9	42.218	-9.803	2337	2037	**-0.46**	**2.49**	0.89	**-3.6**	**8.8**	**100.4**	**112.2**
9	42.218	-9.803	2337	837	**1.81**	**3.88**	0.73	**-11**	**29.9**	**65.0**	**110.2**
9	42.218	-9.803	2337	1237	**0.59**	**2.92**	0.63	**-8.05**	**31**	**78.6**	**104.5**
9	42.218	-9.803	2337	337	**3.12**	**3.14**	0.71	**-2.88**	**8.53**	**45.2**	**108.6**
9	42.218	-9.509	1338	1238	**0.46**	**-0.16**	0.36				
9	42.218	-9.509	1338	338	**-0.89**	**3.87**	0.59	**0.5**	**1.5**	**102.9**	**71.6**
9	42.218	-9.509	1338	838	**0.06**	**0.45**	0.42	**1.8**	**1.09**	**82.4**	**31.2**

Table 1. Comparison of current meter data and simulated current time series. Zero degrees means a flow to the east and positive rotation is counter-clockwise.

This kind of comparison is not meaningful, since the model is not able to reproduce many features that exist in nature. However direction of the flow predicted by the model generally agrees with current meter data. The magnitude of the simulated mean currents is much larger than observed and this is very consistent in all the points considered. Reasons for that are now being investigated but there are two features that must be pointed out: 1) Most of the variability found in current meter data is at the level of Mediterranean water and probably associated with MEDDIES. The model is not able to reproduce such variability at least in this simulation. On future the model domain will include the Strait of Gibraltar and the western Mediterranean Sea in order to simulate the outflow of Mediterranean Water. 2) From current meter analyses it is clear that the poleward slope current decreases to the North. This is unexpected since theory predicts an increase in slope current. All the simulations previously done by IST also predict an increase in slope current. Measurements made by IH a few years ago have shown that meridional density gradient is concentrated further to the south and almost disappear north of Nazaré. This means that the forcing for slope current does not exist north of 41ºN. This pattern in the density field does not exist in Levitus data that has 1º of resolution. This can be an explanation for simulated increase in currents. IST is now conducting numerical experiments using density fields measured by IH to investigate the behavior of slope current at the latitudes of the OMEX site.

Task II.3

A 1-D vertical model developed during OMEX I was applied for the OMEX II-II region using climatological data from Esbensen and Kushnir (1981) and initial conditions from Levitus (1982). A technique for correction of heat fluxes was developed using observed SST producing more accurate results for temperatures and for turbulence parameters such as turbulent kinetic energy, turbulent viscosity and turbulent diffusivities. The model was coupled to an ecological model and run for several years. The idea is to have a reference simulation and then develop a 2-D cross-section model that is able to simulate vertical advection (upwelling/downwelling, internal waves) and compare the results since the vertical motions in water column must provide additional pumping of nutrients to the photic zone that results in enhanced primary production. Results for preliminary simulations are presented in Figures 8 to 10. These results are not representative of an upwelling region and so they show only the classical spring and autumn blooms. It is also remarkable to observe the interannual variability even when the forcing is the same in every year. This makes clear the importance of having a good initial condition.

In order to validate the turbulence closure UWB-b will make available profiles of temperature, kinetic energy and turbulent viscosity as well as atmospheric forcing for comparison with 1-D and 3-D correspondent profiles.

Task II.4

In order to determine input and output fluxes across the OMEX box the results obtained with 3-D ocean circulation model were used. The OMEX box (42ºN to 43ºN; 10ºW to coastline) was divided in four smaller boxes:

- BOX 1 – Coastline to 9º30'W; 42ºN to 43ºN; surface to 110 m.
- BOX 2 – 9º30'W to 10ºW; 42ºN to 43ºN; surface to 110 m.
- BOX 3 – Coastline to 9º30'W; 42ºN to 43ºN; 110 m to bottom.
- BOX 4 – 9º30'W to 10ºW; 42ºN to 43ºN; 110 m to bottom.

The water fluxes were monthly integrated across these box boundaries. Schematic representation of boxes and water fluxes are presented in Figure 11 for August 1994. Larger transports are associated with slope current at levels deeper than 200 m, reaching about 12 Sv at the southern boundary of BOX 4. Part of this transport is then topographically deflected offshore (7 Sv) while the rest passes across the northern boundary of BOX 4 (5 Sv). It is possible that most of the 7 Sv deflected offshore still flow northward around Vigo mountain but west of the western limit of OMEX box (Mazé *et al.*, 1996). According to the previously mentioned comparison with current meter data these transports are probably exaggerated. This is also subject of future investigation.

Future work

For the third year of the project IST has the following plan.

1 – Validation of the model using historical current meter statistics (in collaboration with NUI-Galway). For this task ECMWF atmospheric data for 1994 will be used since there are a reasonable number of observations for that period (**Tasks II.1.5** and **II.4.3**)

2 – To use IH meridional sections of density to force the model in order to obtain a more accurate slope current.

3 – Once the model is calibrated net fluxes across box boundaries will be computed. (**Task II.4.3**)

4 – To compare turbulence parameters already obtained with 1-D vertical model and that will be obtained with 3-D model with data measured by FLY. (**Task II.3.3**).

References

Esbensen and Kushnir, 1981: Oregon St. global heat flux and wind stress. OSU Climatic Research Institute, rep. nº 26 and 29.
Levitus B. (1982) Climatological Atlas for the World Ocean. NOAA Prog. Papers 13, US Government Printing Office, Washington DC.
Martins, F.A., R.J. Neves, P.C. Leitão, in press. A three-dimensional hydrodynamic model with generic vertical coordinate. Hydroinformatics98 Conference Denmark, August 98.
Mazé, J. P., M. Arhan and H. Mercier, 1997: Volume budget of the eastern boundary layer off the Iberian Peninsula. *Deep-Sea Research I*, **44**, 1543-1574.

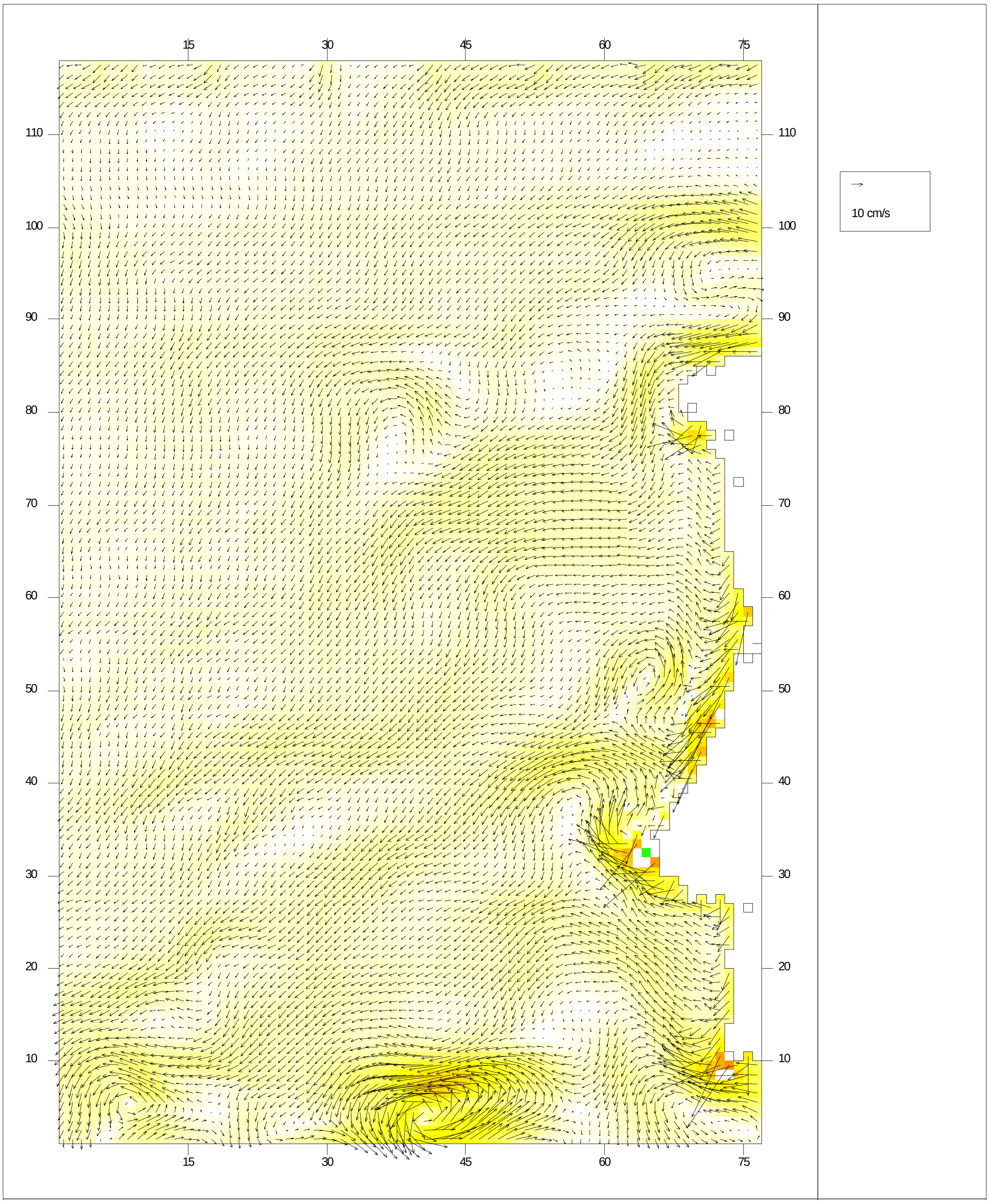

Figure 2. Surface circulation at the end of September.

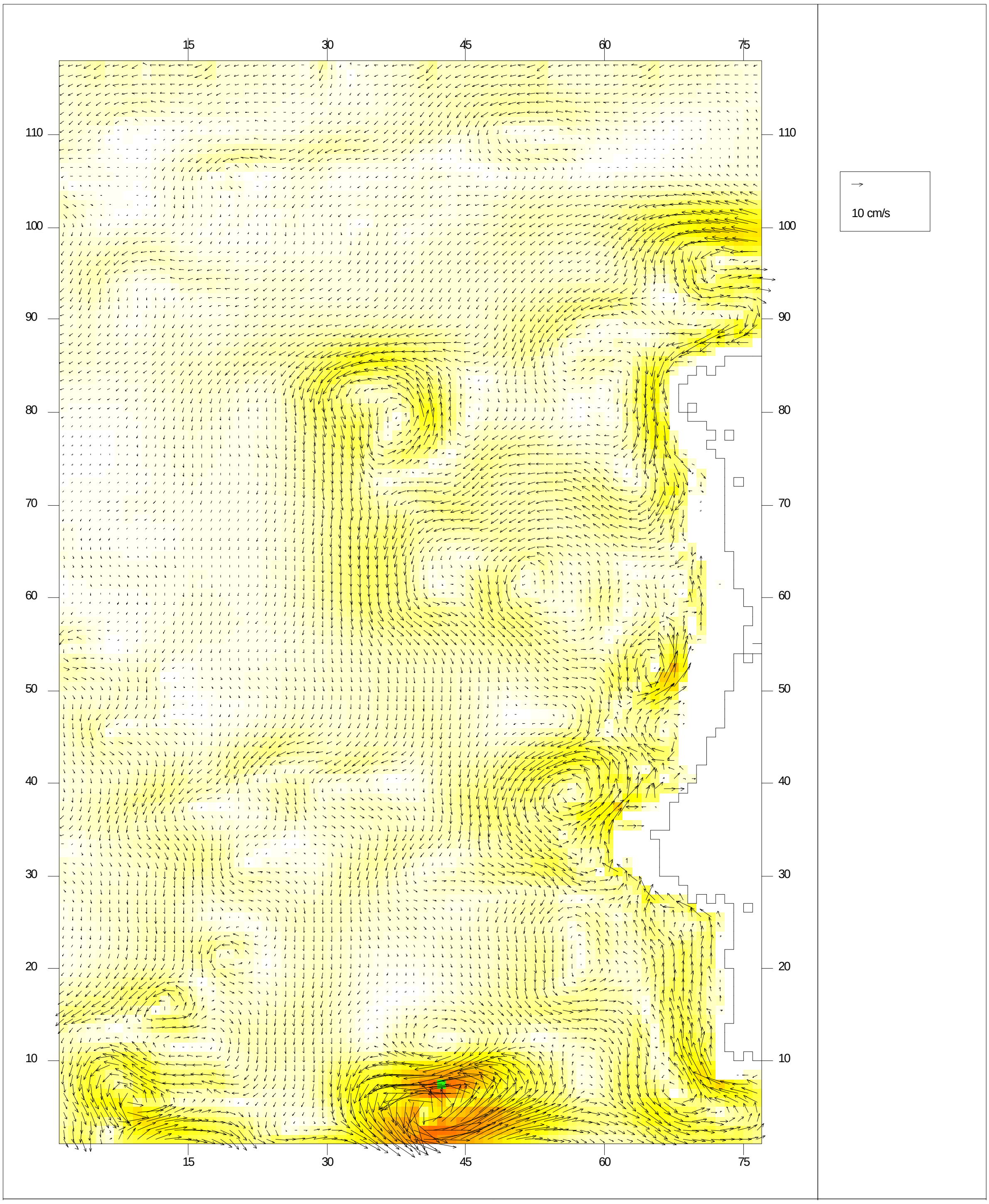

Figure 3. Circulation in layer 15 (near 130 m) at the end of September.

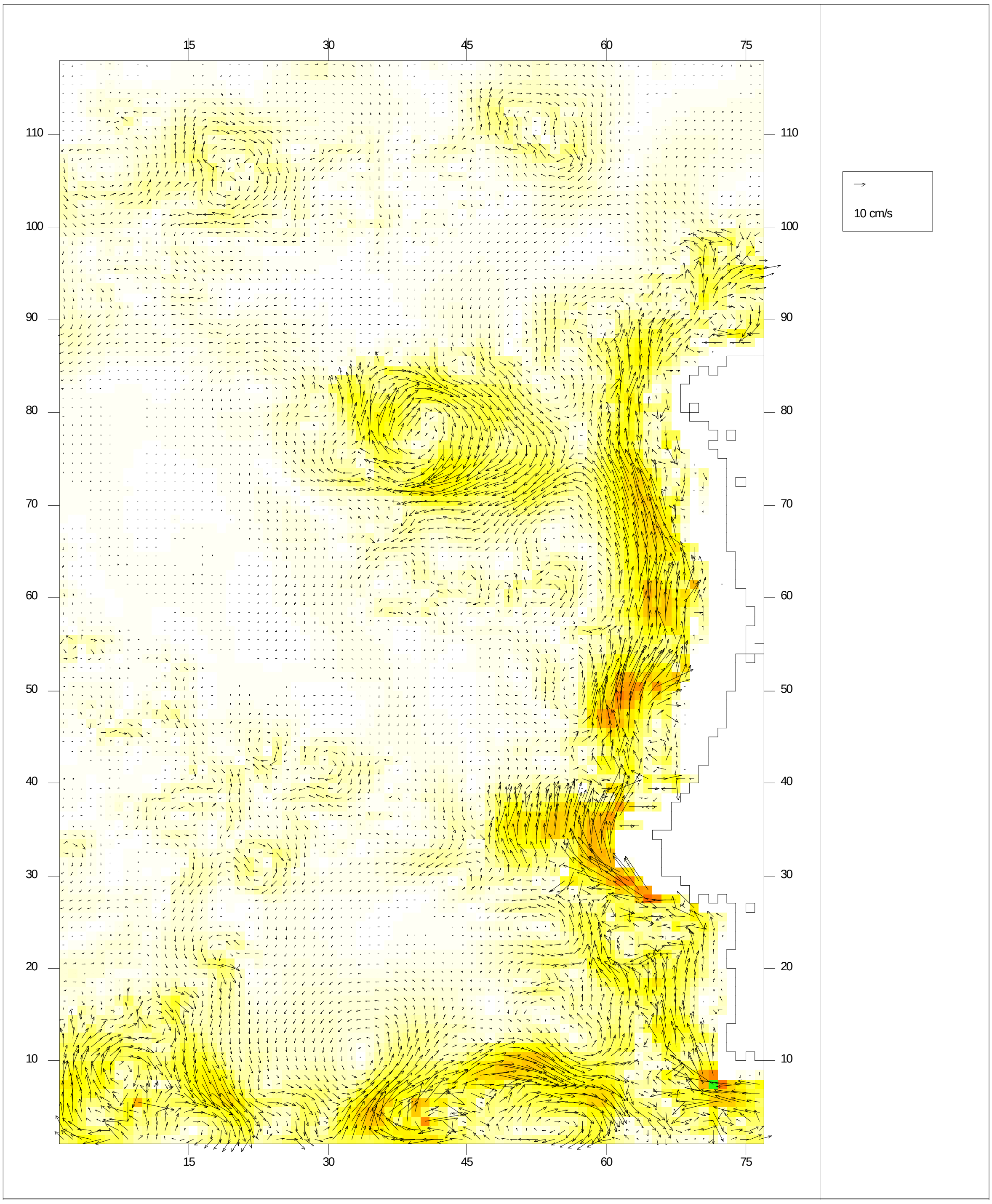

Figure 4. Circulation in layer 3 (near 1000 m) at the end of September.

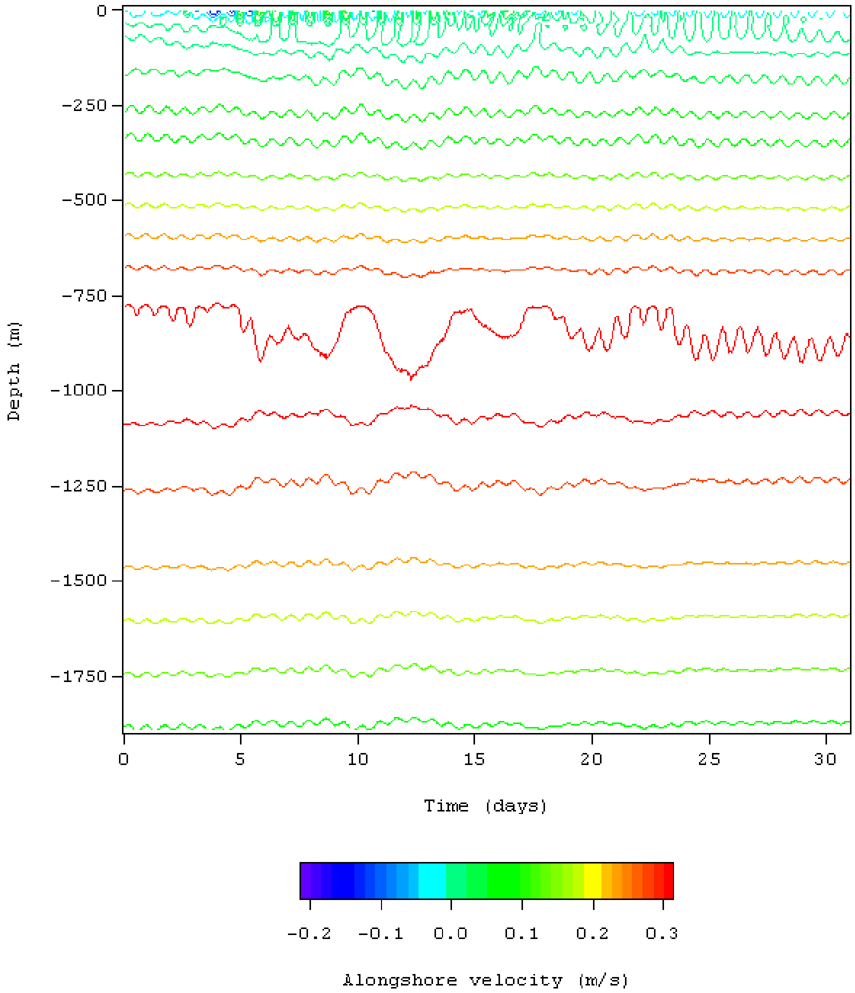

Figure 5. Evolution of alongshore component of velocity at 42.218ºN, 9.803ºW for August 1994.

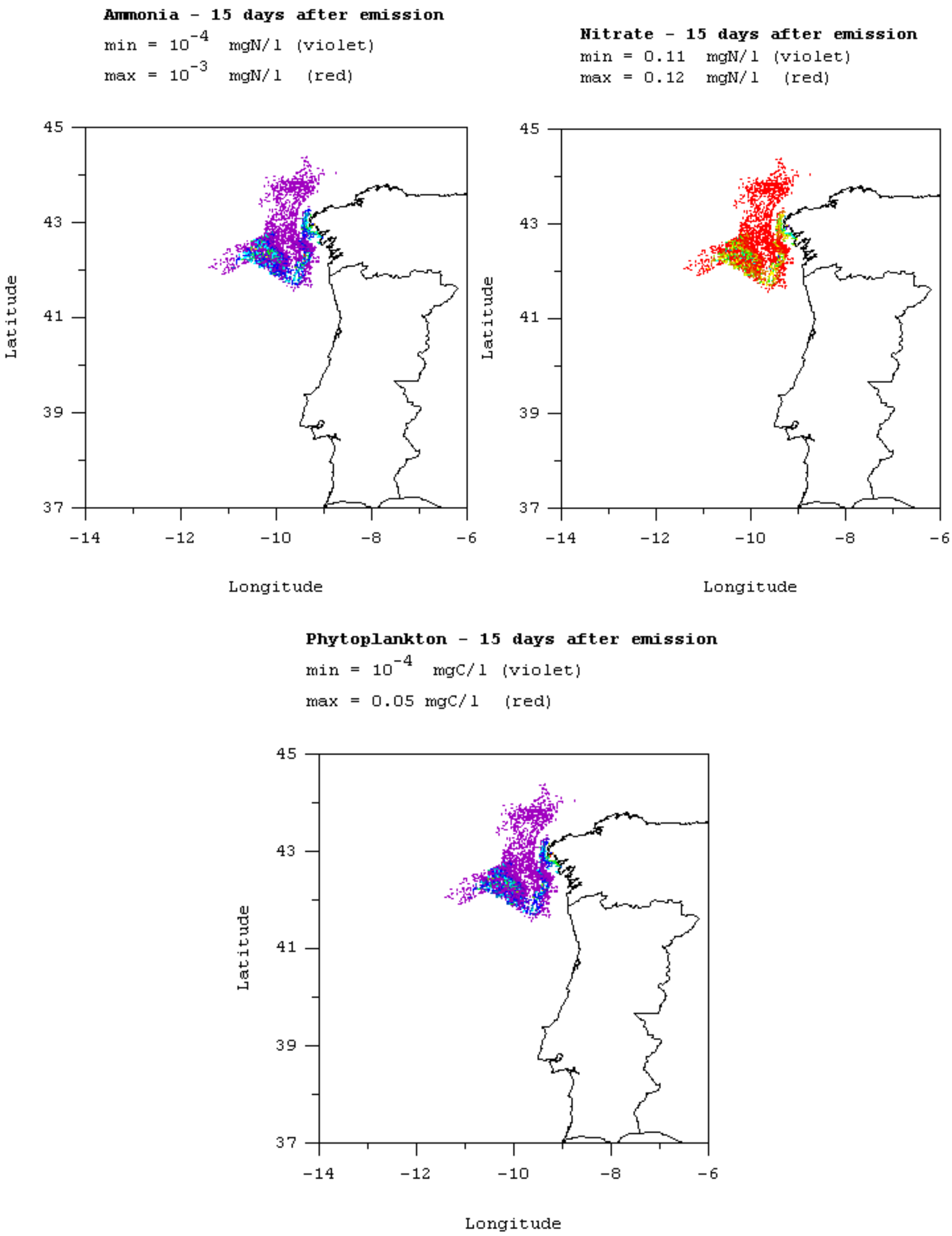

Figure 6. Distribution of particles 15 days after emission and concentration of ammonia, nitrate and phytoplankton.

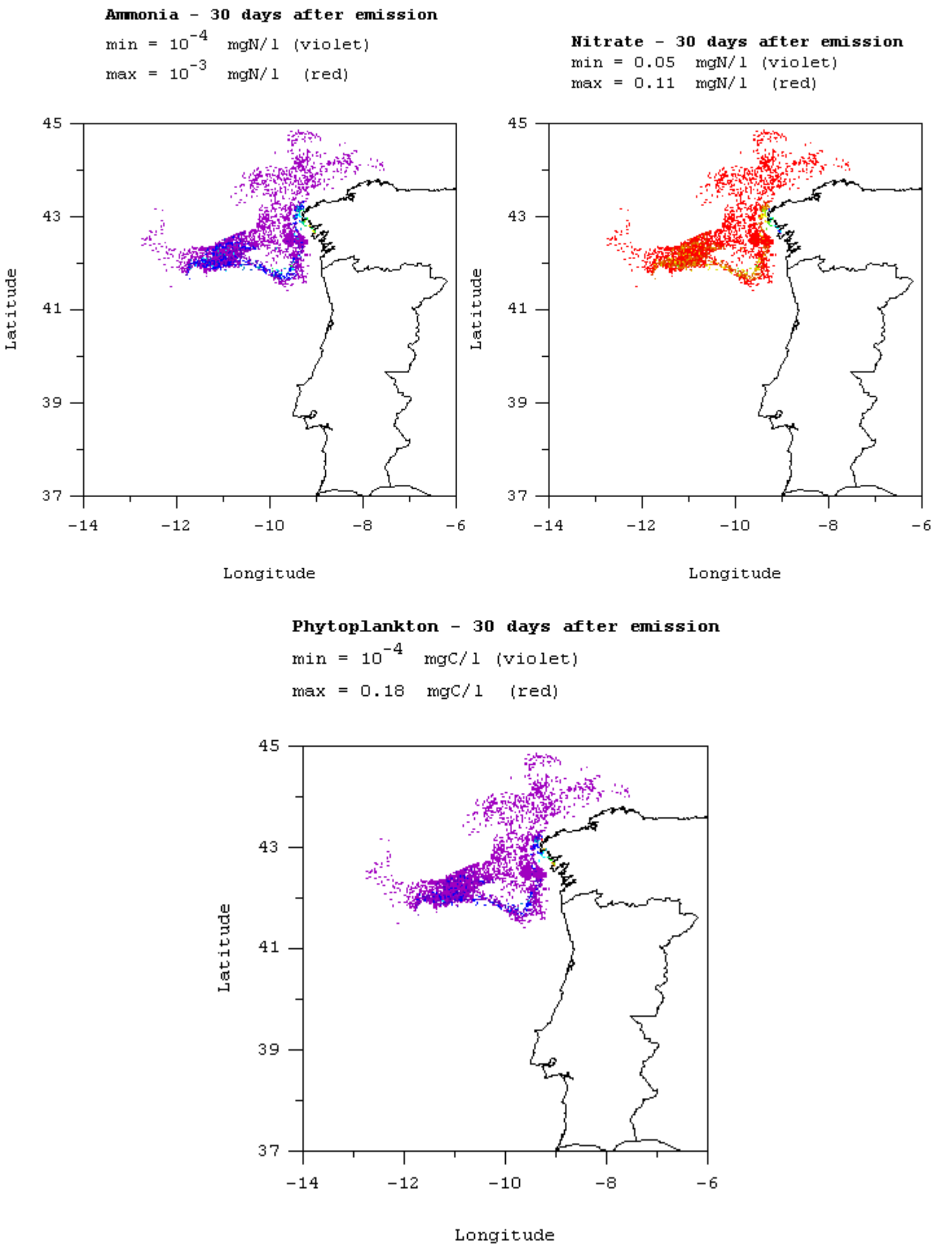

Figure 7. Distribution of particles 30 days after emission and concentration of ammonia, nitrate and phytoplankton.

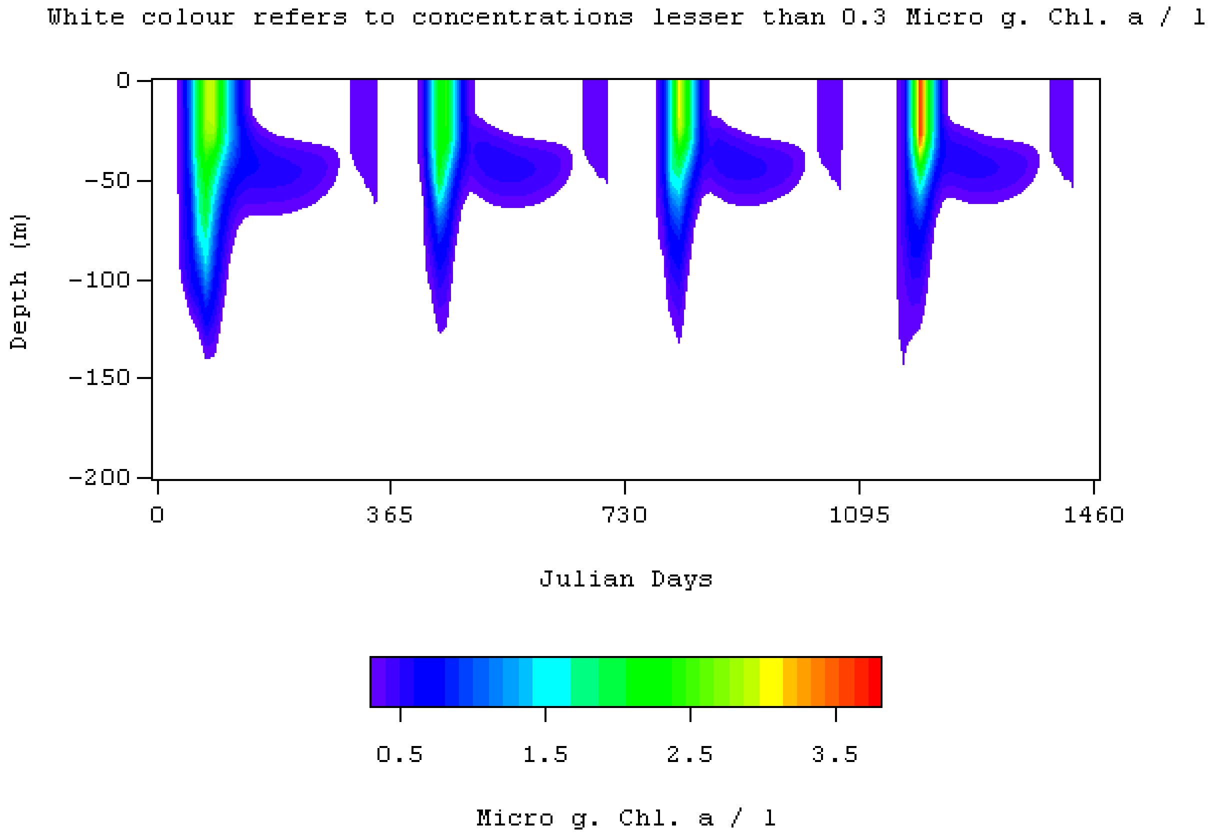

Figure 8. Temporal evolution of Chl *a* during in the four years run with the 1-D model.

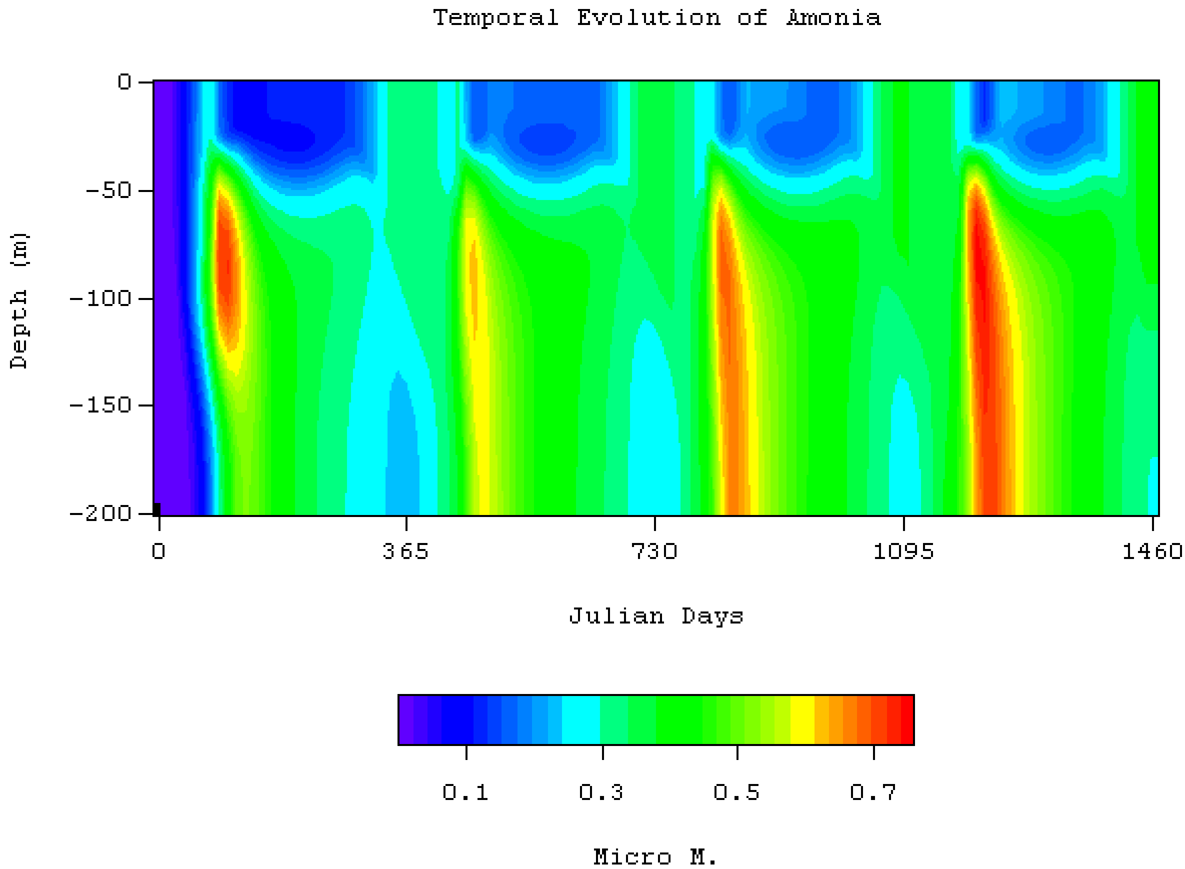

Figure 9. Temporal evolution of ammonia during in the four years run with the 1-D model.

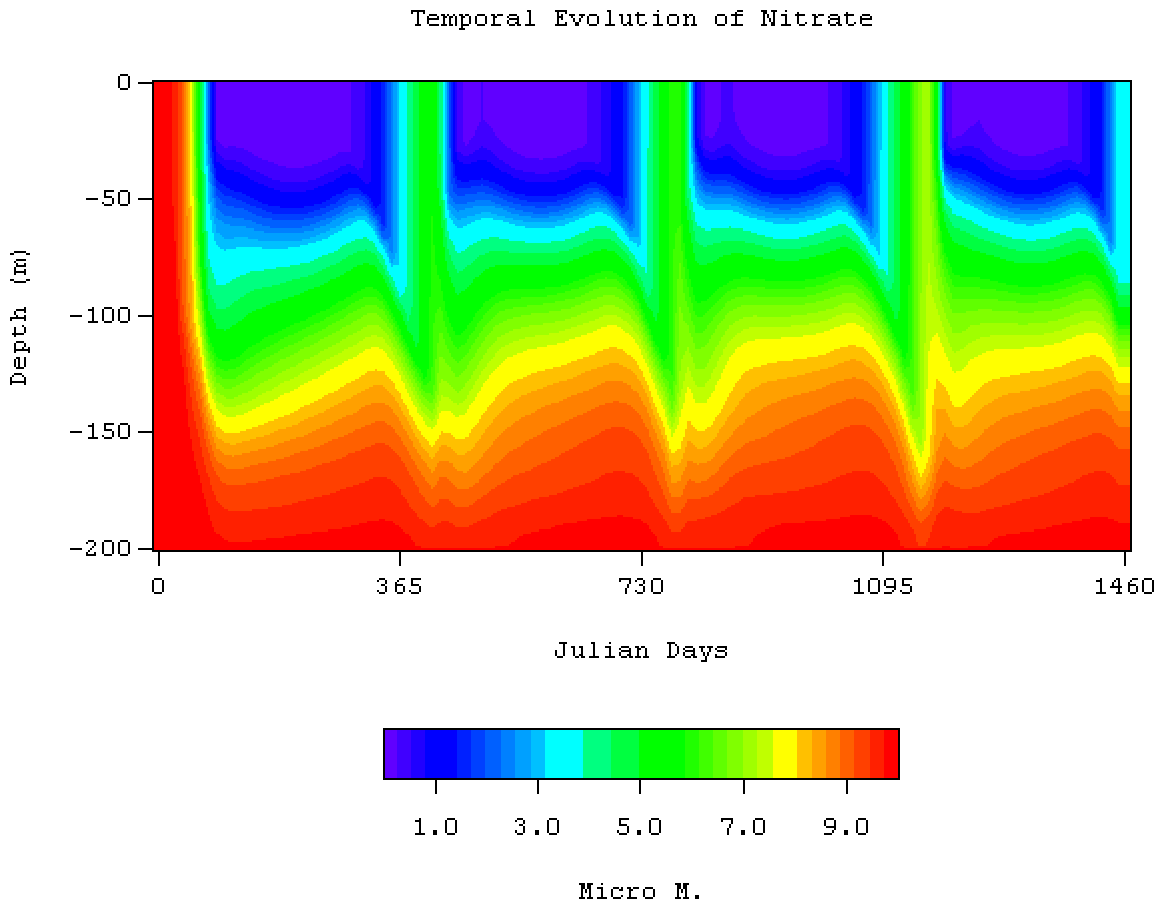

Figure 10. Temporal evolution of nitrate during in the four years run with the 1-D model.

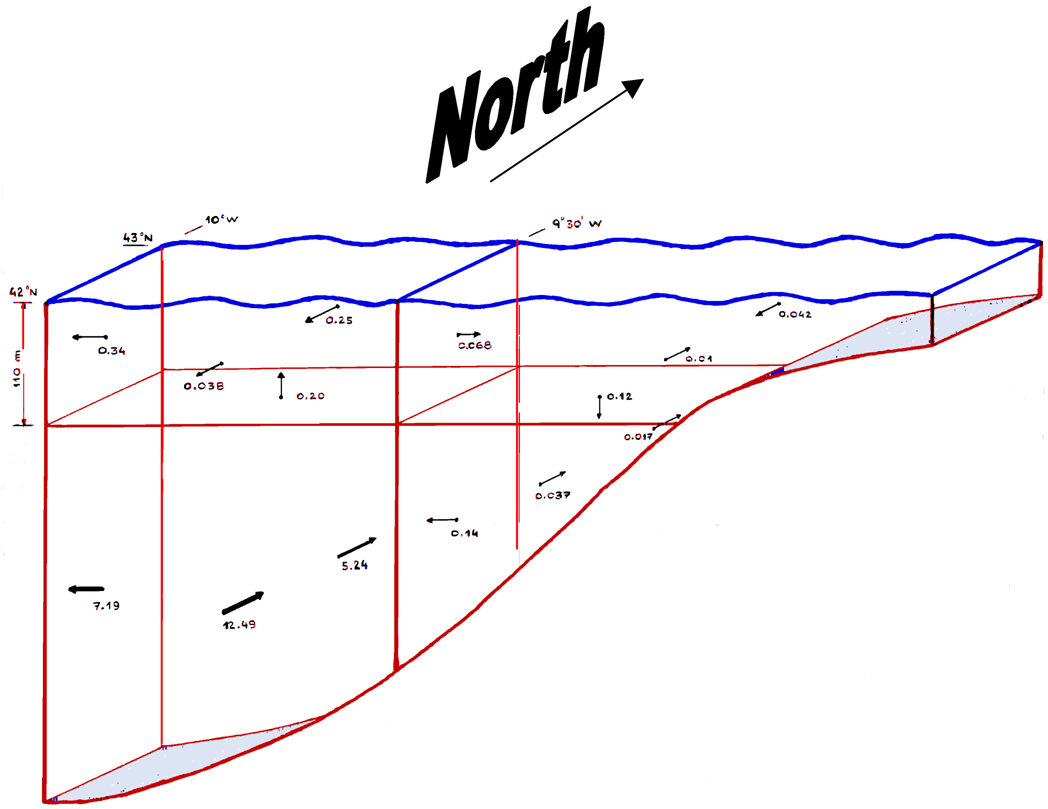

Figure 11. Water Fluxes trough OMEX box in early August. Arrows are not on scale and water fluxes are in Sv.