Three-dimensional simulations of mercury cycling in the Mediterranean Sea.

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Abstract: Circulation in the Mediterranean Sea has been simulated by the 3D model PCFLOW3D for four seasons, based on measured temperature/salinity fields. Data on mercury input from larger rivers and some Hg-enriched point sources were obtained from UNEP reports. Distribution of total mercury in the Mediterranean Sea has been calculated by the same model for the period of two years, simulating separately the transport of dissolved and particulate mercury. Suspended sediment transport was also simulated. The model predicts high mercury concentrations near locations of major river inflow.

Key words: Three-dimensional mercury model, Mediterranean Sea, Mercury transport.

INTRODUCTION

The Mediterranean Sea water has relatively high mercury concentrations, due to natural and anthropogenic sources. Two world's largest mercury mines are located in the Mediterranean catchment (Almaden, Spain and Idrija, Slovenia). Pollution from the atmosphere, arriving mostly from central and northern Europe, is also important.

An international research project was launched in 2002, with the aim to develop an integrated modelling system for simulation of mercury cycling processes in the Mediterranean. The "water model" should simulate the hydrodynamic circulation, with transport and dispersion of several forms of mercury and some basic bio-chemical processes. An atmospheric model should simulate similar mercury processes in the atmosphere. The two models will be coupled to simulate complete mercury transport and fate processes. Measurements of several water quality parameters and different mercury species were carried out during two Mediterranean cruises and also during a few costal campaigns to calibrate and verify the model.

This very difficult task has been partly achieved and first results of the "water model" simulations are presented.

DESCRIPTION OF THE MODEL AND SIMULATION METHODOLOGY

PCFLOW3D is a three-dimensional circulation and transport and fate model. It integrates hydrodynamic module, transport dispersion and sediment transport module. It is based on the finite volume method; the system of differential equations is solved using a hybrid (central-upwind) implicit scheme, while in the transport module the second order Quick scheme is included. In the horizontal plane, the turbulent viscosity and diffusivity are calculated by the Smagorinski principle, while in the vertical direction, the simplified one-equation turbulence model of Koutitas and the Mellor-Yamada turbulence model are included. Simulation of some biochemical processes has also been included. The model is described in detail in RAJAR AND ČETINA (1997), RAJAR ET AL. (2000, 2004).

There are two methods of solving the transport equation in the model, an Eulerian finite difference method (FDM) and a Lagrangean particle tracking method. The FDM (Quick scheme) was used in this research.

Fig. 1 shows the processes, which will be included in the mercury transport module. Mercury transformation equations have only partly been applied in the simulation of processes in the Mediterranean. In the present state, the transport and dispersion of dissolved and particle-bound mercury in both non-methylated and methylated forms can be simulated.

Although the main goal of the research was to investigate long-term trends of mercury pollution, the calibration of the model demanded real-time simulations, which means the modelling of unsteady processes. Also, since it was found that most mercury transport is related to suspended sediment particles, the sediment transport module was

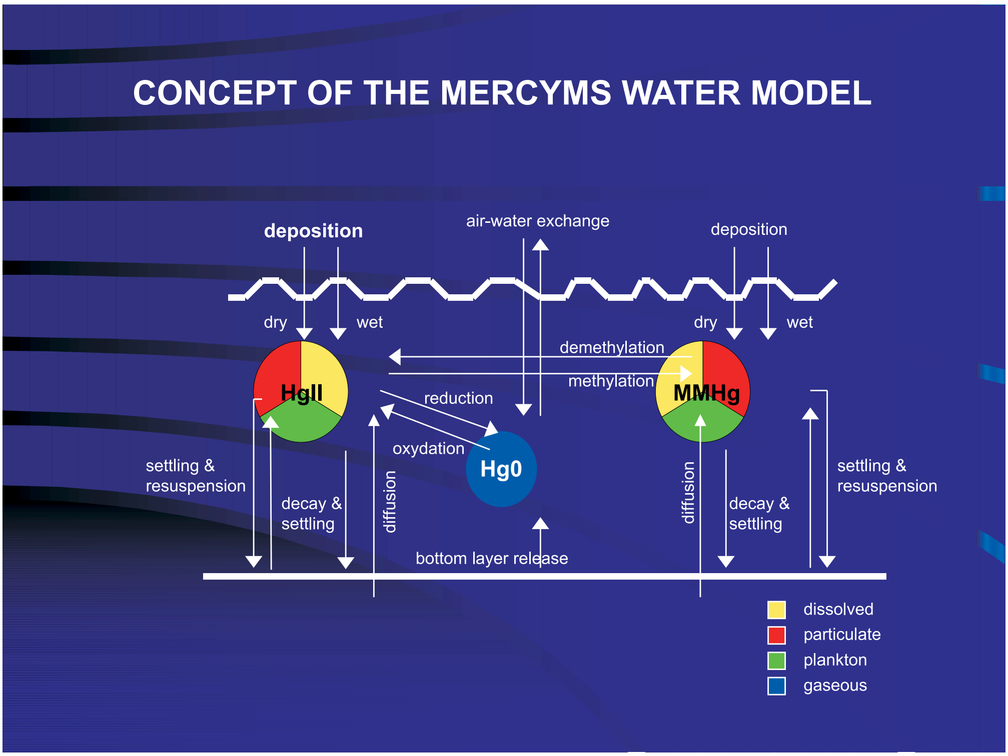

Figure 1. Scheme of the mercury cycling processes that are included in the PCFLOW3D model.

applied. As the transport of any pollutant depends greatly on the hydrodynamic velocity field, a lot of research had to be done to determine it properly.

Data on mercury input from rivers and some point sources have up to now been collected form UNEP reports. As this data are only approximate, the first modelling simulations were simplified. First, 3D hydrodynamic velocity fields were calculated by the PCFLOW3D model for four seasons; as the input data complete 3D temperature and salinity fields, obtained from MODB (Mediterranean Oceanographic Data Base) were used. These velocity fields showed acceptable agreement with measured velocity fields as well as with simulation results of ZAVATARRELLI AND MELLOR (1995). Further on these four velocity fields were fixed and simulations of mercury transport and fate were carried out over two years, season by season.

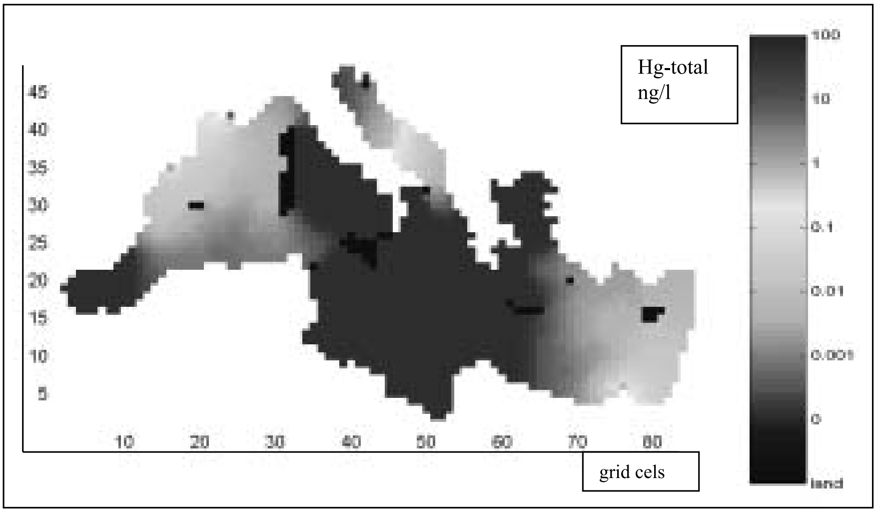

Figure 2. Simulated concentration of total (unfiltered) mercury in the surface layer of the Mediterranean Sea after one year of simulation of mercury input from main rivers and point sources.

RESULTS AND DISCUSSION

Fig. 2 presents results of simulations: concentration of mercury in the surface layer. Input of mercury from 4 major rivers (Po, Ebro, Rhone, Nile) and 7 point sources is taken into account and model simulation ran over 1 year period. Results are shown for total mercury. Mercury input from atmosphere is not yet accounted for.

Except for the hydrodynamic simulations, there was no possibility to calibrate and verify the results of simulated mercury distribution. This is foreseen in the next phase, when results of measurements will be evaluated. Four-week studies with research ship Urania were carried out in 2002 and 2003, with measurements of several water quality parameters and mercury species.

SUMMARY

Some first simulations with the PCFLOW3D "water model" show encouraging results. Verification was done for the hydrodynamic circulation, while calibration and verification of the "mercury module" will be carried out in the next phase, when more results of measurements will be available. Coupling with the atmospheric model will be a difficult task, as both way exchange of mercury forms between the ocean surface and the atmosphere is in question.

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