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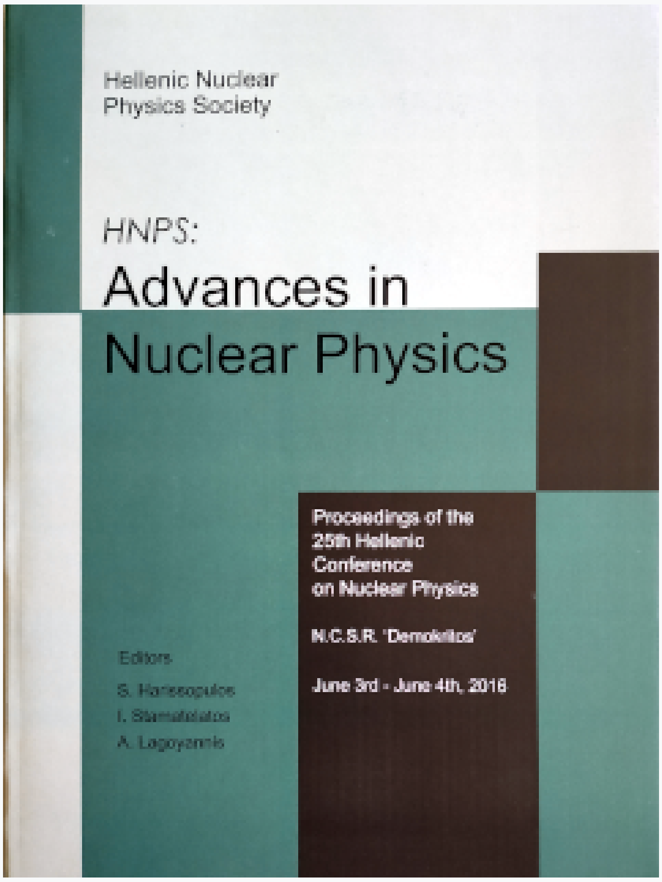

Towards the development of a radiological box model for Aegean Sea: considerations and perspectives

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Towards the development of a radiological box model for Aegean Sea: considerations and perspectives

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Abstract The development steps of the radiological box model of the Aegean Sea are presented here. The applied methodology combines all the available and necessary site specific information. The modelling approach includes terms describing the radionuclide dispersion into oceanic space with time (non-instantaneous mixing), while the model's algorithms also cover whole processes of radionuclides' transfer, bioaccumulation and doses assessment. The model includes 50 marine and sediment boxes, optimized based on experimental radiocesium measurements followed the Chernobyl accident. The process is expected to reveal the key parameters controlling the radionuclides' fate as well as their effect on the model's prediction.

Keywords radiomodelling, marine environment, Chernobyl accident, ^{137}Cs, Aegean Sea

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INTRODUCTION

Environmental radiomodelling is proved to be an effective tool for the management and the protection of all ecosystems, widely applied by the scientific community with constant validation of the model predictions through international programs (e.g. VAMP, BIOMASS, EMRAS, MODARIA). As a part of this effort, the assessment of the sensitivity of different marine environments due to the dispersion after the release of radionuclides and the radiological consequences to the biota are of great concern [1,2]. Marine radiomodelling owe to integrate different aspects like the contamination of the water and bottom sediments, the bioaccumulation of radionuclides in biota and the dose assessments to marine organism and human populations. Due to the extent and complexity of sea environments, box models are suitable for marine radiomodelling since they can cover large distances and long time scales.

Objective of this work is the development of a reliable model for radioecological analysis and the radioprotection of the Aegean Sea. For that reason, data covering the necessary environmental and biological characteristics of the study area, as well as all radiological information, for all available sources including scientific publications, national and international open access databases (i.e. GEBCO, ECMWF, POSEIDON, CIEM, PANGEA), national authorities' records (i.e. ELSTAT, IGME, TIUK), recommendations of international scientific authorities (i.e. ICRP, IAEA, WHO), unpublished scientific data and experts' assessments in relevant fields have been gathered, evaluated and properly combined [3,4]. The algorithmic implementation of the model is based on the well established NRPA

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model [5,6], properly modified in order to describe the complex oceanographic features of the study area.

The model will provide estimations concerning the activity concentrations of the biotic and abiotic components of the ecosystem and the total dose to the population, during and after any radiological event. Hence, Aegean Sea radiomodel is expected to be a management and research tool for the radiation protection of the marine environment and the investigation of the radioecological sensitivity of its components.

MODELLING APPROACH

The development of the Aegean Sea radiomodel was based on NRPA box model modules. Key feature of the NRPA model is that includes terms describing the dispersion of radionuclides into oceanic space as a function of time [7]. The non-instantaneous mixing modelling approach can predict the different time trends for water transport within the marine compartments, fact particularly important for dynamic marine environments as Aegean Sea. The equations describing transfer k (in yr^{-1}) of the radionuclide activity concentration A (in Bq) between boxes i and j, under an external input source Q (in Bq/yr), includes terms γ (unit function) describing the radionuclide dispersion into oceanic space with time T_i (in yr):

$$\frac{\mathrm{d}A_i}{\mathrm{d}t} = \sum_{j=1}^{n} k_{ji} A_j - \sum_{j=1}^{n} k_{ij} A_i \gamma(t \geqslant T_j) - k_i A_i + Q_i, \quad t \geqslant T_i$$

$$A_i = 0, \quad t < T_i$$

where

$$\gamma(t \geqslant T_i) = \begin{cases} 1, & t \geqslant T_i \\ 0, & t < T_i \end{cases}$$

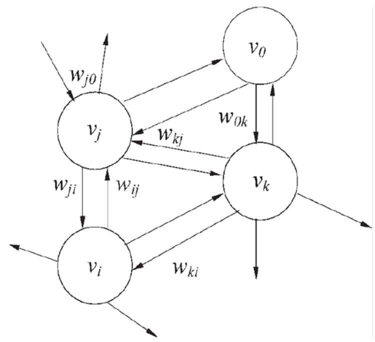
The availability times

$$T_i = \min_{\mu_m(v_0, v_i) \in M_i} \sum_{j,k} w_{jk}$$

are calculated as a minimised sum of the weights for all paths $\mu_0(v_0, \ldots, v_i)$ from the initial box (v_0) with discharge of radionuclides to the box i on the oriented graph $G = (V,E)$ with a set V of nodes v_j correspondent to boxes and a set E of arcs e_{jk} correspondent to the transfer possibility between the box j and k:

$$M_i = \begin{cases} \mu_1(v_0, v_j, v_i) \\ \mu_2(v_0, v_k, v_i) \\ \mu_3(v_0, v_j, v_k, v_i) \\ \mu_4(v_0, v_k, v_j, v_i) \end{cases}$$

$$w_{jk} = F(f_{jk}, f_{kj}, g_{jk}, X_{jk})$$



The weights w are considered as a discrete function F of water fluxes f, geographic information g and expert evaluation X.

The model's algorithms cover whole radiological processes such as radionuclides' dispersion in the seawater, activity transfer between seawater and sediments, activity transfer within different sediment layers, radionuclides uptake by the biota and dose calculation to man and biota (Fig. 1).

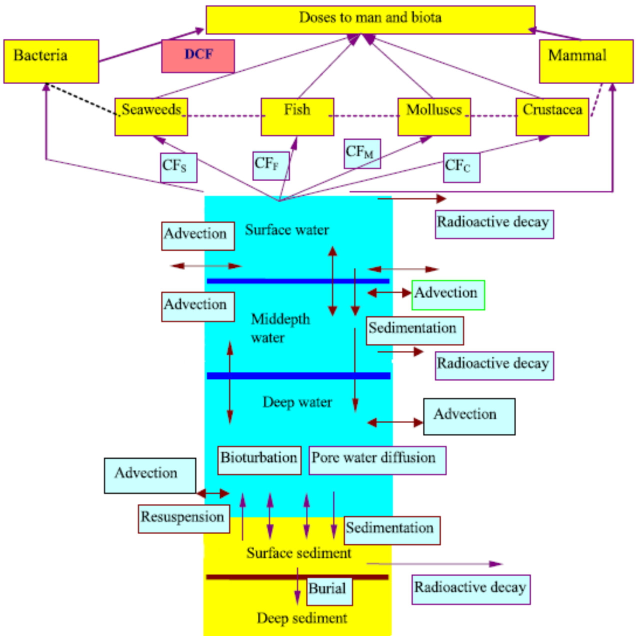


Fig. 1. NRPA box model structure

MODEL DEVELOPMENT

Aegean Sea was parameterized in 20 homogenous marine regions based, in principal, on the morphology and the water circulation and, secondarily, on the fish production and human population distribution (Fig. 2). Each region includes water column stratification (where necessary), conducted with three sediment boxes (surface, middle and deep sediment). The morphological characteristic of each compartment and the water exchange between adjacent boxes were quantitatively determined by the use of Geographic Information System and the calculation of the annual water mass budget, respectively. The water budget equation for each box derived taking into account atmospheric processes (precipitation and evaporation), the freshwater inflows (main rivers and catchments run off), the water exchange with external sea water masses (Ionian, Levantine and Black Sea) and the basic circulation patterns. The process of water mixing within boxes was also included in terms of horizontal and vertical diffusivity.

Appropriate information required by the set of equations applied by the model, were collected, prepared and incorporated. The input dataset consist of: (a) morphological (volume, surface, mean depth, borderlines length, boxes' common surfaces), (b) hydrological (precipitation-evaporation, rivers, catchments run off, external seawater inflows/outflows, transfer rate between boxes), (c) sendimentological (suspended sediment loads, sedimentation rates, sediment distribution coefficient), (d) radiological (time series of 137Cs activity concentrations in water, sediments and marine organisms due to the Chernobyl accident) and (e) biological data, including marine organisms (sea production, radionuclides' concentration rates, dose conversion factors) and human habitants (population distribution, dietary habits, marine time occupancy, dose conversion factors for specific radionuclides).

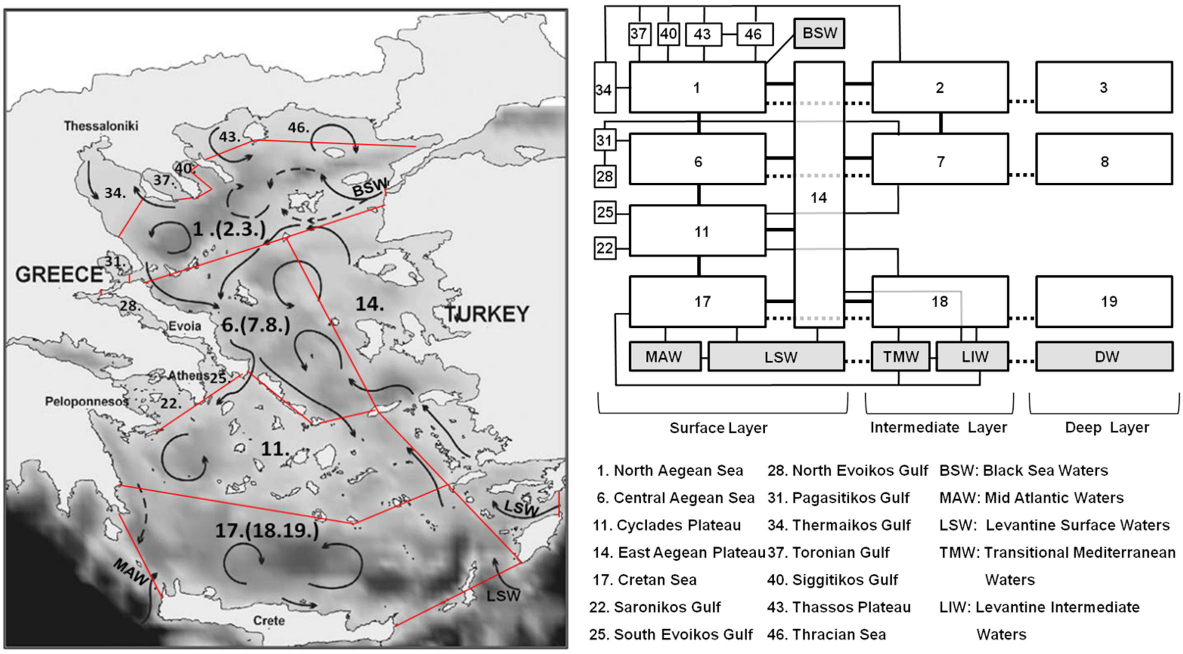


Fig. 2. Marine regions and surface water circulation of Aegean Sea [8], along with the schematic structure of the water exchange between adjacent boxes (white boxes: marine regions; gray boxes: external water masses; solid lines: horizontal water fluxes; das lines: vertical water fluxes).

PRELIMINARY RESULTS AND PRESPECTIVES

The model, before any application, has to be calibrated in order to maximize its reliability. The calibration is performed with the simulation of the ^{137}Cs dispersion following the Chernobyl accident (at April of 1986), in the biotic and abiotic components of Aegean Sea. Starting point of the calibration are the estimations of the total ^{137}Cs fallout [9] and the ^{137}Cs annual flux from the Black Sea at the Aegean Sea after the Chernobyl accident [10]. The simulation results will be compared with the available ^{137}Cs activity concentrations measured in the water, the sediment and the marine biota (fish and mussels) up to now.

At Fig. 3 are presented examples of the first preliminary results of activity concentration evolution for 2 water and 2 sediment boxes along with experimental data, before any parameter adjustments. Further parameters adjustments controlling the input, circulation and removal processes of ^{137}Cs, within reasonable site specific limits, have to be performed in order to improve the results of the simulations. The process will reveal the parameters controlling the radiological behavior of the study area, their interaction, as well as their effect on the model predictions. Thorough sensitivity and uncertainty analysis have also to be performed in order to assess the effects of these parameters variation on the model output and quantify the overall uncertainty associated with the response of the model input uncertainties.

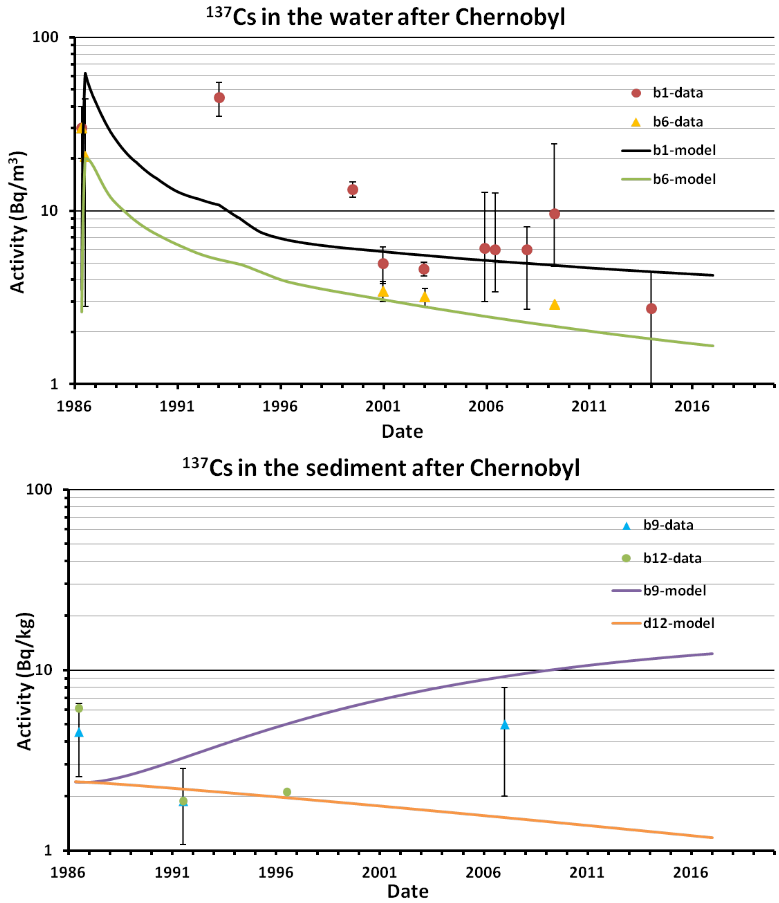


Fig. 3. Preliminary results of the Aegean Sea model application for ^{137}Cs after the Chernobyl accident

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