DEVELOPMENT OF A COUPLED, 3D HYDRODYNAMICAL-ECOLOGICAL-TERRESTRIAL MODELLING SYSTEM: RESULTS FROM AN APPLICATION TO A SMALL, SEMI-ENCLOSED MEDITERRANEAN GULF

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Abstract

The development and application of a coupled modeling system, along with the first results, are described in this work. The model consists of three interacting components, a hydrodynamic, an ecological and a terrestrial sub-model. High resolution experiments were conducted, using a shallow, semi-enclosed gulf as an implementation area, in order to test the model's behaviour. Driven by realistic forcing, the model reproduced the general circulation patterns accurately, whereas the simulated ecological variables showed reasonably good fit when validated against independent field data. With further development and extensive testing, this model system can become a valuable tool assisting in integrated coastal zone management.

Key-words: coupled model, coastal ecosystem dynamics

Introduction

Within the framework of integrated coastal zone management, a coupled modeling system has been developed. This study has three objectives: the development of a coupling methodology in order to link together a general circulation model with a biochemical model and a terrestrial model, the testing of the simulation capabilities of this modeling system especially in reproducing and quantifying basic ecological processes (flow of matter at the lower trophic levels, nitrogen cycling, microbial loop) and finally, the presentation of the results of the first simulation experiments.

Methodology

Model Description

The model system is made up of three interacting components: (a) a hydrodynamic submodel, a 3 dimensional version of the Princeton Ocean Model (POM) [1], that provides the physical transport fields, (b) a water-column ecological submodel, consisting of seven state variables: nitrate, ammonium, phosphate and dissolved organic nitrogen concentrations, phytoplankton, zooplankton and bacterial biomasses and (c) a terrestrial submodel, that estimates the point and non-point nutrient fluxes to the marine ecosystem due to agricultural run-off.

The source code of the well-known, terrain-following, general circulation model POM was used as a basis for the development of the code of the ecological submodel. The ecological model [2, 3], focuses on the mass – energy flow through the microbial food web and therefore is suitable for studying eutrophication processes. The two models, that run simulaneously, are coupled using the same spatial discretization and the same time step (POM's internal mode time step). The coupled model solves the following general equation:

$$\frac{\partial C}{\partial t}=\underbrace{-u\frac{\partial C}{\partial x}-v\frac{\partial C}{\partial y}-(w+w_s)\frac{\partial C}{\partial z}}_{\text{Advection - Sinking}}+\underbrace{A_h\left(\frac{\partial^2 C}{\partial x^2}+\frac{\partial^2 C}{\partial y^2}\right)+A_z\frac{\partial^2 C}{\partial z^2}}_{\text{Turbulent Diffusion}}+\left.\frac{dC}{dt}\right|_{ECO}$$

that describes the rate of change of the concentration of a non-conservative, ecological variable C in the 3-dimensional space and time. POM calculates the advection – turbulent diffusion part, (calculation of u,v,w velocities and horizontal A_h – vertical A_z diffusivities). The term $\left.\frac{dC}{dt}\right|_{ECO}$ represents the system of finite differential equations of the ecological submodel that simulates the rate of change of C due to biochemical processes [3]. Other characteristics of the ecological submodel are: the user-specified integration scheme (3 schemes are available – Euler, Runge-Kutta 2nd and 4th order), the use of a time step cutting technique in order to avoid unrealistic simulation results (e.g. negative concentrations of biochemical variables) [4], dynamic calculation of the settling velocity w_s of phytoplankton.

In order to estimate the nutrient runoff from non point sources a terrestrial submodel was constructed. The watershed of the test area was divided into unit source areas using a grid of 1x1 km. The surface nutrient runoff was subsequently calculated by applying the SCS Curve number equation [5]. The dissolved fractions of the nutrients nitrate, ammonium, organic nitrogen, phosphates were computed daily with the use of SCS by evaluating the rainfall height, evaportranspiration and drainage losses and by taking into consideration the land use, slope, crop management and soil water content [6]. The predicted amount of the dissolved nutrient runoff was assumed to end up in the marine environment through the main streams of the region.

Description of application

The test area, the gulf of Gera, is a shallow, semi-enclosed gulf in the North-eastern Aegean, Greece, surrounded by an intensively cultivated watershed. High resolution experiments were conducted – a 100x100 m grid with 11 sigma layers was used – attempting to simulate the variation in space and time of the physical, chemical and biological prognostic state variables, under typical winter and summer conditions and during the transitional time period between mixing and stratification and vice versa. The model is driven by realistic forcing: wind stresses, variable surface and open boundary conditions, tidal elevation, solar radiation and nutrient fluxes from agricultural runoff.

Results and Discussion

The general circulation patterns are reproduced quite well, while the simulated biochemical variables showed reasonably good fit when validated, with statistical methods, against independent field data, collected on a monthly basis. The simulation results emphasize the importance of the hydrodynamic-physical processes and mass exchanges between the gulf and the oligotrophic pelagic waters of the Aegean in determining the trophic level of the gulf ecosystem. During the winter period, environmental conditions impose a poor renewal regime, with residence times of up to 2-3 months. Nutrient inputs from terrestrial sources lead to an increase by about 50% of the water column nutrient stock, and, if the physical conditions (light, temperature) are optimum, this can give rise to phytoplanktonic blooms. During summer conditions, the renewal of the gulf waters is more intense and biochemical variables are kept at low levels. This coupled model can be used as an efficient tool in developing an integrated methodology for the sustainable development of the coastal zone.

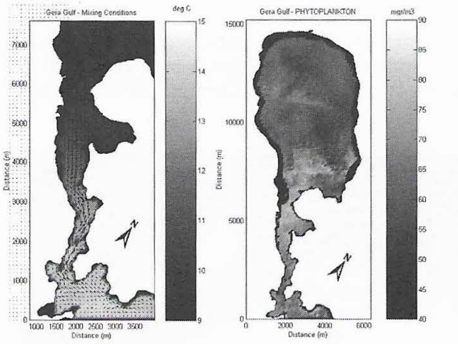

Fig. 1. Distribution of simulated quantities at 5m depth during typical mixing conditions (March): (a) velocity and temperature field and (b) phytoplanktonic carbon.

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