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The modelling system for simulation of the oil spills in the Black Sea

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Abstract

A development of the real-time integrated modeling system for weather, currents, wind waves coupled with oil slick transport and fate model is presented. The local area weather forecasting model MM5 is used for operational forecasts in the Black Sea region. It was coupled with 3D hydrodynamics and sediment transport model, and with the third-generation wave model WAVEWATCH III. This set of models supplies information on currents, waves and sediment concentration to the 3D model of oil slick transport and fate OILTOX. The oil slick model describes most important processes of oil transport and weathering. The examples of application to the North-western shelf of the Black Sea and Dnipro-Boog Estuary are given.

Keywords: modeling system; oil spill model; “spillet”; Black Sea

1. Introduction

The growing concern over the impact of the accidental spill in the new oil transport routes from Eastern to Western Black Sea is motivating factor for the development of the decision support tools to evaluate the oil spill response strategies, to provide the environmental impact assessment and to use in the contingency planning and training. The experience of many spill response actions worldwide, including recent “Prestige” accident, demonstrates importance weather forecasts to predict movement and fate of the spill. The sea-state forecasts are required to assess the lifetime of an oil spill. Increasing computational resources allow coupling the oil spill models with the models of weather, circulation and wave forecast (Reed et al., 1999). During last years a number of regional operational integrated weather, sea state forecasting systems were developed for the Mediterranean Sea. An example is POSEIDON system for the Aegean Sea (Soukissian et al., 2002). The paper presents recent development of the modelling system for simulations and predictions of the Black sea state and accidental oil spill. The system includes coupled weather forecast model MM5, circulation model based on POM and wave forecast model WAVEWATCH III that provide information for 3D oil spill model OILTOX. The key features of models are described and two examples of application are given.

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2. The description of modelling system

2.1 The weather forecast model

The limited area model MM5 V.3 is a core of the weather forecasting system that was developed by IMMSP and UCEWP with support Ukrainian Hydrometeorological Service to produce the operational forecasts for the Ukraine. The Fifth-Generation NCAR / Penn State Mesoscale Model MM5 (Grell et al., 1994) is nonhydrostatic model that contains capabilities of multiple nesting, four-dimensional assimilation and set of parameterizations of the microphysical fields and planetary boundary layer. The forecasting system includes preprocessor, MM5 model and postprocessor. Preprocessor retrieves every 12 hr GRIB bulletins from DWD with analyses and global model forecasts which contain horizontal winds, temperature, geopotential and moisture on 11 levels. These fields are necessary to provide initial and boundary conditions on the coarse grid. The coarse grid 37x37 with 81 km mesh cover large area in the Eastern Europe. The lateral conditions are updated every 12 hr. The nested grid 73x73 with 27 km allows refine forecast on the Ukraine territory and the Black Sea. The model uses 31 sigma levels in vertical. A planetary boundary layer was parameterized using scheme NCEP MRF model. The roughness height over sea was parameterized by modified Charnock relation. The forecasts at 48 hr are run once a day at 6 UTC. The procedure of initialization includes assimilation of data retrieved from meteorological stations bulletins and soundings on coarse grid area in –24-0 hr of model time. The Black Sea surface temperature for the forecast period is taken from DWD analysis. The available data from meteorological bulletins are assimilated in the 0-6 hr of model time. Postprocessor produces forecasts for specific locations, 2D field of meteorological parameters for other models and visualizes results at the web page http://www.meteoprog.com.ua.

2.2 The wave model

The wave model WAVEWATCH III V. 1.18 (WW3) is a third generation wave model developed at NOAA/NCEP (Tolman, 1999). The governing equations include refraction and straining of the wave field due to temporal and spatial variations of the mean water depth and the mean current and wave growth and decay due to the actions of wind, nonlinear resonant interactions, dissipation (`whitecapping') and bottom friction. The prognostic parameters are gridded fields of 16 mean wave parameters such as the significant wave height and directions and significant wave period. WW3 is forced by MM5 10 m height winds. The surface currents are supplied by circulation model. The wind and currents time step is 3 hr. The model uses the forecasts wave spectra as the initial conditions for the next run. The finest spatial resolution is $6'$, number of nodes is 160×60, number of spectral components is 25 and directions is 24. Timestep is 300 s.

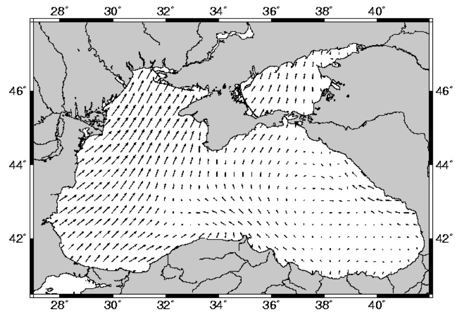

Figure 1 Wind field at 10 m predicted by MM5 at 10.00 UTC 25 September 2002

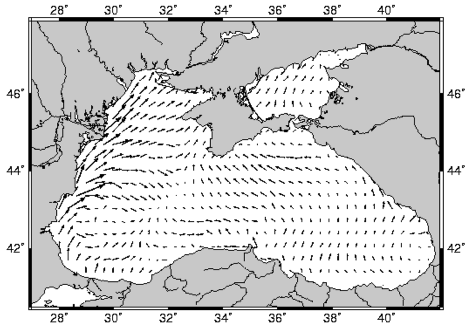

Figure 2 Surface currents predicted by circulation model at 10.00 UTC 25 September 2002

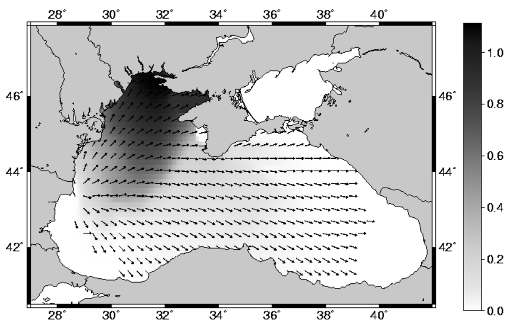

Figure 3 Wave direction and height predicted WW3 at 10.00 UTC 25 September 2002

2.3 The circulation model

The hydrodynamics is simulated on the basis of the three-dimensional, time-dependent, free surface, primitive equation POM model (Blumberg and Mellor, 1987). The prognostic variables of the hydrodynamics code are the three components of the velocity, temperature, salinity and surface elevation. The σ - coordinate system, mode splitting and two-equation model of turbulence are important features of model. Suspended sediment transport is an option of model. The surface wind stress and heat fluxes are provided by MM5 with time step 3 hr. The resolution is 10x10 km, number of nodes is 137×68 and number of σ - layers is 21. Internal mode time step is 1000 s

2.4 The oil spill model

OILTOX is model to simulate oil transport and fate in five interacted "phases": oil-on-surface, oil-in-water, oil-on-bottom, oil-on-suspended sediments, oil-at-shoreline. It is under development by IMMSP and UCEWP to support response on oil spill in the Black and Azov seas and large river reservoirs in the Ukraine. The model describes main transport and weathering processes. The model of surface slick describes the spreading due to gravity and surface tension force, advection by wind and surface currents, evaporation, emulsification, oil-shore interaction, entrainment of oil in the water by breaking waves and resurfacing entrained droplets. OILTOX uses a Gaussian "spillet" representation to describe the concentration field as the sum of contributions from a collection of "spillets". "Spillets" are distributed among phases and possess a set of specific for phase properties (volume, density, viscosity, water content etc.). A new Lagrangian numerical approach allows simulation of spreading of elongated slick with spatially variable thickness for both instantaneous and continuous spills (Brovchenko and Maderich, 2002). The horizontal and vertical turbulent diffusion processes are simulated by use Lagrangian stochastic simulation technique based on the random walk method for Gaussian "spillets". Algorithms of evaporation, emulsification, partitioning and sedimentation are based on state-of-art published research (Reed et al., 1999).

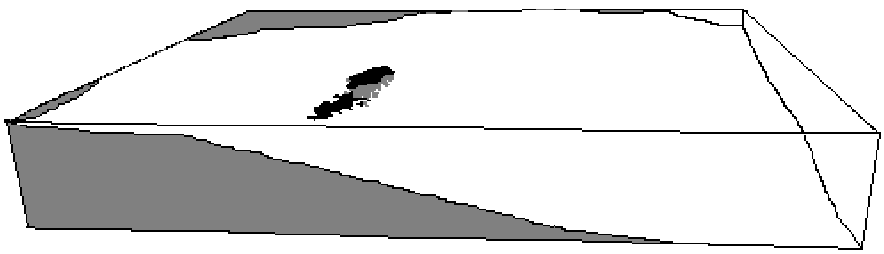

Figure 4. 3D representation by interactive visualization tool of the oil spill at the North-western shelf of the Black Sea.

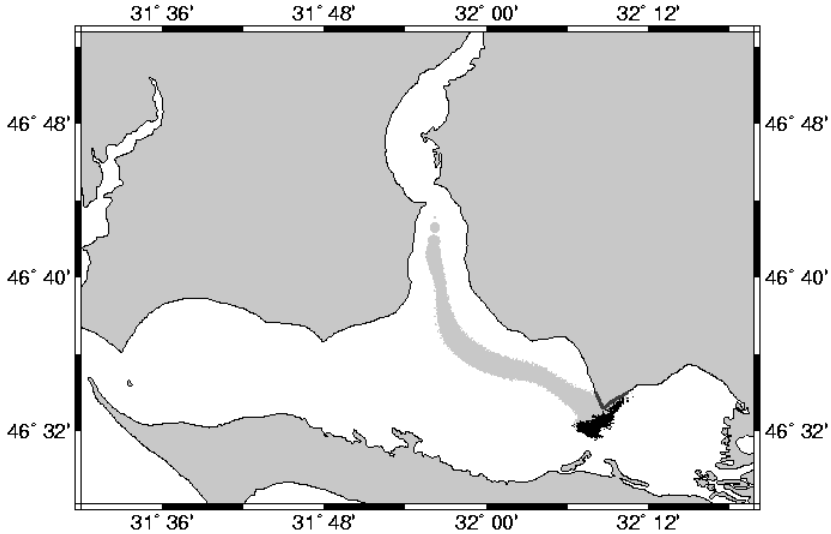

Figure 5 Simulated trajectories of the "spillets" in the Dnipro-Boog Estuary during 25 hr after beginning of spill.

The database of model includes information about hundred of types of oil that is transported through the Black Sea and their main physical-chemical properties. The modelling system was designed to operate at LINUX based network of PC. OILTOX also can be used in stand-alone version with environmental parameters, including wind and state of the sea that are specified by user.

3. Applications

The modeling system was adapted to the Black Sea basin. The results of simulations of surface wind, waves and currents in the Black Sea as obtained by coupled model system are shown in Figures 1-3. The hypothetical scenario of oil spill 75,000 tons of crude oil on the north-western shelf of the Black Sea 25.09 2002 at distance around 50 km from Odessa oil terminal was considered. Oil slick drifted by wind surface current to shallow area. Together with standard 2D visualization by GMT the oil spill evolution was tracked by interactive 3D tool based on OpenGL technology. The Figure 4 shows surface slick (dark gray), oil-in-water concentration (light gray) and oil-on-sediments concentration (dark gray). As seen in figure the model reproduces processes of surface slick entrainment by the breaking waves, generation of oil droplets, diffusion by subsurface turbulence and gradual resurfacing of droplets by buoyancy forces that contributes in the forming of frequently observed thin oil film tail ("sheen") behind the thick slick area.

Another example is the Dnipro-Boog Estuary that is the largest in the Black Sea basin. Two large cities (Mykolayiv and Kherson) with ports and refineries are placed In the estuary and it is on the way to the Dnipro basin system. From 2004 the version of system which contains the circulation model and OILTOX completed by database and GUI will be in use by State Departments on the Environment and Natural Resources in the Kherson and Mykolayiv. In Figure 5 the simulated trajectories of the "spillets" in the Dnipro-Boog Estuary during 25 hr after start of hypothetical spill 5000 tons of crude oil. The atmospheric forcing (observed wind, air temperature, humidity and cloudiness), river discharge and level in estuary mouth were available every 3 hr.

3 Conclusions

This paper presents development a 3D oil spill model OILTOX based on an extended Lagrangian concept that include five interacted phases of oil in spill. The model is coupled with weather forecast model and wave and circulation model. Whole system was adapted to the Black Sea and first results of tests showed potential of such multipurpose modeling system.

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