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Oil Spill Modeling Using 3D Cellular Automata for Coastal Waters

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ABSTRACT

Oil spill accident is very harmful to the coastal and marine ecology and mankind. The simulation and prediction of the transport and fade of spilled oil is one of the important issues to the oil spill contingency plans.
Cellular Automata (CA) is one of the dynamic modeling tools easy to use. It usually divides the space into regular grid cells in 2D or 3D. And transformation functions according to physical, chemical and biological phenomena are set to define the dynamic process between local neighboring cells. Because the data structure of CA is very similar to the raster data model in the Geographic Information Systems (GIS), the CA model can be easily integrated with GIS to provide environmental database and to display the simulation results. The algorithm of a 3D CA model can be straightforwardly extended from those of 2D CA model.
This paper used 3D CA model to simulate the spreading, evaporation, advection due to wind and current on the water surface, evaporation, shoreline deposition with islands and shorelines. The horizontal and vertical dispersion, advection in the water column and seabed sedimentation were also modeled by this 3D CA approach. Conservation of mass and many physical oil transport rules were used in the prediction model.
Several simulation cases were applied in the area of 10km * 10km. The horizontal grids are divided into 100*100. And 5 layers in the water column are used in the maximum water depth of 50m. Islands, shorelines and water depth are also included in the simulation cases. It is proved 3D CA model is a capable and efficient way to simulate and predict the movement of the oil slick.

KEY WORDS: Cellular automata; oil spill; Geographic Information Systems; spreading; advection; shoreline deposition; horizontal and vertical dispersion

INTRODUCTION

Because oil spill accidents happened very often in the last decades, the related tasks, such as: oil spill monitoring, prediction and management, became very important issues. Marine ecology will be impacted by the oil spill incident. Oil slick may be mixed with sea water and sink toward sea bottom in the water column. Ecological environment of the sea bottom may be affected by the sunken oil. Coast will be polluted and hard to clean if oil slick floats to the land. Contingency plans should be initiated as soon as oil spill accident happened. Oil dispersion model can predict the dynamic behavior and the distribution of the oil slick according to the local ocean current, wave and other environmental conditions. Suitable action then can be made by the decision makers with the results from this prediction. Therefore, study of the dynamic behavior of the oil spill is one of the key issues in the emergency response decision support systems.
Lab test and analytical approaches can be used to predict the dynamic behavior of the oil spill (Okuyama et al., 1988; Cekirge et al., 1990; Karpen and Galt, 1979). However, it is too hard for the lab test and analytical methods to consider all the environmental factors, such as: wind, ocean current, tidal current, turbulence, wave, evaporation, shoreline deposition etc., in simulation processes. Wang et al. (2005), Pierre (1996) and Sebastiao et al. (1995) had put wind and ocean current into their numerical model. Riazi et al. (1999) added more factors, such as: evaporation, dissolution, settlement, into his numerical model. Shaw (2003) had considered the impact of the wave to the oil slick. Thorpe (2000) had investigated the behavior of the oil dispersion in the shallow water. Oil slick mass in the water surface will be broken into particles by wave and mixed with sea water. Part of the oil particles will float to water surface and mixed with floating oil again. At the same time, rest of the oil particles will sink toward sea bottom. We can tell that behavior of the oil spill is a three dimensional dispersion process (Korotenko, 2000). Oil slick particles can be measurable up to water depth of 20 meters (Cretney et al., 1981; Sorstrom, 1987; Genders, 1988). It is hard to include many environmental factors in the numerical models at a time. And three-dimension model is even harder to establish.
Cellular Automata (CA) is one of the dynamic modeling tools easy to build in 2D or 3D environments and convenient to add many environmental factors, such as: shoreline boundary, wind, current, evaporation etc., in the model. Adding vertical dispersion and advection factors to the CA model, oil spill behavior prediction in 3D can be simulated more realistic.
Because the data structure of CA is very similar to the raster data model