USE OF APPLIED OCEANOGRAPHY IN STOCHASTIC MODELING
OF OIL SPILLS ON THE OUTER CONTINENTAL SHELF

Robert P. LaBelle

Minerals Management Service
Branch of Environmental Modeling
Reston, Virginia 22091

ABSTRACT

The Department of the Interior analyzes the likelihood and potential impacts of oil spills associated with production and transportation of oil in Federal waters of the Outer Continental Shelf (OCS). A computerized simulation model, the Oil Spill Risk Analysis (OSRA), is used to provide the quantitative basis for oil spill risk assessment in the preparation of Environmental Impact Statements as part of the offshore leasing process.

The oceanographic research program which supports the OSRA model is outlined with emphasis on the application of study results for each OCS Region: Atlantic, Pacific, Gulf of Mexico, and Alaska. The representation of winds and surface currents used to simulate the transport of spilled oil (as modeled by OSRA) is discussed, including circulation models currently in use and planned for each Region.

INTRODUCTION

In managing the Outer Continental Shelf (OCS) Leasing Program, the Minerals Management Service (MMS) of the Department of the Interior uses computer simulation modeling to assist in analyzing the potential effects of oil spills on the marine and coastal environment. The Oil Spill Risk Analysis (OSRA) model is used to estimate the likelihood of spill occurrence and contact to ecological or economic resources located throughout the U.S. OCS.¹ Because oil spills are a major concern associated with offshore oil development in all Federal lease areas, quantitative assessments of risks are needed to describe and analyze the effects of alternative leasing proposals. The OSRA model is not designed to simulate a particular real-time event, but rather to model a series of randomly occurring spill events from many potential spill sites and sources. This allows projection of contact probabilities estimated over the 15- to 25-year lifetimes of OCS leases. Therefore, a wide array of seasonal surface current and wind conditions in each region is needed to simulate trajectories that are then used to calculate the statistics of potential contact. Since OSRA does not calculate winds and currents directly, input data for a quantification of such features are derived from a combination of

direct measurements and mathematical modeling. The model is supported by an oceanographic research program maintained by the OCS Environmental Studies Program of the MMS. The relationship between OSRA and this program, as well as the major oceanographic study efforts currently used to provide inputs to the oil spill model, have been described in a recent publication.² The present paper will outline several circulation models that are projected to be used in future modeling of oil spill trajectories in the four OCS Regions: Atlantic, Pacific, Gulf of Mexico, and Alaska.

ATLANTIC REGION

While MMS and other agencies have funded direct field measurements of current and hydrographic parameters along the east coast of the United States, adequate coverage of temporal and spatial variability is neither feasible nor cost effective. An alternative for establishing accurate simulations of transport and velocity patterns within individual OCS lease sale areas is a computer-based numerical model of circulation, with appropriate physical considerations and governing equations of motion. The development of such a model is now being proposed by MMS through the Environmental Studies Program. A separate future procurement will fund a companion field program designed to provide input data to the selected circulation model, and to evaluate the skill of the model in producing surface current representations.

The objectives of the circulation modeling study are to develop a three-dimensional, numerical, time-dependent circulation model with sufficient temporal and spatial resolution to accurately simulate mesoscale features such as short-term wind events, Gulf Stream frontal events and shelf currents along the Atlantic coast. Products from this model will be used to provide the OSRA model with realistic representations of surface and subsurface transport, on a monthly or seasonal basis. The representations should account for currents induced by long-term climatological wind forcing, as well as the influence of short-term variability of wind speed and direction. The significance of extreme wind forcing by hurricanes and other major storms will also be examined. Other factors that will be quantitatively evaluated with respect to their relative

contribution to net surface transport include wave motion, tidal motion, the presence of oil on the surface, and the buoyancy effect from fresh water in and near large estuaries.

The influence of the Gulf Stream is a prime concern in the development of a satisfactory circulation model. The dynamics of Gulf Stream movement, including frontal events such as eddies, meanders, and filaments, must be accurately simulated, and their influence quantified for surface and subsurface current representations. An additional requirement is that the model must be interfaced with the circulation model used by MMS in the Gulf of Mexico to represent Loop Current/Florida Current water mass movement. This will allow accurate oil spill modeling of lease areas that are located off southern Florida, as well as provide specific boundary conditions for the Atlantic circulation model.

PACIFIC REGION

The main objective of the California Shelf modeling effort was to better understand the factors driving the shelf circulation, in order to model both surface and sub-surface currents. Previous runs of the OSRA model for lease areas offshore California made use of results of a diagnostic Characteristic Tracing Model (CTM), developed for MMS by Dynalysis of Princeton.³ The CTM utilizes the climatological hydrography generated from historical data and observed wind stress to obtain climatological circulation, thus providing a large-scale perspective on seasonal currents in the region. However, the primary function of the CTM is to provide the open ocean boundary conditions for a more sophisticated three-dimensional, time-dependent numerical model with higher resolution. The General Circulation Model (GCM) of Dynalysis will be used in future runs of the OSRA for oil spill trajectory analysis off the west coast.⁴

The GCM incorporates realistic turbulent mixing so that the evolution of the upper oceanic mixed layer can be accurately simulated. It also incorporates wind and density forcing and can also simulate tidal and storm surge processes. It can be run in both the diagnostic mode, where the density field is prescribed and held fixed, and in the prognostic mode, in which the density field is allowed to evolve dynamically under prescribed surface wind and other forcing. The GCM is also capable of being run in a truly predictive mode, with forecast synoptic winds as input, or in a hindcast mode with known winds. Climatological density fields from an historical observational data base are used for initialization. To efficiently use resources, the model for the California Shelf has been formulated in orthogonal curvilinear coordinates (Figure 1) so that high nearshore resolution all along the coast is feasible and practical. The along-shore grid spacing resolution varies from 16 km to 50 km with the highest resolution occurring near coastal promontories. The off-shore spacing is approximately 4 km near the coast, varying gradually to 25 km and uniform from thereon offshore. Such resolution should

help to model the larger features of significant wind-induced mesoscale variability that is associated with the California Current, such as eddy activity and large scale meanders. The equations which form the circulation model together with their boundary conditions are solved by finite difference techniques. The finite difference equations employed conserve energy, mass and momentum, and introduce no artificial horizontal diffusion.

Seasonal circulation has been calculated using the model in the diagnostic mode with the density field defined by the climatological data set.⁴ The results include a well-defined California Current and counter-current, as well as other recognizable features of the California climatological circulation. A year-long prognostic simulation was also made using the GCM driven by synoptic winds derived from the National Weather Service Limited Fine Mesh model. The resulting circulation exhibits dominant features of the southward California Current, the poleward under-current along the shelf slope, the nearshore, northward current during winter, and intense spring and summertime upwelling all along the coast. Figure 2 presents an example of seasonal variation in circulation based on a 3-month average of prognostic results. Calculations also depict a dramatic Spring Transition and a strong response to a winter storm event.

GULF OF MEXICO REGION

Ongoing and planned studies sponsored by MMS support a 4-year program in numerical ocean circulation modeling for the Gulf of Mexico. The aim of the program is to progressively upgrade in modest increments an existing numerical ocean circulation model of the Gulf developed by the Naval Ocean Research and Development Activity (NORDA).⁵ The final model should have a horizontal resolution of about 10 km and vertical resolution approaching 1 to 10 m in the mixed layer, 10 m at the thermocline, and 100 m in deep water. Throughout the program, the validity of the upgraded model will be continuously tested, and velocity field time series delivered periodically based on the most realistic simulation of Gulf circulation available.

Experiments in the first year with a two-layer hydrodynamic primitive equation model on a 0.2 degree grid concentrated on correctly specifying the coastline and bottom topography for maximum realism in circulation simulation. In the second year, the grid was increased to 0.1 degree and simulations were generated by wind forcing, port forcing, and wind plus port forcing. An example of the Loop Current-driven circulation is presented in Figure 3 as a model simulation of surface currents on a specific day from a 10-year simulation. A new large anticyclonic Loop Current eddy is shown forming with meanders on the wall of the Loop Current. In the western Gulf, a Loop Current eddy is shown reaching the coast of Mexico and moving northward as it dissipates. The remainder of the 4-year program will further develop the capability for diagnostic and prognostic circulation modeling,

including improved simulation of shelf and slope circulation features.

ALASKA REGION

MMS is presently evaluating the use of Applied Science Associates' Coastal Sea Pollutant Transport model for simulating oil spill trajectories in the many OCS lease areas off-shore Alaska. The model system consists of linked sub-models for wind, hydrodynamics, ice cover, storms, and shallow water waves.⁶ A three-dimensional numerical hydrodynamic model has been developed and is being tested in the three major model regions shown in Figure 4. This model computes sea elevation, currents, temperature, and salinity due to wind, tide, and density forcing. A two-dimensional stochastic weather model, which incorporates a storm model, is used to compute wind conditions for input to the hydrodynamic model. Ice cover location, contour, and thickness are provided as a function of time using atlas data for normal, mild, and severe ice years. The shallow water wave forecast model provides information on nonlinear induced wave-current bottom stress to the hydrodynamic model.

Results from the Coastal Sea model will be processed through the tracking portion of the OSRA model to allow calculation of oil spill contact probabilities to land and other resources in lease sale areas. Other studies that may be linked to the circulation model include a nearshore oceanographic study off the Yukon River Delta and a model that predicts the probable fate of oil in the coastal and surf zones.

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REFERENCES

1. Smith, R.A., J.R. Slack, T. Wyant and K.J. Lanfear. The Oilspill Risk Analysis Model of the U.S. Geological Survey. Geological Survey Professional Paper 1227, pp. 40, 1982.
2. LaBelle, R.P. and C.M. Anderson. The Application of Oceanography to Oil-Spill Modeling for the Outer Continental Shelf Oil and Gas Leasing Program. MTS Journal 19(2): 19-26, 1985.
3. Kantha, L.H., A.F. Blumberg and G.L. Mellor. A Diagnostic Technique for Deducing the Climatological Circulation as Applied to the South Atlantic Bight. Dynalysis of Princeton Report No. 69, pp. 124, 1981.
4. Blumberg, A.F., L.H. Kantha, H.J. Herring and G.L. Mellor. California Shelf Physical Oceanography Circulation Model. Dynalysis of Princeton Report Nos. 88.1, 88.2, pp. 368, 1984.
5. Hurlburt, H.E. and J.D. Thompson. A Numerical Study of Loop Current Intrusions and Eddy Shedding. J. Phys. Ocean. 10: 1611-1651, 1980.
6. Spaulding, M.L., T. Isaji and M. Reed. A Pollutant Transport Model System for Alaskan Seas. Paper submitted to American Society of Civil Engineers publication "Physics-Based Environmental Modeling of Material Release and Waste Disposal in Estuaries, Bays, and Open Coasts", in press, 1986.

Figure 1. Dynalysis of Princeton curvilinear coordinate system selected for General Circulation Model.

Figure 2. Distributions of seasonal averages of near-surface currents during summer 1981, as calculated by the Dynalysis General Circulation Model.

Figure 3. NORDA/Jaycor model simulation of surface currents for a specific day from a 10-year simulation.

Figure 4. Applied Science Associates' three major hydrodynamic model regions.