The Application of Oceanography to Oil-Spill Modeling for the Outer Continental Shelf Oil and Gas Leasing Program

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ABSTRACT

In managing the Outer Continental Shelf (OCS) Leasing Program, the Department of the Interior analyzes the potential effects of oil spills on the marine and coastal environment. Computerized simulation modeling, supported by an oceanographic research program, is used to predict potential spill occurrence and contact to spill-sensitive areas of ecological or economic concern. These predictions are used to analyze and describe the oil-spill risks related to individual lease sales and play an important part in leasing decisions, such as to impose stipulations or to delete individual tracts. This paper provides a description of how the Oil-Spill Risk Analysis (OSRA) model of the Minerals Management Service has been adapted to account for the variations in each of the OCS region's physical oceanography and biological environments, and an overview of the related applied oceanographic research efforts. Emphasis is on the representation of wind and surface currents used to simulate the transport of spilled oil in each region.

INTRODUCTION

This paper presents an overview of how applied oceanography contributes to quantitative efforts in estimating the environmental hazards of exploration and development of oil resources in Outer Continental Shelf (OCS) lease areas. The Minerals Management Service (MMS), through the Secretary of the Interior, is charged by the OCS Lands Act and Amendments of 1978 with the expeditious and orderly development, subject to environmental safeguards, of offshore oil and gas resources. In order to protect the environment while pursuing such development, and as mandated by the National Environmental Policy Act of 1969, the Department of the Interior prepares an Environmental Impact Statement (EIS) for each offshore lease sale. Because oil spills are a major concern associated with offshore oil development in all OCS lease sale areas, quantitative assessments of risks are used to describe and analyze the effects of alternative leasing proposals.

To address this need, the Interior Department developed the original version of the Oil-Spill Risk Analysis (OSRA) model in 1975. This large, computerized model has since been improved and run in over thirty different cases to provide analysts with probabilistic estimates of oil-spill occurrence and contact with ecological and economic resources located throughout the U.S. OCS regions. As used in the EIS process, this information contributes to the decisions made by the Secretary of the Interior on tracts offered for lease, as well as those to be withheld from leasing because of unacceptable risk to the specific environmental resources in the proposed sale areas.

The OCS leasing program includes a 5-year lease sale schedule which is reviewed annually. Each lease sale area is defined, issues of concern are identified, and an EIS is prepared and reviewed. The purpose of an EIS is to describe the proposed sale and the existing environment, describe the potential effects the proposed sale may have on the environment, and analyze any alternatives to the proposal. An issue which is always of major concern throughout the EIS is the potential effect of oil spills on resources such as endangered species, marine mammals, marine birds, commercial and sport fishing, coastal recreation, etc. Environmental studies and other sources are used to identify and map the location of these resources. The OSRA model is then used to predict the probability of one or more large spills occurring and contacting these resources over the lease lifetimes. This enables analysts to describe the likelihood and magnitude of potential effects.

After the lease sale, MMS monitors the activities on leased areas throughout basic stages in oil and gas development: exploration, development, production, and abandonment. This includes onsite inspections and the review for approval of various permits and plans. Many of these reviews, notably for exploration, development and production, and pipeline plans, require MMS to perform some level of environmental analysis. If oil spills are considered a major concern of the plan, the OSRA model is run in a site-specific mode to support these analyses.

OIL-SPILL RISK ANALYSIS MODEL

The OSRA model is not designed to simulate a particular spill 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 Federal OCS leases. Therefore, a wide array of seasonal surface current and wind conditions in the region is needed to simulate trajectories that are then used to estimate the statistics of potential contact. The OSRA model is described in detail in Smith et al.[1] For each run of the model, large numbers of oil spills are simulated in a random fashion from actual and/or potential platform sites and transportation sources, such as pipeline and tanker routes.

It is important to note that the OSRA model does not calculate surface currents directly. Input data for a statistical quantification of surface currents are derived from a combination of direct measurements and mathematical modeling. In most areas, observational data on ocean currents are too sparse, both spatially and temporally, to derive meaningful statistics on current variability. Data on winds, however, are usually sufficient for the variability and persistence of local winds to be modeled through the use of statistics of the wind-induced drift component of the surface currents. The model's oil-spill trajectory algorithm consists of the vector sum of the seasonal surface current component and the surface wind-drift component. A wind factor, which is the fraction of the velocity of the wind assumed to be imparted to the wind-induced drift component, is assumed to be 3.5%. Seasonal surface currents can be derived from measurements, atlas data, or actual modeling of the local coastal circulation patterns. As simulated spills are moved, all contacts with ecological or economic resources identified in the area are recorded. The model has been designed in a modular fashion so that other trajectory movement algorithms can be incorporated as needed. One example of this is discussed in the "Alaska OCS Region" section presented later in this paper.

The scope of MMS modeling efforts includes simulating spills in each of the four OCS Regions: Atlantic, Gulf of Mexico, Pacific, and Alaska. These regions are divided into the OCS planning areas shown in Figures 1 and 2. An overview follows of how applied oceanography is used by the OSRA oil-spill model in risk analyses for these areas.

OFFSHORE LEASING AND ENVIRONMENTAL STUDIES

The scope of Federal offshore leasing, including currently producing leases and cumulative number of wells drilled since 1954, is outlined in Table 1. Total revenue exceeds $68 billion from the production of 6.4 billion barrels of oil and condensate during this

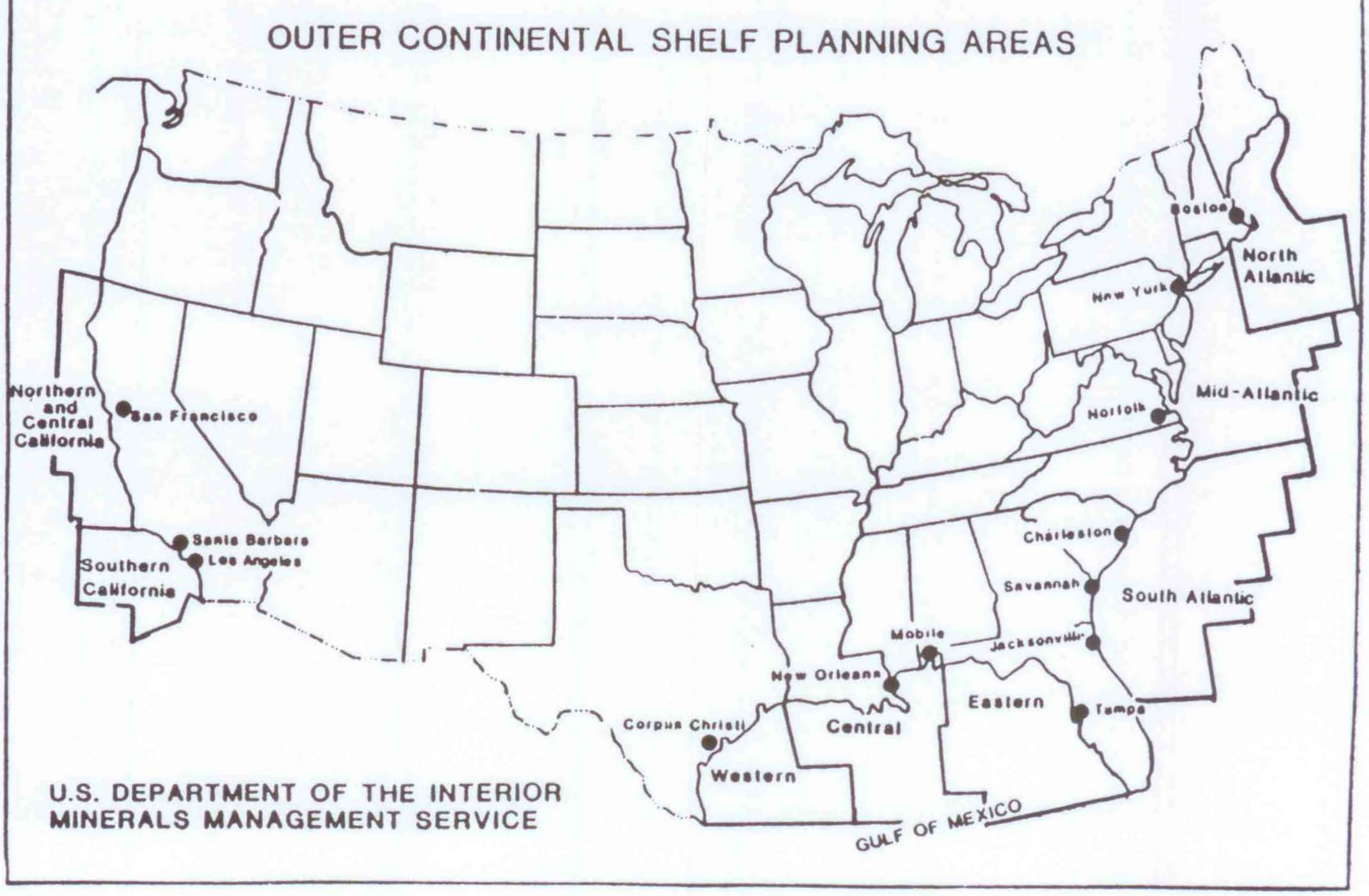

Figure 1. *Map of the MMS planning areas for the lower 48 states under the October 1984 5-year offshore leasing schedule.*

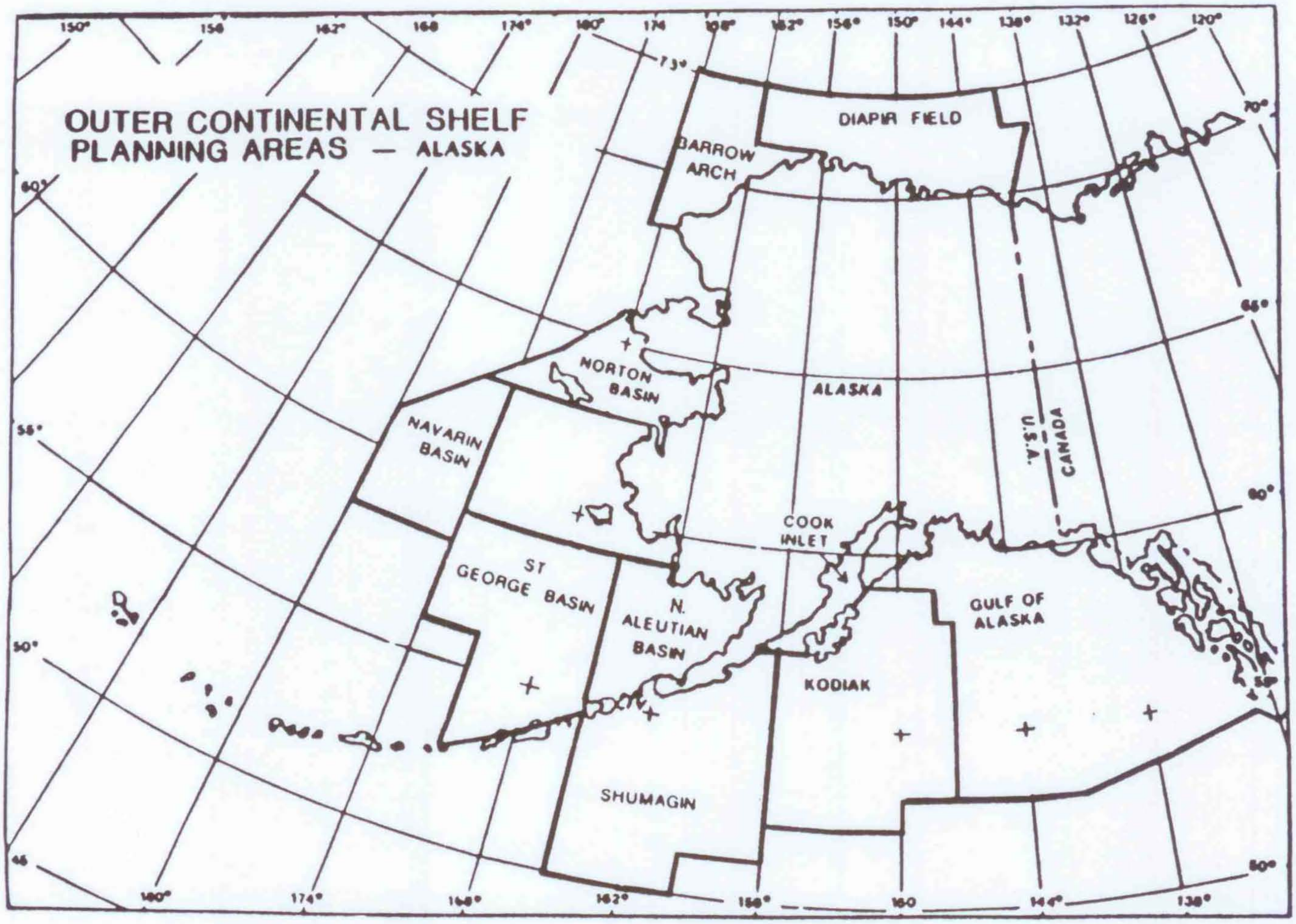

Figure 2. *Map of the MMS planning areas for Alaska under the October 1984 5-year offshore leasing schedule.*

TABLE 1.
Federal Offshore Statistics*

As of December 31, 1983:	
Area Under Lease	18.5 million acres
Tracks Under Lease	3,772
Producing Leases	1,393
— In Gulf of Mexico	1,345
— Offshore California	38
— Offshore Alaska ("Producible")	3
From 1954 Through 1983	
Total Revenue	$68.1 billion
Total Production (Oil & Condensate)	6.4 billion barrels
Wells Drilled in Federal Waters	22,095
—Off Louisiana	18,494
—Off Texas	2,537
—Off California	762
—Off Mississippi/Alabama/Florida	219
—Off Atlantic Coast	44
—Off Alaska	27
—Off Oregon/Washington	12

*Source: U.S. Department of the Interior, Minerals Management Service, OCS Report MMS 84-0071, September 1984.

period. These benefits were obtained at certain levels of risk to coastal and marine environments. One of the ways that MMS complies with its mandate of protection of the environment concomitant with minerals resource development is by sponsoring the OCS Environmental Studies Program (ESP).

The ESP directs and funds the largest single-agency, mission-oriented oceanographic research program in the Federal Government. Since its inception in 1973, the ESP has expended approximately $374 million on studies of the OCS environment, distributed among the OCS regions as shown in Figure 3. The program provides information on an array of disciplines including physical oceanography, marine biology, endangered species, and fates and effects of marine pollutants (see Figure 4). Physical oceanography accounts for roughly 22% of the ESP's cumulative expenditures through fiscal year 1984 and has been funded for more than $8 million per year in eight out of the last nine years, as shown in Figure 5. The studies support a wide variety of information needs for MMS, including Environmental Impact Statements, compliance with the Endangered Species and Marine Mammal Protection Acts, and program monitoring. Within each planning area, study needs are identified several years in advance in order to procure information in

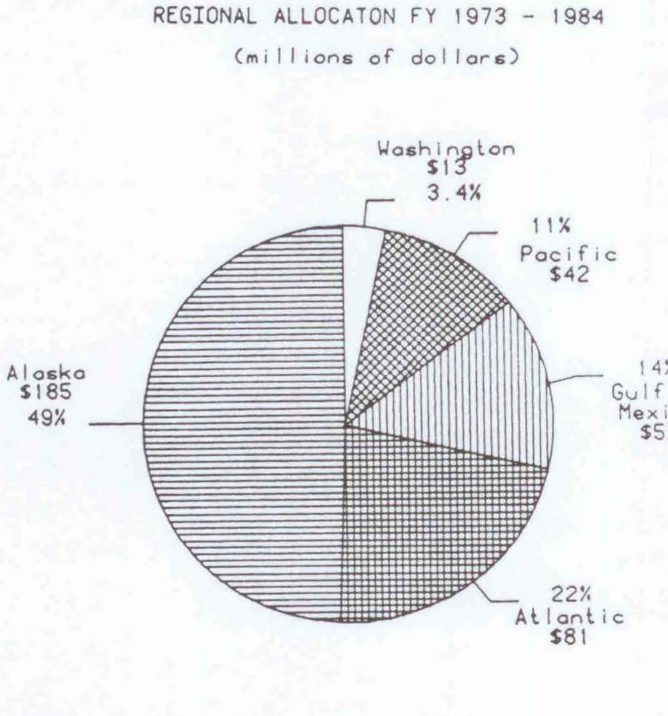

Figure 3. *Distribution of the OCS Environmental Studies Program expenditures by OCS Region from 1973 through fiscal year 1984. (Source: Department of Interior, MMS, Branch of Environmental Studies).*

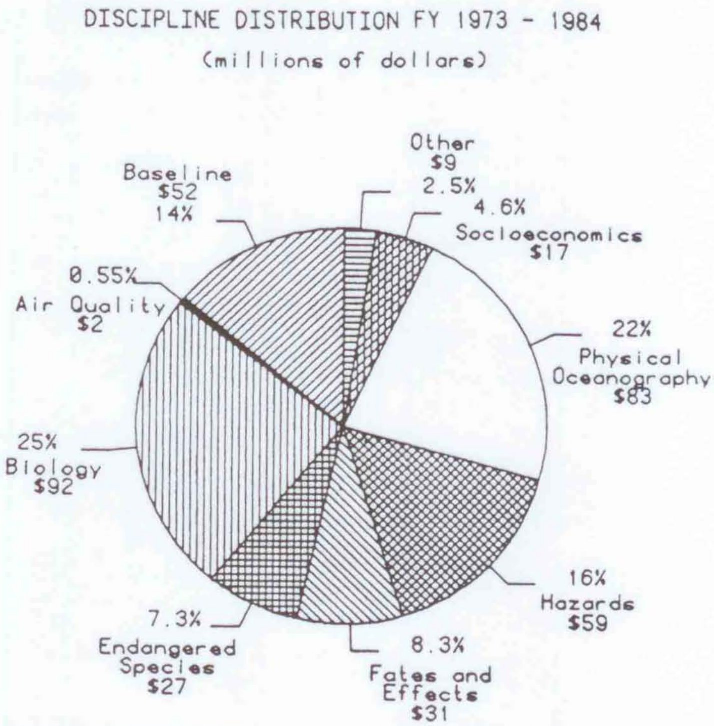

Figure 4. *Distribution of the OCS Environmental Studies Program expenditures by study disciplines from 1973 through fiscal year 1984. (Source: Department of Interior, MMS, Branch of Environmental Studies).*

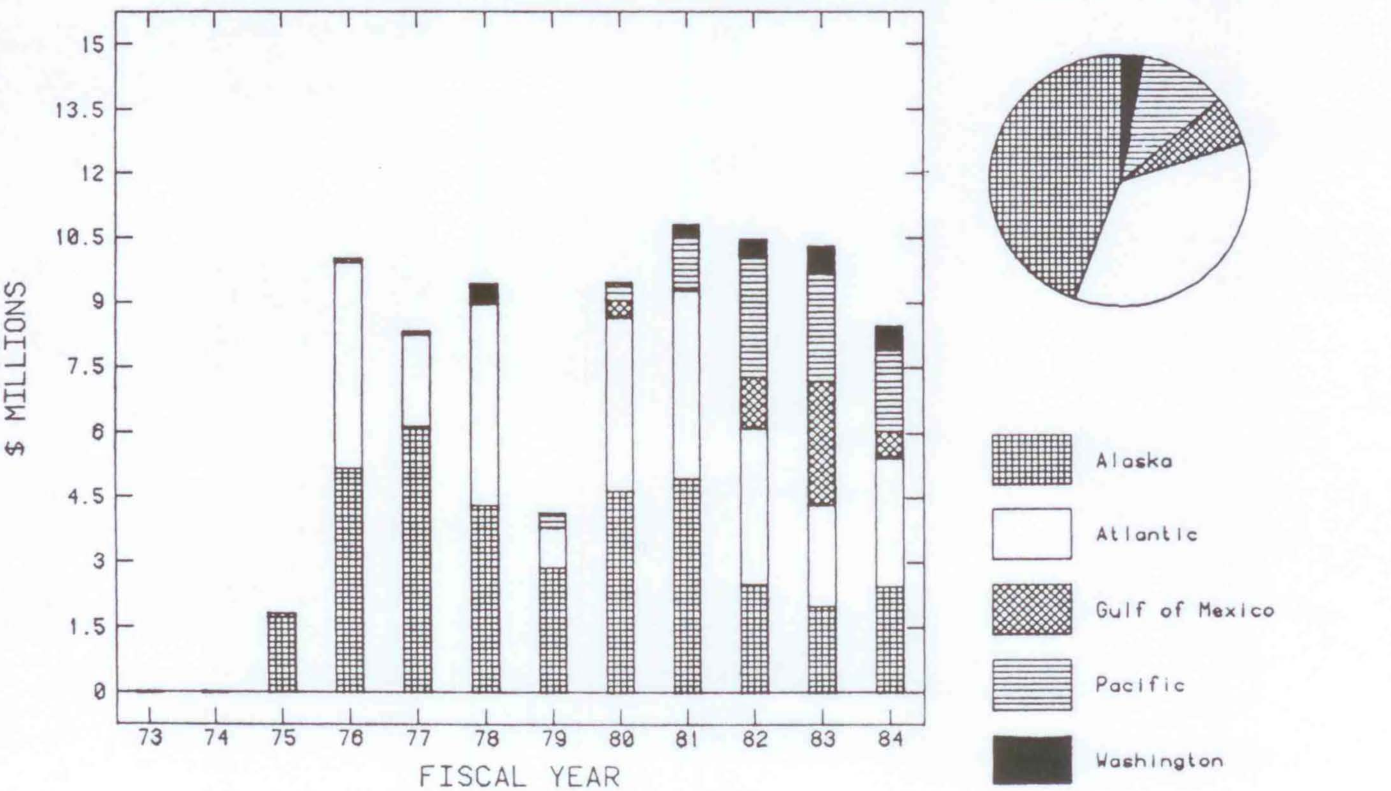

Figure 5. *Distribution of the OCS Environmental Studies Program expenditures on physical oceanography studies by fiscal year and by OSC Region. (Source: Department of Interior, MMS, Branch of Environmental Studies).*

the desired time frames. A primary use of the physical oceanographic data and much of the biological information is to create and improve inputs to MMS oil-spill modeling efforts. The major oceanographic study efforts currently used by the OSRA model in simulating surface trajectories are described below.

Atlantic and Pacific OCS Regions

For oil-spill modeling in both the Atlantic and Pacific OCS regions, MMS has adapted the OSRA model to use representations of seasonal surface water velocity fields provided by Dynalysis of Princeton, Princeton, N.J., using their Characteristic Tracing Model (CTM). The Characteristic Tracing Model is a technique to synthesize existing oceanographic data and has thereby substantially improved the accuracy of the OSRA model. The governing equations and the numerical procedures used in the CTM have been described.[2,3] A detailed discussion of the observations used in this model in the South Atlantic, including data sources, measurement devices, and distributions of data by ¼-degree squares and depth has also been presented.[3] Given the extremely large regions of oceans that are modeled for oil spills, the CTM makes use of hydrographic measurements which have relatively large spatial and temporal coverage and are readily obtained from historical data archives. A diagnostic method, which combines data and dynamic modeling, is used for deducing the current and transport distributions by utilizing known bathymetry and observed sea-surface wind stress and hydrographic data.

As an example of the application of this method, Figure 6 shows CTM representations of the winter climatological surface currents off the East Coast of the United States. The Gulf Stream can be seen following the shelf break in the South Atlantic Bight and veering off the coast into the Atlantic near Cape Hatteras. A southward current that joins the Gulf Stream near Cape Hatteras is also evident. The version of the CTM used by the OSRA model produces seasonal wind-free current representations. The OSRA model then adds the effects of local wind-induced currents as calculated for each season from long-term records of nearby wind stations or buoys. In this way the variation and persistence of winds are taken into account and projected over the 25-year lease lifetimes.

The wind-driven component provides the dominant contribution to the seasonal currents off the U.S. West Coast. Thus, the nearshore geostrophic surface current representations calculated by the CTM (shown in Figure 7 for the fall season) would be considerably enhanced by the strong south-southeastward winds that generally blow approximately parallel to the California coast. Nearshore surface seasonal currents are strong and flow poleward during winter and spring, but slacken considerably during summer and fall in this region. The more offshore currents do not exhibit such strong seasonal variability. The use of the CTM for calculating seasonal currents for the Pacific region is fully described elsewhere.[4]

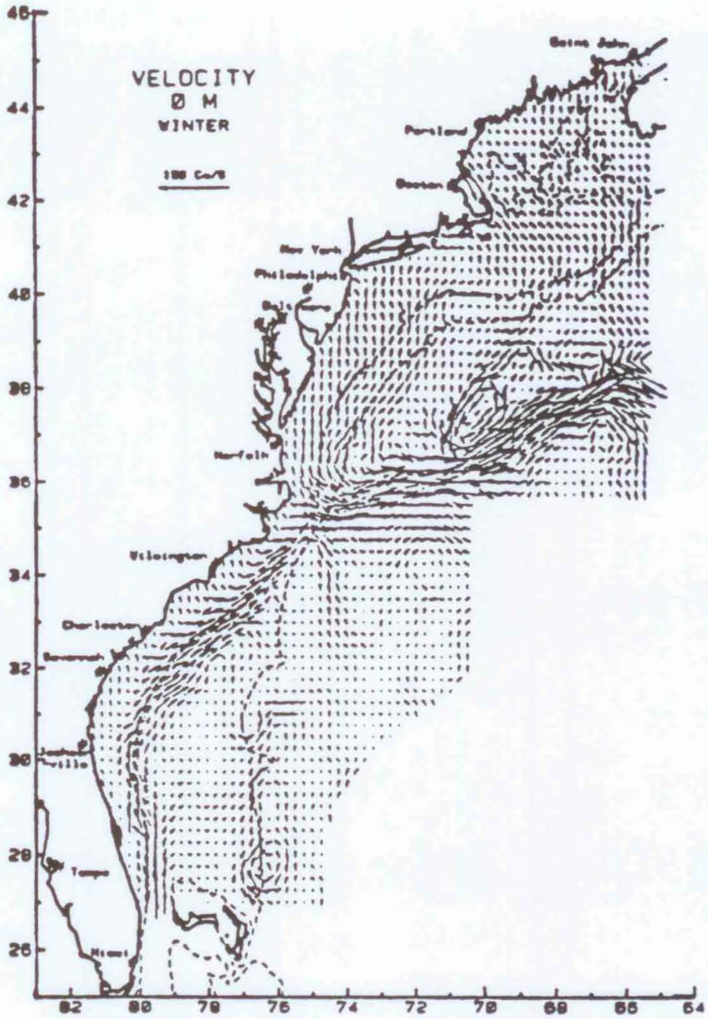

Figure 6. *Winter climatological surface currents off the East Coast of the United States. (Source: Kantha et al., 1983[3])*

In addition to the studies mentioned above, the Minerals Management Service has, since 1980, supported meteorological data-gathering buoys located along the southern, central, and northern California coasts. This buoy network is providing the first long-term, at-sea record of near-surface meteorological conditions over the California OCS. At the present time, the network is providing a continuous record of winds, waves, air and sea temperatures, and barometric pressure for eight locations along the coast. Prior to the establishment of this buoy network, only meteorological observations from shore stations and from ships in the area were available. Buoy data are used by the MMS for oil-spill modeling, air-quality modeling, and studies of ocean currents. Other uses are in weather forecasting for local fishermen and oceanographic research programs being conducted by several universities.

Gulf of Mexico OCS Region

Representations of seasonal velocity fields in the Gulf of Mexico have also been provided to MMS by Dynalysis of Princeton. The currents are calculated us-

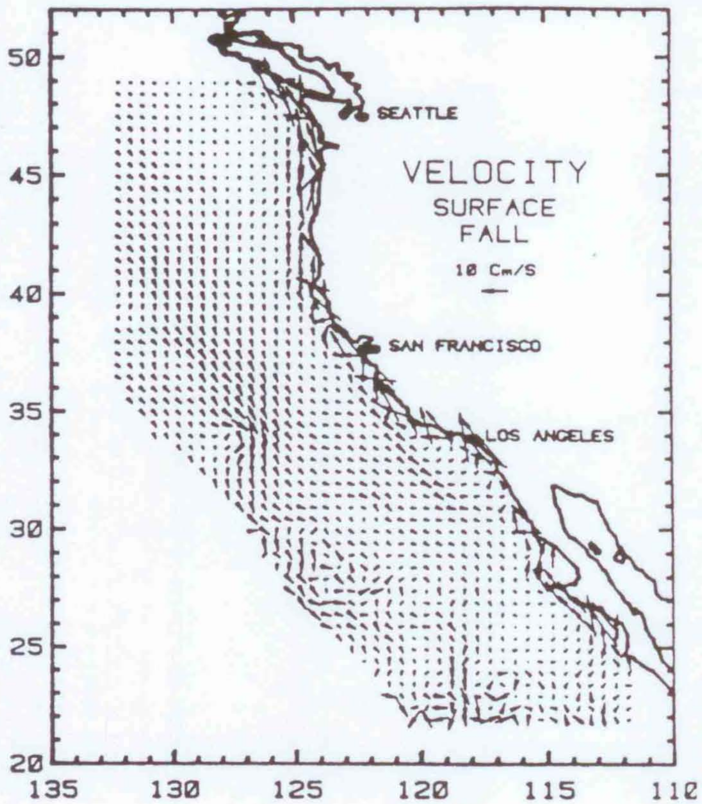

Figure 7. *Geostrophic currents (no Ekman component included) at the surface for fall from CTM calculations. (Source: Blumberg et al., 1984[4]).*

ing the complete set of Gulf temperature and salinity data files maintained by the National Oceanographic Data Center (NODC). The edited raw data were averaged on a 1-degree-square grid at the standard NODC depth levels. This data set includes all the data which were archived prior to 1979 and consists of over half a million temperature and salinity observations. However, because the amount of data is insufficient to form meaningful Gulf-wide monthly distributions, seasonally varying distributions were constructed. For further description of these data, see Blumberg and Mellor.[5] Seasonally varying surface currents in the Florida Straits and South Atlantic (east of 81° W. longitude) were also provided by Dynalysis using their CTM approach.

Ongoing and planned studies sponsored by MMS support a 4-year numerical ocean circulation modeling program for the Gulf of Mexico. The goal of these efforts is to understand Gulf current patterns and hydrology as well as to develop the capability for diagnostic and prognostic circulation modeling.

Alaska OCS Region

Potential oil spills and their transport continue to be a major focus of environmental assessments for OCS lease sales in Alaska. An interagency agreement between the Minerals Management Service and the National Oceanic and Atmospheric Administration (NOAA) provided financial and technical guidance in the development of a circulation and trajectory model for use in this region. This model is the Rand Corporation's three-dimensional model for estuaries and coastal seas (Liu and Leendertse, 1979[6] and 1981[7]). Initially calibrated and utilized in the Southeastern Bering Sea and the Beaufort Sea, the model now incorporates the entire Alaska OCS, including the Gulf of Alaska. The water and ice motions in the Alaska offshore regions are very complex. Field studies have indicated that water and ice movement are influenced by tides, weather, the extent of ice cover, and the salinity and temperature distributions of these waters. The basic three-dimensional Rand model is formulated on a finite difference grid, according to the equations of motion for water and ice, continuity, state, the balance of mass, heat, salt, pollutant, and energy. This allows for the computation of the vertical density structure and baroclinic circulation. Under ice-free conditions, a meteorological model, together with the local residual current, is used to compute the movement of oil. The meteorological model includes a storm-tracking feature. Figure 8 illustrates examples of oil-spill trajectories launched in Norton Sound under 25 stochastic weather scenarios during the winter.

Oil movement beneath the ice is more complicated. When the relative speed between the ice and water is less than a critical or threshold value, the oil will be contained by the underside roughness of the ice, and thus will move the ice. The threshold value is a function of the density of oil and water, the surface tension between oil and water, the underside roughness of ice, and the thickness of oil. When the threshold value is exceeded, the oil begins to move at a speed proportional to the speed of the water. The details of these computations can be found in Liu and Leendertse.[8,9]

The Rand model was developed to consider the important physical factors during the transport process for these waters including tide-induced residual circulation, major seasonal current systems, local wind-driven circulation, a Stokes' drift component due to the surface-wind-wave field, the movement of ice and underlying currents, and the properties of oil itself (such as density and viscosity).

For each Alaska lease sale EIS analysis, results from the Rand circulation/trajectory model are processed through the tracking portion of the OSRA model. This allows calculation of the probabilities of oil spill contact to land and other resources in the sale area. Details of the application of the Rand and other circulation models to OSRA runs for Alaska can be found in Samuels et al.[10]

FUTURE EFFORTS

As future oil and gas exploration and development occur, environmental assessments may require improvements to the simulation of trajectories and circulation of these areas. In Alaska, high-resolution modeling of circulation will be done in conjunction with a nearshore oceanographic study off the Yukon River Delta. Other models that predict the probable

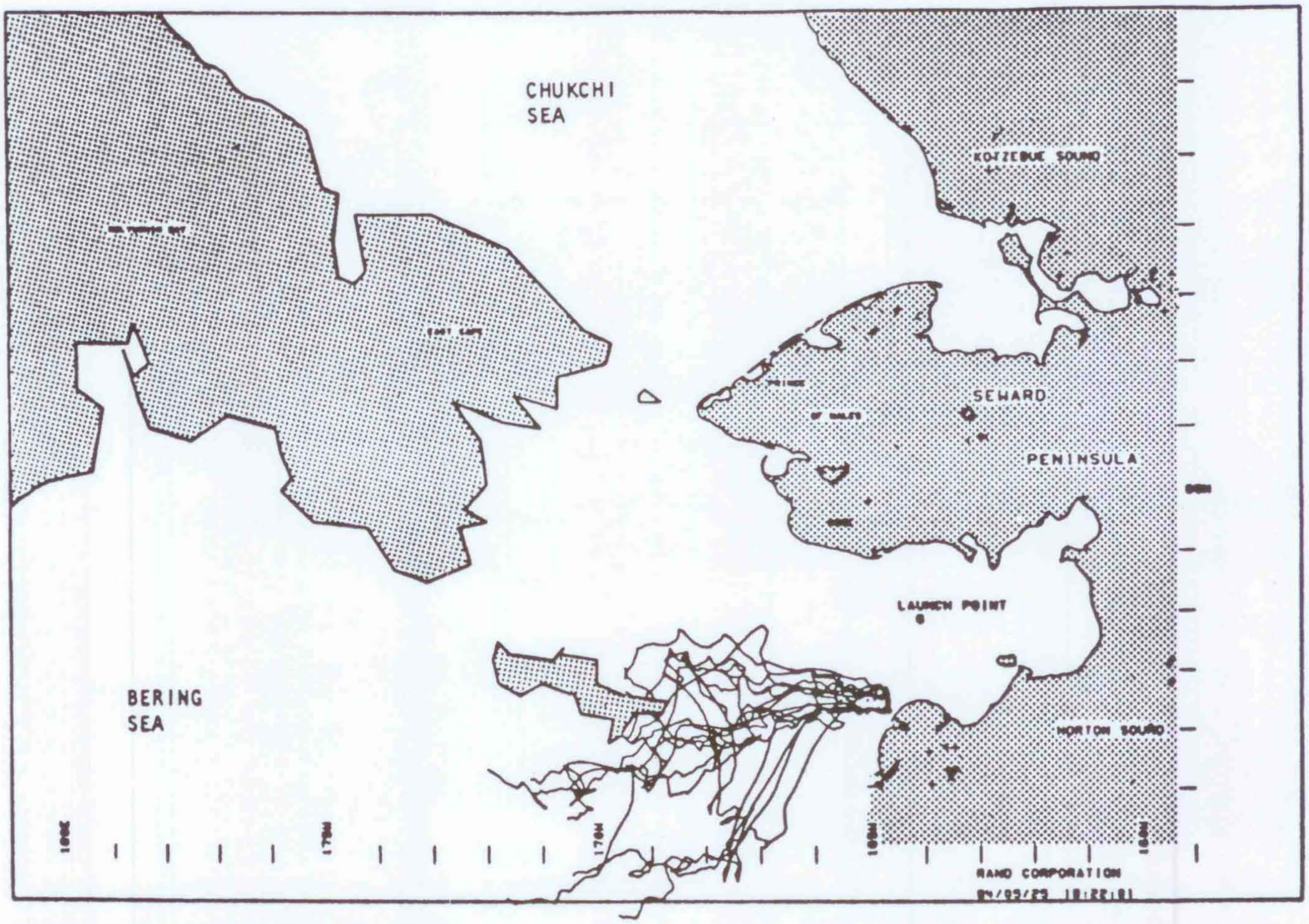

Figure 8. *Thirty-day displacements of oil spill trajectories launched from a hypothetical spill site under 25 stochastic weather scenarios during the winter oceanic period. (Source: The Rand Corporation, Santa Monica, CA, 1984).*

fate of oil in the coastal and surf zones will be added to the circulation and trajectory model.

In the Gulf of Mexico region, a multi-year effort is underway to develop a deep-water circulation model. The contractor for this study, Jaycor, Inc., Alexandria, Virginia, is making phased improvements to the model originally developed by Hurlburt and Thompson.[11] Shelf and slope circulation features may be added later using the deep-water model to establish boundary and Loop Current forcing conditions.

Present modeling and field measurement efforts in the Santa Barbara Channel and off central California should lead to improvements in circulation modeling in that region. These studies include the first time-intensive measurement programs for the California coast and will greatly extend available climatological data.

The use of state-of-the-art circulation models and data has also allowed the OSRA model to successfully hindcast the movement of actual oil spills. Amstutz and Samuels[12] describe good correlation between simulated and actual trajectories of both the *Argo Merchant* and Santa Barbara oil spills, as well as similar distributions of drift bottle landfalls and modeled simulations off Southern California. The continued use of the OSRA model, coupled with products of the Environmental Studies Program, provides analysts with a sound quantitative approach to offshore environmental impact analysis and represents an important area of applied oceanography.

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