STATISTICAL ESTIMATES OF SHORELINE OIL CONTACT IN THE GULF OF MEXICO

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ABSTRACT

As steward of the Federal offshore lands known as the Outer Continental Shelf (OCS), the U.S. Department of the Interior (DOI), Minerals Management Service (MMS), is responsible for balancing the Nation's search for commercial oil and gas with protection of the human and marine environments. The MMS regulates the development of mineral resources in an environmentally safe manner by analyzing environmental consequences of the OCS program prior to lease sales or approval of industry's plans. The Oil-Spill Risk Analysis (OSRA) model was developed by the DOI for the analysis of possible oil-spill impact from offshore oil and gas operations.

The OSRA model produces statistical estimates of hypothetical oil-spill occurrence and contact from projected OCS operations. The model generates an ensemble of sea surface oil-spill trajectories by initiating thousands of oil-spill simulations at hypothetical spill locations to statistically characterize oil-spill risk in areas of prospective drilling and production and along projected pipeline routes.

The hypothetical spills are initiated every day and move at the velocity of the vector sum of the surface ocean currents plus an empirical wind-induced drift of speed equal to 3.5% of the local wind speed, with a wind-speed-dependent direction (Samuels et al., 1982). The model generates oil-spill trajectories by integrating interpolated values of the wind and ocean current fields at intervals short enough to use the full spatial resolution of the ocean current and wind fields. The OSRA model, as applied to the Gulf of Mexico, uses 3-hourly ocean current fields over 7 years (1993-1999) generated by the Princeton Regional Ocean Forecast System (PROFS) (Oey et al., 2004). The PROFS is driven by synoptic winds, heat flux, and river flows. The wind field is based on the European Center for Medium-Range Weather Forecasts surface winds enhanced by observations from meteorological buoys and Coastal-Marine Automated Network stations. The same wind field used to force the ocean model is used to move the oil in the spill trajectories.

As an example of environmental assessment, the OSRA model was used to estimate the spreading of oil spills by simultaneously modeling fractions of each spill, referred to as spillets. The spillets were used to calculate additional statistics, in particular, the length of coastline contacted by a large spill. The coastline was divided into equal length segments. Assumptions were made regarding what fraction of the spill (i.e., the number of spillets) that contacted a land segment would constitute a contact larger than the "level of concern." Sensitivity of the analysis to key assumed parameters, such as the number of spillets and the level of concern, were tested.

INTRODUCTION

The Department of the Interior (DOI), Minerals Management Service (MMS), an agency of the U.S. Government, conducts and regulates the commercial development of oil and natural gas on the U.S. Outer Continental Shelf waters. The MMS analyzes the environmental consequences of the program prior to making decisions regarding lease sales and approval of industry plans. The Oil-Spill Risk Analysis (OSRA) model was developed by the DOI for the analysis of possible oil-spill impact from offshore oil and gas operations. A numerical ocean circulation model for the Gulf of Mexico, the Caribbean Sea, and the adjacent U.S. southeastern shelf and slope regions was run to simulate the time period of 1993 through 1999. The resulting ocean current data will be used in the MMS OSRA model to estimate the frequency of oil-spill contacts from offshore spills. This report describes the testing, and evaluations of the trajectory estimates and their statistic contacts to the coastline.

THE OCEAN MODEL

The results we present in this paper are based on the results of ocean model hindcasts using the Princeton Regional Ocean Forecast System (PROFS) from 1993 through 1999, performed by Oey et al. (2004). The model is based on the Princeton Ocean Model (Blumberg and Mellor, 1987; Mellor and Ezer, 1991). The model domain extends westward from 55°W and also north of 5°N, thus including the Gulf Stream, the Gulf of Mexico and the Caribbean Sea (Figure 1). Inflow and outflow transports are specified across 55°W, determined as the depth-integrated velocities at the boundary, and are meant to account for the large-scale transports through 55°W (Fig. 1). The three-dimensional velocity, temperature, and salinity fields at the open boundary are calculated according to Oey and Chen (1992). The temperature and salinity fields at the boundary are prescribed from the Generalized Digital Environmental Model monthly temperature and salinity climatology (Teague et al., 1990). The forcing data included a 6-hourly wind field obtained from a combination of National Data Buoy Center data and the European Center for Medium-Range Weather Forecasts analysis, daily river discharges from 34 U.S. rivers in the Gulf of Mexico, and satellite sea-surface height anomaly and sea-surface temperature. The satellite data were used in an assimilation scheme based on optimum interpolation. An example of model output in the Gulf of Mexico and Caribbean Sea is shown in Figure 2. The near-surface current and eddy fields are obtained from a combination of satellite data and model. Ten-day estimated ocean particle trajectories from July 19 through July 28, 1997, are shown (Figure 2). The hindcast has yielded mean circulation and variances that are consistent with observations (Oey, et al., 2004).

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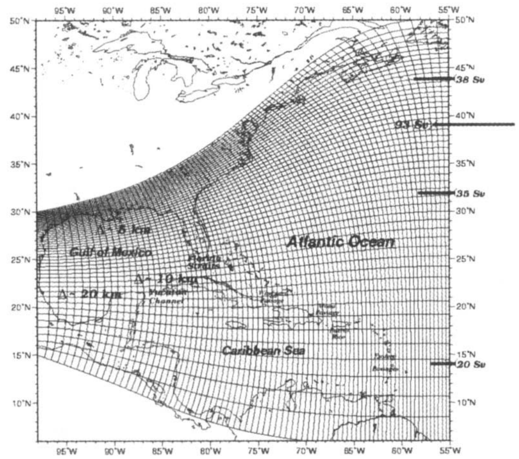
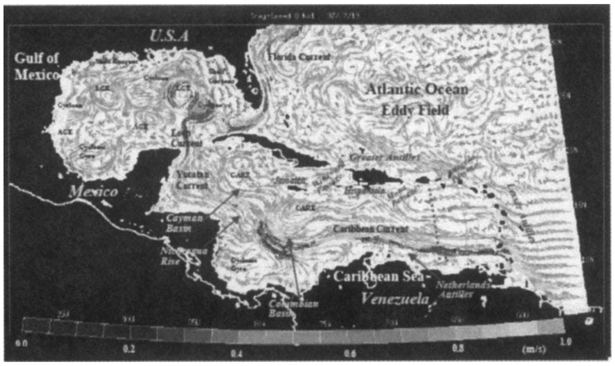


FIGURE 1. STUDY DOMAIN OF THE PROFS OCEAN MODEL. THE TRANSPORT BOUNDARY CONDITIONS ARE SPECIFIED AT 55W.



YC: Yucatan Current	CARE: Caribbean Eddy
LC: Loop Current	ACE: (Smaller) Anticyclone
LCE: Loop Current Eddy	

FIGURE 2. AN EXAMPLE MODEL OUTPUT OVER THE GULF OF MEXICO AND CARIBBEAN SEA: NEAR-SURFACE CURRENT AND EDDY FIELDS OBTAINED FROM A COMBINATION OF SATELLITE DATA AND MODEL. SHOWN ARE TEN-DAY TRAJECTORIES FROM JULY 19 THROUGH JULY 28, 1997. COLORS INDICATE SPEEDS SUCH THAT GREENISH BLUE IS ≈0.5 M/S AND RED IS ≥1 M/S.

OIL SPILL MODEL

The Oil-Spill Risk Analysis (OSRA) model was developed by the DOI for the analysis of possible oil-spill impact from offshore oil and gas operations (Samuels et al., 1982; Smith et al., 1982; LaBelle and Anderson, 1985; Price et al., 2002). The hypothetical oil spills are initiated every day and move at the velocity of the vector sum of the surface ocean currents plus an empirical wind-induced drift of speed equal to 3.5% of the local wind speed, with a wind-speed-dependent direction. The model generates oil-spill trajectories by integrating interpolated values of the wind and ocean current fields at intervals short enough to use the full spatial resolution of the ocean current and wind fields. The OSRA model, as applied to the Gulf of Mexico, uses 3-hourly ocean current fields over 7 years (1993-1999) from the hindcast runs of the ocean model described above. The same wind field used to force the ocean model is used to move the oil in the spill trajectories.

For this particular application, the OSRA model was used to estimate the spreading of oil spills by simultaneously modeling fractions of each spill, referred to as spillets. The dispersion of the oil spill is represented by adding a random component to both velocity components at each time step. The random component used a constant coefficient and a uniform random number generator. The spillets were used to calculate additional statistics, in particular, the length of coastline contacted by a large spill. The coastline was divided into equal-length segments of 20 kilometers (km) (Figure 3). The spillets were not allowed to "re-float"; when a spillet contacted land, it stopped moving, and the land contact was recorded. Assumptions were made regarding what fraction of the spill (i.e., the number of spillets) that contacted a land segment would constitute a contact larger than the "level of concern" (LOC). Sensitivity of the analysis to key assumed parameters, such as the number of spillets and the LOC, were tested.

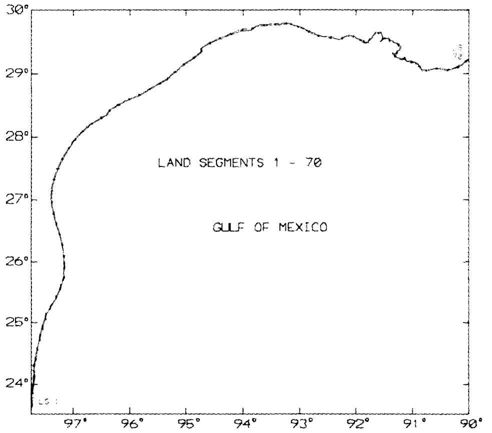


FIGURE 3. THE INDIVIDUAL NUMBERED LAND SEGMENTS. EACH IS 20 KM IN LENGTH.

RESULTS

The base statistical trajectory run initiated a spill on 360 days per year for the 7 years of wind and ocean current, resulting in 2,520 trajectories of 1,000 spillets each. Three launch points for the hypothetical trajectories were chosen in the Gulf of Mexico, on the Texas/Louisiana shelf at 20, 40, and 80 km offshore (Figure 4). Example trajectories are shown from Launch Point 1 (Figure 5) and Launch Point 3 (Figure 6). The trajectories show the strong coastal current from Louisiana waters to Texas waters in winter. Figure 6 also shows the effect of an offshore Loop Current Eddy represented in the ocean model. The Loop Current Eddy causes many of the spillets to move to the south-east, in an anticyclonic pattern, around the eddy (Figure 6).

In addition to the statistics for the trajectories using 1,000 spillets, statistics were calculated for trajectories of 500 and 100 spillets each. The results are shown in Table 1. The launch points closer to land had higher lengths of coastline contacted at shorter time intervals, but slightly less for the 30-day interval. This is consistent with more of the spills bringing oil to the coast from launch points near the coast, and for longer overall trajectories for spills starting further from the coast. An attempt to remove the bias from the average coastline contact from spills that did not contact the coast at all (i.e., spills that remain offshore and do not contact land) was addressed by averaging only spills that have coastline contacts greater than zero (Table 2). The results of this unbiased (or perhaps over-biased) average, is that the averages for

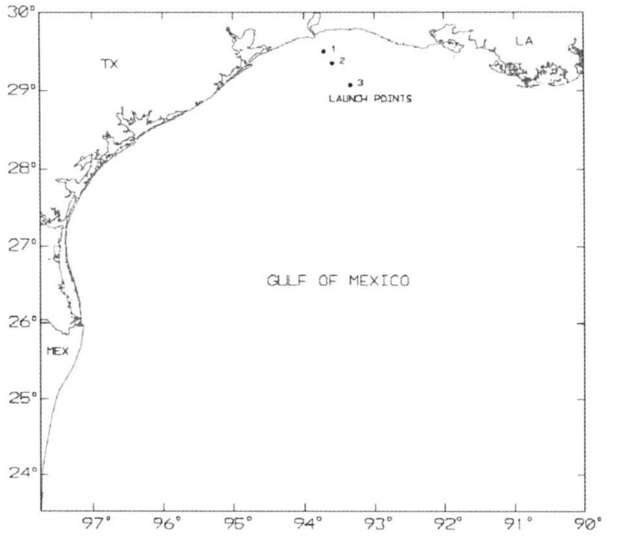


FIGURE 4. THE THREE EXAMPLE LAUNCH POINTS—20 KM, 40 KM, AND 80 KM OFFSHORE.

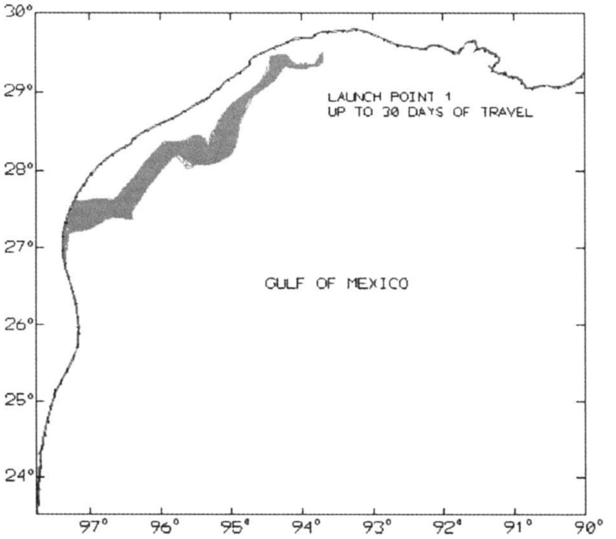


FIGURE 5. EXAMPLE TRAJECTORY, STARTED AT LAUNCH POINT 1, 30 DAYS, AND 1000 SPILLETS. THE SPILLETS ARE TRANSPORTED PRIMARILY BY THE COASTAL CURRENT AND THE WIND.

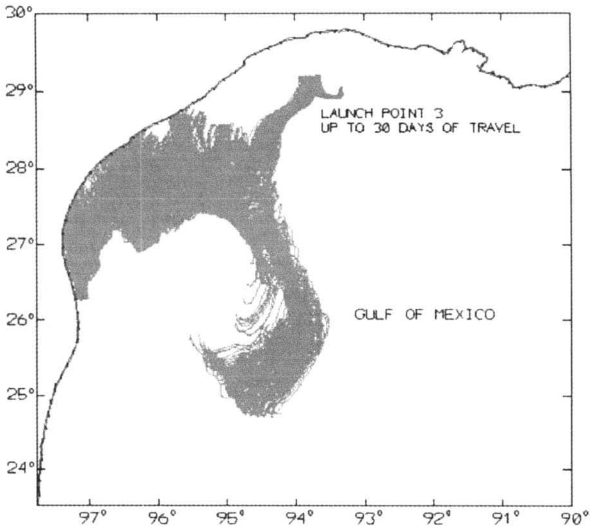


FIGURE 6. EXAMPLE TRAJECTORY, STARTED AT LAUNCH POINT 3, 30 DAYS, AND 1000 SPILLETS. SOME OF THE SPILLETS ARE TRANSPORTED OFFSHORE AROUND A ANTICYCLONIC LOOP CURRENT EDDY.

all the launch points are greater for all time intervals. The average coastline contacts are more similar among the launch points for the same time intervals, with only slight increases in coastline contacted based on the distance of the launch point from the coast.

The LOC was tested by tabulating land segments contacted by 1 or 10 spillets from the 1,000 set, 1 or 5 from the 500 set and 1 from the 100 set (Table 3). The results show that average for sets from 1 of 1,000 and 1 of 500 have slightly higher contact lengths, since only 1 spillet constitutes a contact to the land segment.

Finally, additional statistics were calculated for trajectories starting every other day (1,260 trajectories) and every fourth day (630 trajectories), as shown in Table 4. The sensitivity of the averages to the number of total trajectories indicates that the average coastline contacted and the standard deviations are nearly equal. However, the 95% confidence interval, since it is weighted by the number of estimates, increases for fewer trajectories. This is due to the fact that the reduced number of trajectories is from the same "population" and is based on the same overall oceanographic and wind conditions. So, for a less computer-time-intensive estimate, the smaller number of trajectories gives the same average results, with slightly larger confidence intervals.

Table 1. Average Kilometers of Coastline Contacted at 1% Level of Concern (LOC)

Num	Launch Point 1			Launch Point 2			Launch Point 3		
	3 days	10 days	30 days	3 days	10 days	30 days	3 days	10 days	30 days
1000	14.2	29.7	41.7	8.6	27.7	45.7	2.5	23.0	51.0
500	14.2	29.8	41.9	8.6	27.7	45.9	2.5	23.1	51.2
100	14.5	30.7	43.5	8.9	28.8	48.0	2.6	23.8	53.5
100	30.5	36.0	45.0	32.4	39.2	50.8	34.7	42.5	59.1

Table 2. Average Kilometers of Coastline Contacted at 1% LOC Excluding Any Trajectory That Did Not Contact Land

Num	Launch Point 1			Launch Point 2			Launch Point 3		
	3 days	10 days	30 days	3 days	10 days	30 days	3 days	10 days	30 days
1000	30.1	35.5	43.3	31.4	37.9	48.5	33.4	41.6	56.6
500	30.1	35.6	43.4	31.5	38.0	48.6	33.1	41.5	56.8
100	30.5	36.0	45.0	32.4	39.2	50.8	34.7	42.5	59.1

Table 3. Average Kilometers of Coastline Contacted at Different LOC's
Based on the Number of Spillets From any Trajectory that Contact Land
Launch Point 3, 30 Daysa

	1% LOC (10 of 1000)	1% LOC (5 of 500)	1% LOC (1 of 100)	0.1% LOC (1 of 1000)	0.2% LOC (1 of 500)
Average	51.0	51.2	53.5	65.7	62.2
Standard Deviation	32.4	32.7	34.6	44.2	41.5
95% Confidence Interval	+1.3	±1.3	±1.3	±1.7	±1.6

Table 4. Sensitivity of the Average Kilometers of Coastline Contacted at 1% LOC
By Reducing the Number of Trajectories
Launch Point 3, 30 Days, 1000 Spillets

	All (2520)	Every Other (1260)	Every Fourth (630)
Average	51.0	51.2	51.2
Standard Deviation	32.4	32.1	33.4
95% Confidence Interval	+1.3	+1.8	+2.6

CONCLUSIONS

The estimates of the length of coastline contacted by hypothetical oil spills using the OSRA methods were consistent with other estimates (Barker and Galt, 2000). The variations of the mean lengths of oiled coastline for the cases of ranges of numbers of spillets and numbers of trajectories were within the confidence interval, for similar cases. The sensitivity cases using fewer trajectories preserve the average values, with reduced confidence. The results of these estimates might be changed slightly if the spillets were allowed to "re-float" and contact other land segments. Additional sensitivity of the results to the length of the shoreline segments was not directly tested. The results of the length of the contacted shoreline should not be very sensitive to the length of the segments, unless the segments are very large. Using smaller segments would refine the length estimates somewhat, particularly if only a fraction of the specific spill contacted land. The magnitude of the random coefficient is another element that must be estimated, and should be related to the regional ocean conditions. Increasing the amount of dispersion could increase the coastline contact. The results would generally be reduced if oil weathering was considered in the calculations, but this is a strong function of the oil properties, and the methods used here were intended for general application. The ocean circulation and wind forcing of any particular coastal region have a highly controlling affect on the transport of spilled oil, and the coastline contacts are highly dependent on the regional oceanographic conditions. Thus, any oil-spill trajectory analysis must be based on the best available input functions to obtain a useful product.

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