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REPORT

THE FATE OF THE ARCTIC IN OFFSHORE OIL BLOWOUTS

Acknowledgments

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Executive Summary

The objective of this study is to illustrate the water surface and shoreline reach potential of various crude oil release scenarios from oil and gas leases in the outer continental shelf of the Chukchi and Beaufort Seas off the Arctic coast of Alaska.

We conducted a stochastic model-predicted fate analysis for hypothetical crude oil spills at two sites where the federal government sold leases, one in the Chukchi and one in the Beaufort. We used the world-wide industry standard OilMap software to model trajectories. Three release scenarios were simulated for each site, using meteorological and oceanographic data recorded from 2009-2013. The scenarios assumed oil releases of a type and volume considered in federal government environmental reviews. They corresponded to eventual well control both without and with a relief well and a late season release not controlled prior to winter ice (after which OilMap does not model oil movement). Each scenario was modeled until all oil was in contact with pack ice.

1. The first scenario modelled a crude oil release under characteristic August conditions that was capped within 10 days of the initial release. This scenario, which was modelled for 120 days, included a 20 percent removal rate for response countermeasures.

2. The second scenario similarly modelled a crude oil release in July that was controlled by a relief well 33 days after the initial release. This scenario, which was modelled for 150 days, included a 20 percent removal rate for response countermeasures.

3. The third scenario modelled a crude oil release in October that was not capped throughout the modelled timeline. This scenario was modelled for 90 days, and assumed that conditions prevented any effective use of response countermeasures.

OilMap's stochastic trajectory and fate models were run 100 times for each scenario, using randomly selected start times and the associated wind and oceanographic data from five years of historical data.

Using conservative assumptions and parameters, the model predicts widespread impacts from oil releases in all scenarios. Shoreline impacts were projected at 100 percent probability in Alaska and Russia in the event of an uncontrolled October blowout in the Chukchi Sea, and as almost certain (from 98 to 100 percent probability) in both Alaska and Canada, should the same scenario occur in the Beaufort. In the Chukchi spill scenarios, the range of possible marine impacts extends over 800 miles from east to west, and over 900 miles from north to south, and covers an area of >300,000 square miles. In the Beaufort Sea spill scenarios, the range of possible marine impacts extends over 600 miles from east to west, and over 150 miles from north to south, and covers an area of >30,000 square miles.

1 Introduction

Stochastic modelling is a probabilistic technique commonly used to determine the likelihood of possible future outcomes, given a set of variable influencing factors. It is based on computed assimilation and analyses of historical data that take into account a certain degree of randomness, or unpredictability. Stochastic models are often run hundreds or thousands of times to derive a distribution of potential outcomes. The larger the collection of variable inputs (for instance, oceanographic and meteorological data) and the number of runs, the higher the expected accuracy of predicted outcomes. Stochastic modelling is a valuable tool that can assist in the decision-making or planning process, including the identification of reasonable mitigation to prevent or minimize the risk of an incident reaching and potentially affecting a sensitive area, or the allocation of adequate resources to effectively respond to a spill-related incident.

This study examined central locations in specific leases held and proposed for exploration and production in the Chukchi and Beaufort Seas by Shell Gulf of Mexico Inc. and Shell Offshore Inc., respectively. The modelling was conducted prior to Shell's 2015 decision to abandon drilling in the region.

Version 6.0 of the world-wide industry standard spill prediction software 'OilMap' was used for this stochastic modeling analysis. OilMap is a computer-based spill model and response system developed by Applied Sciences Associates (ASA) that has been used internationally since the early 1990s by major oil companies, governments, universities, and research organizations (See Appendix A).

OilMap data inputs include shoreline definition, area circulation features (i.e., local ocean currents), long-term local wind-time series data, spill location, and hydrocarbon product properties and characteristics. The model output predicts water surface reach and shoreline areas that are most and least likely to be affected by a spill, as well as the percentage of a model's simulations in which oil is predicted to reach a shoreline. The stochastic simulations provide valuable insight into the probable behaviour of potential spills under the meteorological, oceanographic, and river conditions typical to a specific geographic location in a given calendar month, based on historical local data.

Computer models inherently rely on multiple assumptions and approximations that can affect predictive outcomes. These may include complex model algorithms, physical and environmental conditions, and in the case of trajectory models like OilMap, the properties and characteristics of the modelled substance. Although OilMap uses the best available data, results should be regarded only as best available estimates of a spill's likely (or unlikely) distribution and fate. Stochastic model predictions are thus most useful for determining trends in a substance's movement in the event of a spill and areas most likely at risk, rather than a prediction about any specific spill.

OilMap's standard requirements for a stochastic study of spill releases include:

- A good description of the local geography (i.e., land and water boundaries);
- A good description of the major hydrodynamic circulation features of the water body (or water bodies); and
- A long-term (i.e., five years or more) local wind-time series dataset from one or more unobstructed coastal wind station(s) or numerical model data.

The objective of the stochastic modelling is to determine the probability of any given geographic reach and fate occurring (e.g., < 10 percent chance; 50 percent chance; >90 percent chance) for a crude oil spill originating at the study locations, identify areas most and least likely to come in contact with a spill, and help direct the determination of spatial and temporal boundaries for the Fate and Effect Analysis of a spill.

For this analysis, six stochastic scenarios were modelled, with three separate scenarios for each of the two locations, each based on 100 individual simulations with randomly selected, different start times within the selected month. Shoreline data were obtained from the modelling software provider. The description of the local water circulation field was based on hydrodynamic data for the area provided by Tetra Tech, which retrieved and formatted the data from the North American Regional Reanalysis (NARR), discussed more fully in section 2.3, below. Five years of local wind-time series data also came from Tetra Tech, who retrieved and formatted the data from HYCOM global model (see section 2.2).

Delineation of the study area boundary and data used as input to the modelling are presented in Section 2 as are the modelling assumptions used. Results of the stochastic scenarios are presented in Section 3. Conclusions are provided in Section 4, and references in Section 5.

2 Study Area and Model Data

2.1 STUDY AREAS

The Study Areas are located based on hypothetical drilling locations within previously sold U.S. federal government lease blocks, one in the Chukchi Sea and one in the Beaufort (Figures 2.1 and 2.2 and Table 2.3).

FIGURE 2.1: CHUKCHI SEA SCENARIO LOCATION

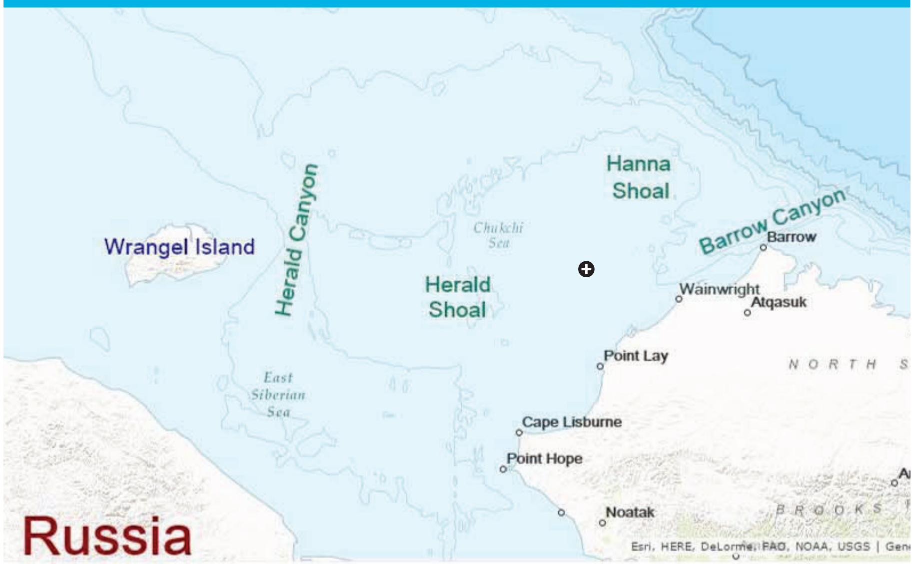


FIGURE 2.2: BEAUFORT SEA SCENARIO LOCATION

2.2 OCEANOGRAPHIC/HYDRODYNAMIC DATA

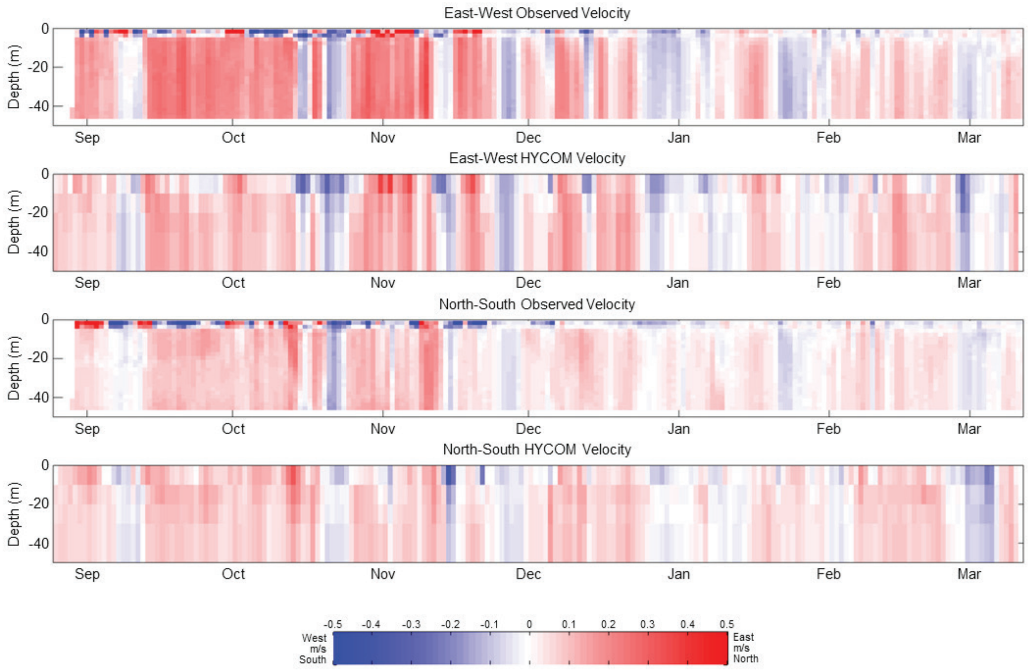
Oceanographic data were retrieved from the HYCOM global model (HYCOM 2013). HYCOM is a three-dimensional model incorporating assimilation of observational data and real-time simulation of the global ocean and is maintained by a partnership associated with the Global Ocean Data Assimilation Experiment (See Appendix B). HYCOM simulates the global ocean on non-tidal timescales, with data available daily. Data were retrieved from fields representing water velocity in the top ten metres of the water column.

The HYCOM data used did not include ice field or variables to describe ice in the area. As a result, ice interaction was modelled through the use of ice polygons, based on data derived from the Sea Ice Atlas (see Section 2.6.6).

2.2.1 OCEANOGRAPHIC/HYDRODYNAMIC DATA QUALITY CONTROL

The currents in HYCOM are non-tidal in nature, with data available on a one-day time step. The predicted currents were compared against available observations by upward-looking Acoustic Doppler Current Profilers (ADCPs) deployed from 2011 to 2012. The ADCPs provide information on the tidal currents in the region, and also on the ability of HYCOM to match the residual (non-tidal) currents. Figure 2.3 shows a plot of the currents throughout the water column as predicted by HYCOM and observed by the ADCP HS01. The ADCP is moored at a depth of approximately 55 metres, facing upwards. The measurement of currents at the surface is less accurate than within the water column. The plots are split into comparisons of the east-west and north-south components of velocity.

FIGURE 2.3: COMPARISON BETWEEN HYCOM AND CHUKCHI ADCP HS01 FULL WATER COLUMN

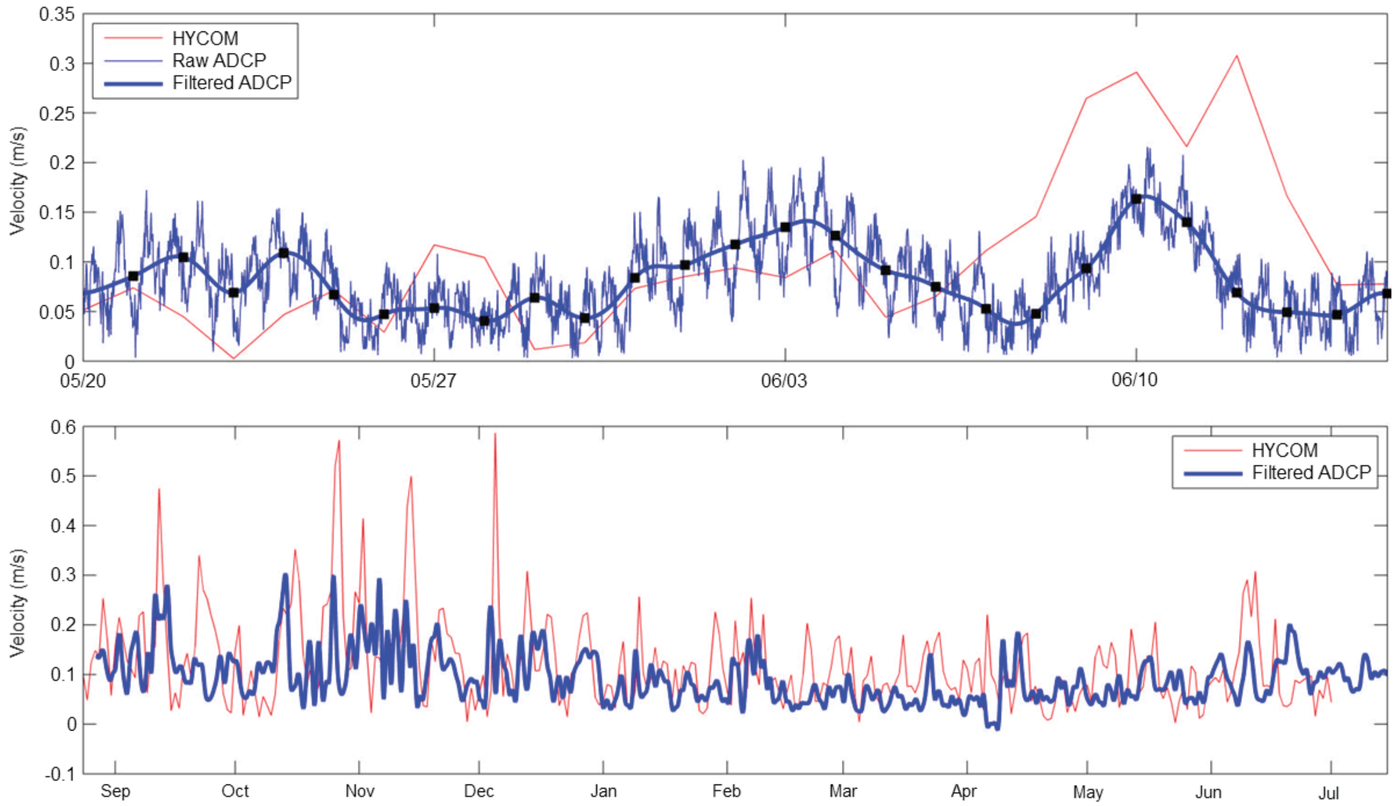


ADCP data retrieved from http://www.nodc.noaa.gov/archive/arc0064/0093399.

HYCOM predictions retrieved from http://tds.hycom.org/thredds/GLBa0.08/glb_analysis.html.

The transport of water through the Bering Strait is generally northward, though the flow can be slowed or briefly reversed by adverse winds, common in winter. This ‘Bering Water’ often flows along the coast towards the northeast (Pickart 2004). In deeper waters north of the Chukchi shelf, the clockwise Beaufort Gyre dominates circulation. Currents are generally to the north and east at the location of the ADCPs, with occasional weak reversals where currents flow southwest. The model matches the general patterns of currents at this location, especially with regard to the timing of shifts from one regime to another. The surface currents from HYCOM are plotted against the top-most valid ADCP bin in Figure 2.4. The ADCP data are displayed in two forms, one with the complete time series including tidal currents (top panel), and one with a low pass filter applied to better match the HYCOM time intervals (bottom panel). The low-passed panel displays the full period of record for the ADCP deployment. The model matches some of the current variability, and in fact over-predicts velocity during a number of short events.

FIGURE 2.4: COMPARISON BETWEEN HYCOM AND CHUKCHI ADCP HS01 NEAR-SURFACE CURRENT TIME SERIES



ADCP data retrieved from http://www.nodc.noaa.gov/archive/arc0064/0093399.

HYCOM predictions retrieved from http://tds.hycom.org/thredds/GLBa0.08/glb_analysis.html.

TABLE 2.1: HYCOM MODEL EVALUATION	
	ADCP HS01
Bias (m/s)	-0.004
RMS Difference (m/s)	0.098
Model Skill (-)	0.59

2.3 METEOROLOGICAL DATA

Historical wind data have been gathered from the North American Regional Reanalysis (NARR) for a large portion of the Arctic Ocean every three hours since the late 1970s. The NARR is a reanalysis model, which means it incorporates observations into a numerical weather prediction model to provide the best estimate of meteorological conditions at all locations in the model domain. Data were retrieved from the fields 'ugrd10m' and 'vgrd10m' representing the wind velocity at a height of 10 metres over the sea or land surface (the industry standard for wind data and also the default wind height used by OilMap).

2.3.1 METEOROLOGICAL DATA QUALITY CONTROL

Evaluating the NARR model surface wind fields against wind speeds from nearby buoys allows an understanding of possible biases and errors in the model and provides confidence in using the modelled wind fields for spills throughout the region. Buoy data are available from a deployment in the Hanna Shoal region of the Chukchi Sea from August to October, 2011. Meteorological and oceanographic parameters measured by the buoys include wind speed and direction, air and sea surface temperature, statistical wave parameters, and near-surface currents. Land-based stations are less applicable to oil spill simulations, but considering the short periods of record available from the buoys a comparison between NARR and observed winds was also made at NDBC Station RDDA2, Red Dog Dock.

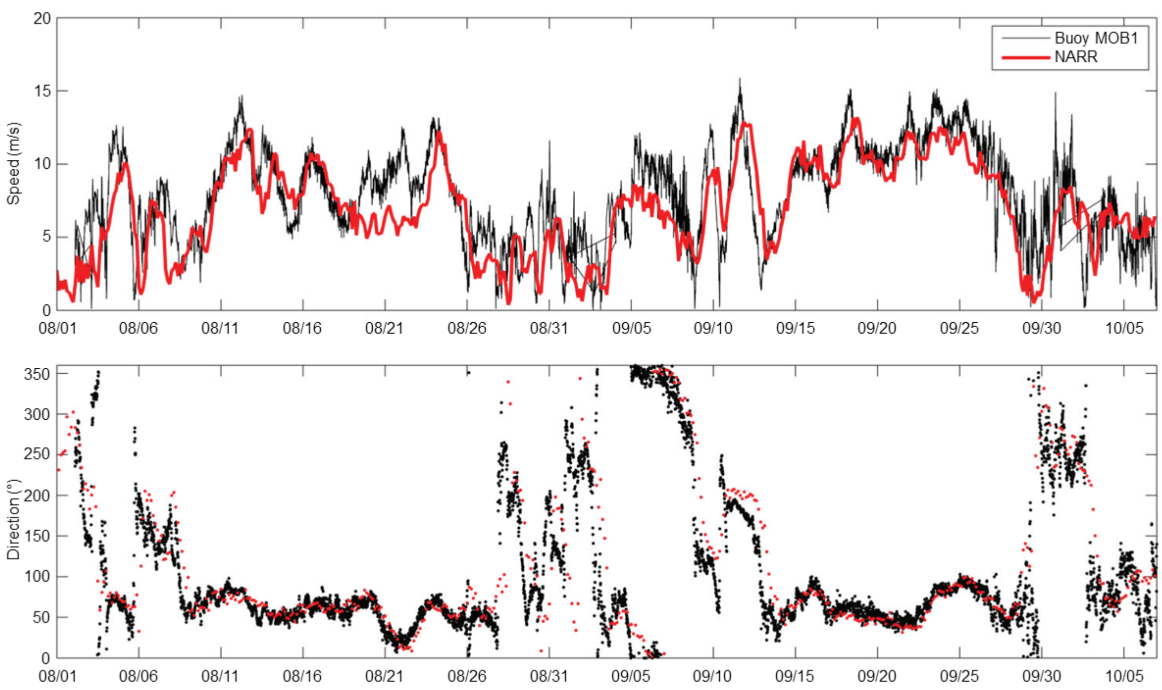
Wind speed and direction from NARR and the surface buoy MOB1 are plotted in Figure 2.5 Wind speeds at the buoy were corrected to the 10 m observation elevation. Figure 2.6 plots the same parameters against observations at Red Dog Dock. The NARR winds follow the pattern of storms and calm, though under-estimate maximum wind speeds, especially at Red Dog Dock. As a result, a small adjustment was made in the OilMap wind input (within the normal range of 3 to 3.5 percent). Wind direction is well predicted even when speed discrepancies occur. Small temporal lags appear during some events, though these are less likely to impact spill prediction.

Statistics on the model's skill in matching observations at this location are presented in Table 2.2. The model bias is the average of the difference between observed and modelled (or reanalysis) wind speed. The negative model bias indicates that the NARR data show slower wind speeds than the observation. The best fit multiplier is the increase factor in NARR wind speeds that would result in a zero bias. This could be implemented as an increase in the wind drag factor.

TABLE 2.2: NARR MODEL EVALUATION

	BUOY MOBI	RED DOG DOCK
Model Bias (m/s)	-0.81	-0.39
Best Fit Multiplier	1.115	1.089
Root Mean Square (RMS) Difference (m/s)	2.34	3.03
Model Skill (-)	0.85	0.72

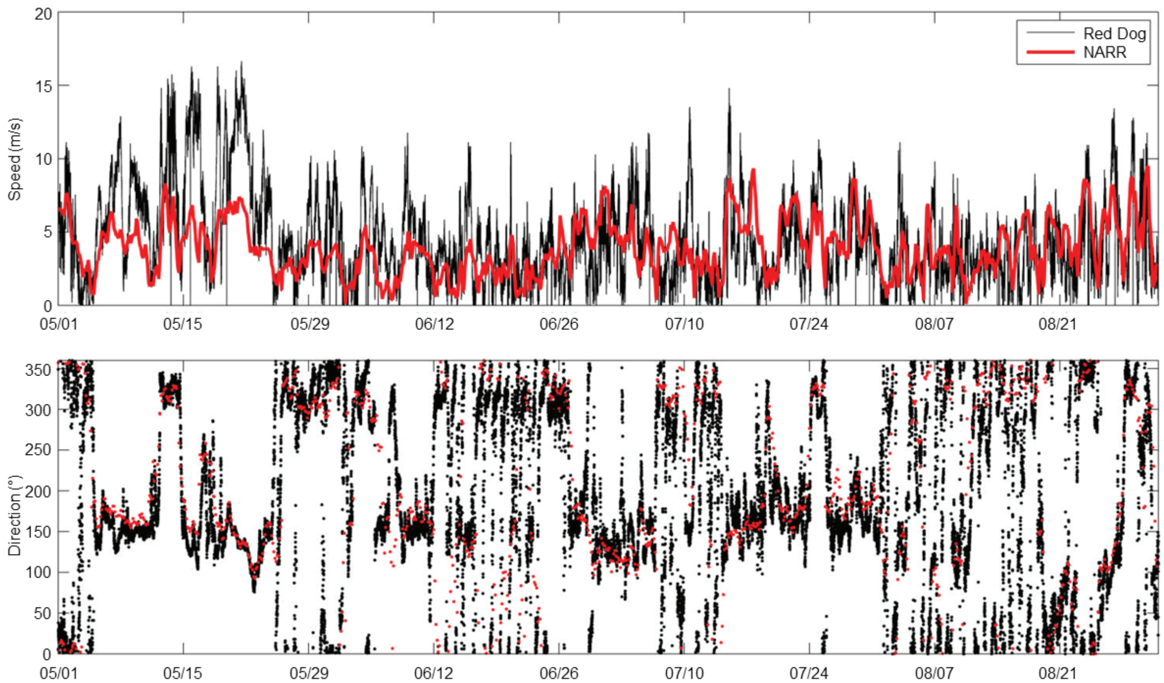
FIGURE 2.5: COMPARISON BETWEEN NARR AND HANNA SHOAL BUOY MOBI WIND SPEED AND DIRECTION



Buoy data retrieved from http://www.nodc.noaa.gov/archive/arc0064/0093399.

NARR data retrieved from http://www.esrl.noaa.gov/psd/data/gridded/data.narr.html.

FIGURE 2.6: COMPARISON BETWEEN NARR AND RED DOG ROCK WIND SPEED AND DIRECTION



Red Dog (Station RDDA2) data retrieved from http://www.ndbc.noaa.gov.

NARR data retrieved from http://www.esrl.noaa.gov/psd/data/gridded/data.narr.html.

Other statistical methods used to measure model performance are root-mean-square error and a comprehensive 'model skill' equation (Equation 2.1). Root-mean-square error is presented in the same units as the original data and represents the magnitude of all errors over the entire predicted time period. Model skill is a measure of the agreement between predicted and observed data, with a skill of 100 percent representing a perfect match (Wilmott et al. 1981). It differs from the statistical correlation statistic r or r2 in that a prediction that was perfect in magnitude but inverted in sign would still have a perfect r2, whereas the skill would be negligible. The statistical analysis was performed without any speed correction. RMS error and model skill improve only slightly once a multiplier is applied.

EQUATION 2.1: MODEL SKILL

$$Skill = (1 - \frac{\sum|X_{Model} - X_{Data}|^2}{\sum(|X_{Model} - \overline{X_{Data}}| + |X_{Data} - \overline{X_{Data}}|)^2})$$

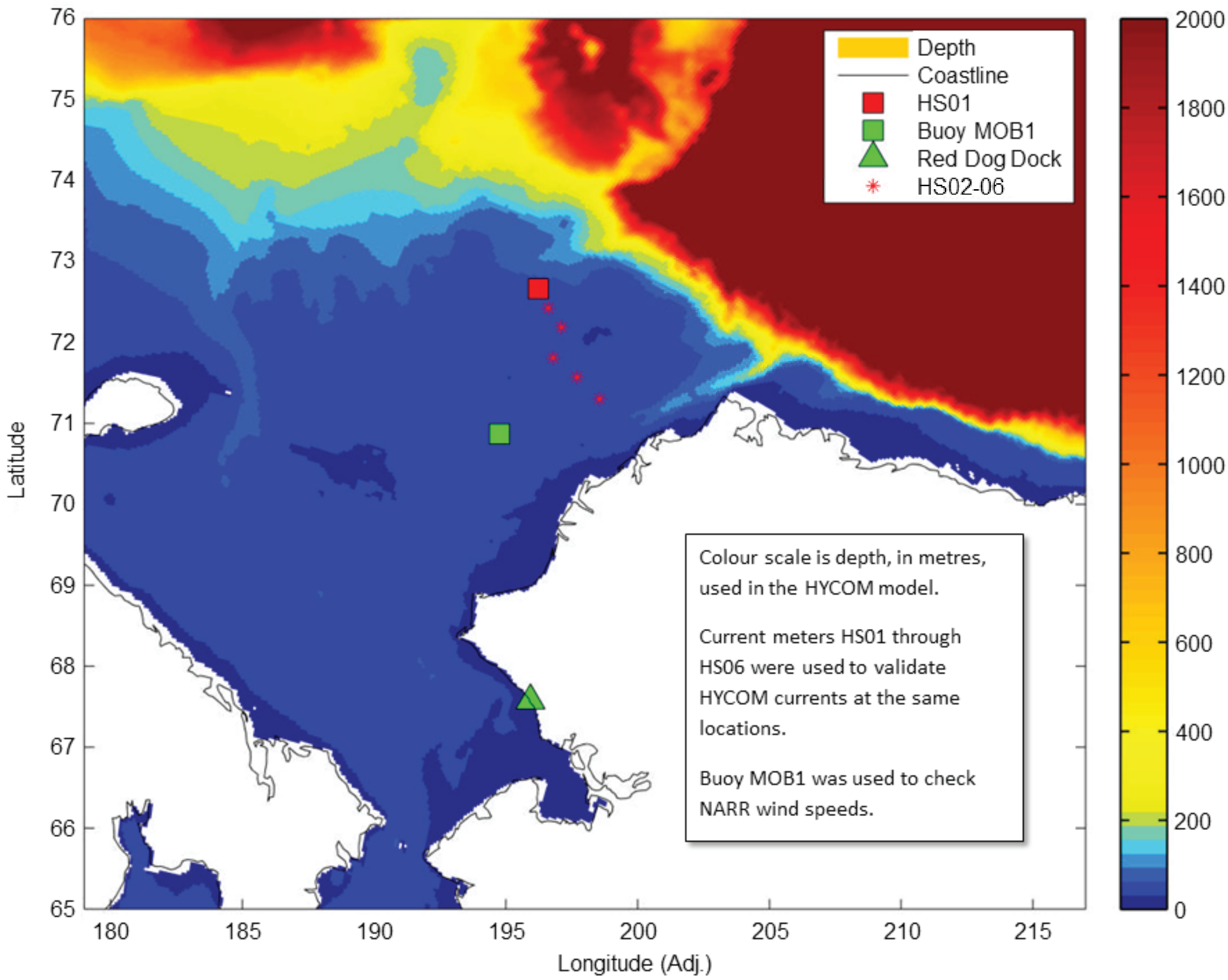
2.3.2 MISSING METEOROLOGICAL DATA

NARR data from 06-Oct-2011 21:00 to 10-Oct-2011 00:00 were incomplete or corrupted on the server. These data were replaced with the same time period in 2012. There was a modest (8 to 10 m/s) wind event during the 2012 time period used for replacement. Two similar single-day gaps on 19-Jan-2009 and 06-Jan-2010 were filled by repeating the data from the previous day.

2.4 QUALITY CONTROL DATA SOURCES

Quality control data sources were identified in the region, from recent oceanographic measurements by the Chukchi Sea Environmental Studies Program. Current meter data were available from the National Oceanographic Data Center (NODC) due to a data-sharing agreement among NOAA, Shell, ConocoPhillips, and Statoil. Locations of the meteorological and oceanographic validation data sources are shown in Figure 2.7, overlain on the bathymetry from the HYCOM model.

FIGURE 2.7: HYCOM AND NARR VALIDATION LOCATIONS CHUKCHI SEA



2.5 CHARACTERIZATION OF THE CRUDE OIL

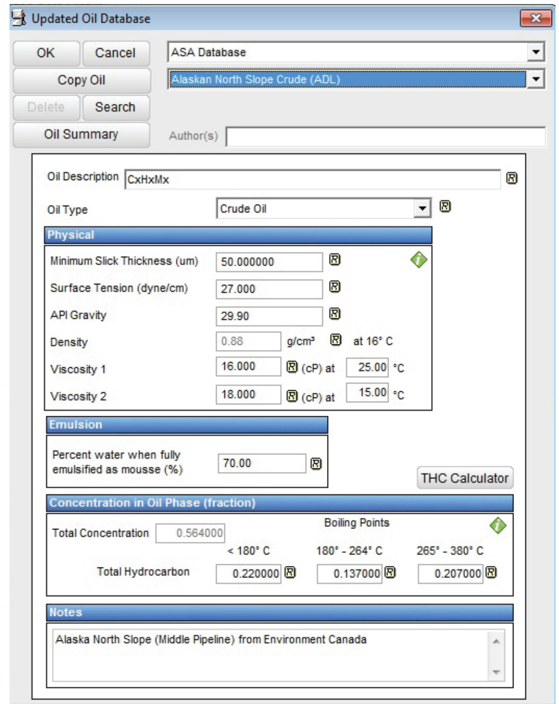
The crude oil chosen for the study, Alaska North Slope (ANS) Crude Oil, was based on available literature, information provided by Shell to the U.S. Department of the Interior, as well as other oil spill modelling studies conducted in the region. The properties and characteristics of ANS crude oil used in the modelling are summarized in Figure 2.8.

OilMap uses the oil's physical properties and characteristics to calculate processes involved in its weathering, including spreading, evaporation, and dispersion.

The spreading of spilled oil on water occurs primarily due to gravity. Heavy, viscous products, such as bunker or some crude oils will spread relatively slowly. Evaporation rates of spilled products depend on the products' chemical characteristics (volatile products evaporate extremely quickly), the water temperature, and the wind speed.

Dispersion occurs when, due to wave energy at the water surface, the spilled product breaks into small droplets and is dispersed into the water column. ANS Crude Oil is considered Type 3 (Medium oil: Oil contamination of intertidal areas can be severe and long-term) by NOAA, and is on the list of "persistent oils" under the International Convention for the Prevention of Pollution From Ships, 1973 as modified by the Protocol of 1978.

FIGURE 2.8: KEY CHARACTERISTICS OF ANS CRUDE OIL



2.6 MODEL INPUTS/ASSUMPTIONS

A number of assumptions were used in order to run the models.

2.6.1 SUB-SURFACE MODELLING VERSUS SURFACE RELEASE

In the event of a release from the well-head, the actual source of the released crude oil would be at the ocean floor. A single well-head release scenario was run for both the Chukchi and Beaufort seas using OilMapDeep/3D. OilMapDeep/3D tracks both the surface and subsurface movement of oil as well as calculating oil well blowout dynamics. The oil's distribution in various environmental compartments (water surface, atmosphere, water column, and shoreline) is determined. The model tracks both oil entrained into the water column by breaking waves (due to wind energy) and oil that resurfaces.

The model was run taking into account the scenario parameters, including release depth, gas/oil ratio, and blowout geometry to determine if it was necessary to start the stochastic model at the ocean floor, rather than at the sea surface. While there can be significant stratification of currents in the region, for the specific release sites chosen, the model results, i.e., the resulting trap height, trap diameter (just over 2 m, see Figure 2.9), and time to reach the ocean surface (approximately 4 seconds, see Figure 2.10) confirmed that starting the spill at the ocean floor did not materially affect the results (for either the Chukchi or the Beaufort location). Thus, the modelled scenarios use the simplifying assumption of an oil release at the sea surface.

FIGURE 2.9: WIDTH OF BLOWOUT PLUME OIL

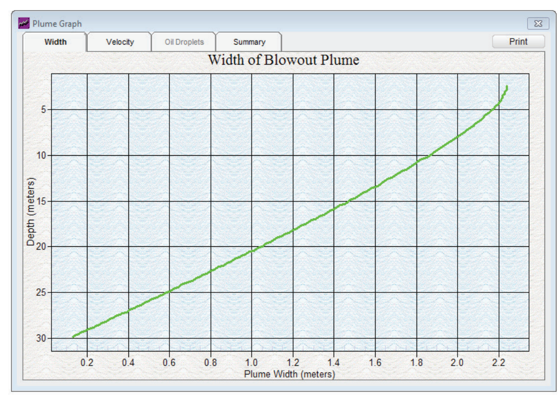
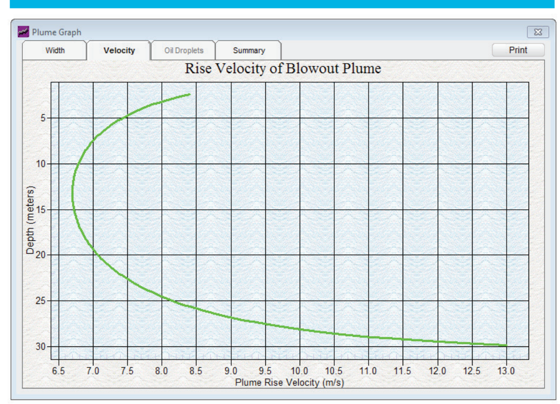


FIGURE 2.10: RISE VELOCITY OF BLOWOUT PLUME



2.6.2 MODEL PARAMETERS USED

The following model parameters were used for the model integrations.

PARAMETER	DESCRIPTION	VALUE
Number of Stochastic Runs	The number of individual simulations that will be run and used to generate the stochastic probabilities within the month range specified.	100
Month Range	The range of months over which the model is run	Varies with Model Run
Model Time Step	The model time step controls the interval at which calculations of oil transport and weathering (evaporation, entrainment, and emulsification) are done.	60 min
Number of particles	This specifies the number of individual spillets that are to be used in the simulation to represent the spilled oil. The total amount of oil spilled is uniformly distributed among the number of spillets.	2500
Distribution of Mass on Grid Cells	Method by which the model calculates the (random) distribution of spillets.	Gaussian Spread
Wind Factor	The wind factor determines the wind drift that moves surface spills and is specified as a percentage of the wind speed. A wind factor of ~3-4% of the surface wind has been empirically determined to be the optimal value for open seas.	3.5%
Horizontal Dispersion	Horizontal Dispersion controls the random horizontal component of the oil's movement (m^2/s).	10.0 m^2/sec (used for open waters)
Vertical Dispersion	Vertical Dispersion controls the random vertical component of the subsurface oil's movement (cm^2/s).	10.0 cm^2/sec (used for well-mixed water column)
Stochastic Weathering	Determines which fate and effect models are included	Evaporation and Entrainment
Horizontal Wind Grid Resolution	Horizontal distance between NARR wind data points	10.5 Nautical Miles
Vertical Wind Grid Resolution	Vertical distance between NARR wind data points	22.5 Nautical Miles
Horizontal Current Grid Resolution	Horizontal distance between HYCOM current data points	4.0 km
Vertical Current Grid Resolution	Vertical distance between HYCOM current data points	3.7 km

2.6.3 RELEASE RATES

The release rates used in the models were based on AVALON/MERLIN discharge model output from the Alaska Outer Continental Shelf, Environmental Impact Statement/Environmental Assessment, prepared by the Bureau of Ocean Energy Management, Regulation and Enforcement, Alaska. Specifically, the 10-day release scenario uses approximately the average of the rates predicted by the agency for the first 10 days of a release, and the 33-day release scenario uses approximately the average of the rates predicted over the first 33 days. As the AVALON/MERLIN model only predicted flow rates for 74 days, a conservative estimate of 30,000 bbls/day was chosen for the October scenarios.

In the July and August scenarios, these volumes were reduced by 20 percent, to reflect the possibility that conventional and alternative countermeasures would be available and applied in those months (but not October because of pack ice formation). This is greater than the total percentage of crude oil removed from the surface of the water through such countermeasures during the MC 252 (Deepwater Horizon) incident, a highly optimistic assumption given the much greater logistical and environmental challenges in the Arctic.

2.6.4 RELEASE DURATIONS

Three release durations were modelled for the Chukchi and Beaufort Seas:

- August release, capped in 10 days (simulating a spill expeditiously controlled without a relief well), modelled for 120 days;
- July release, capped in 33 days (simulating a spill controlled by a relief well drilled as fast as the industry claimed it could have one in place), modelled for 150 days;
- October release, not capped (coming too late in the season to be effectively stopped before pack ice onset).

Significantly, the modelled scenarios did not factor in the movement of crude oil trapped in or under pack ice (oil was modelled as static once it encountered 80% pack ice, and all oil had encountered pack ice by the end of each scenario). This limited the effective duration of the modeling runs in all scenarios, thereby producing conservative estimates of oil spread in each.

2.6.5 RELEASE LOCATIONS

As there are numerous possible proposed Shell drilling locations in each of the areas of interest, a single, central location was chosen for each (see Table 2.3):

TABLE 2.3: SCENARIO RELEASE LOCATIONS		
SITE	LATITUDE	LONGITUDE
Chukchi Sea	71° 15′ N	162° 48′ W
Beaufort Sea	70° 22′ N	146° 01′ W

2.6.6 ICE IN THE REGION

OilMap treats the interaction with partial sea ice cover as summarized in Table 2.4, below.

TABLE 2.4: OILMAP ADJUSTMENTS FOR REPORTED ICE COVER				
ICE COVER (%)	ADVECTION	EVAPORATION	ENTRAINMENT	SPREADING
0 – 30	No change	No change	No change	No change
30 – 80	35° to right	Linear reduction with ice cover	Linear reduction with ice cover	Terminal thickness increased in proportion to ice coverage

Ice cover data were obtained from Sea Ice Atlas, a joint project funded by the Alaska Ocean Observing System (AOOS), the Alaska Center for Climate Assessment and Policy (ACCAP), and the Scenarios Network for Alaska and Arctic Planning (SNAP). Ice data were entered on a monthly average basis for subareas within each of the two seas modelled.

OILMAP considers defined ice areas as fixed in space. Changes in position of ice coverage with time can be approximated by defining ice coverage polygons with a series of temporal coverages with defined start and end times.

When the surface oil encounters ice at a 50 percent cover, the angle of movement of the oil is changed to 35 degrees to the right (northern hemisphere) due to the presence of the ice. The change in the deflection angle of the oil in ice reflects the increased Coriolis Effect, due to broken ice cover penetrating lower into the water column.

Since OILMAP's implementation has no explicit modeling of the movement of ice, the models were run until oil reached pack ice, thus making the spreading predictions more conservative.

3 Model Results

Stochastic modelling was developed to simulate surface water trajectories of 100 individual spill releases for each of the three spill scenarios in the two locations of interest (Table 3.1).

TABLE 3.1: STOCHASTIC MODEL SCENARIOS						
SPILL SCENARIO	SPILL LOCATION	MONTH	OIL TYPE	SPILL RELEASE RATE (BBL/DAY)	SPILL RELEASE DURATION (DAYS)	MODEL DURATION (DAYS)
1	Chukchi Sea	August	ANS Crude Oil	35,000*	10	120
2	Chukchi Sea	July	ANS Crude Oil	28,000*	33	150
3	Chukchi Sea	October	ANS Crude Oil	30,000	90	90
4	Beaufort Sea	August	ANS Crude Oil	35,000*	10	120
5	Beaufort Sea	July	ANS Crude Oil	28,000*	33	150
6	Beaufort Sea	October	ANS Crude Oil	30,000	90	90

* Adjusted release rate inclusive of the 20% reduction due to response countermeasures

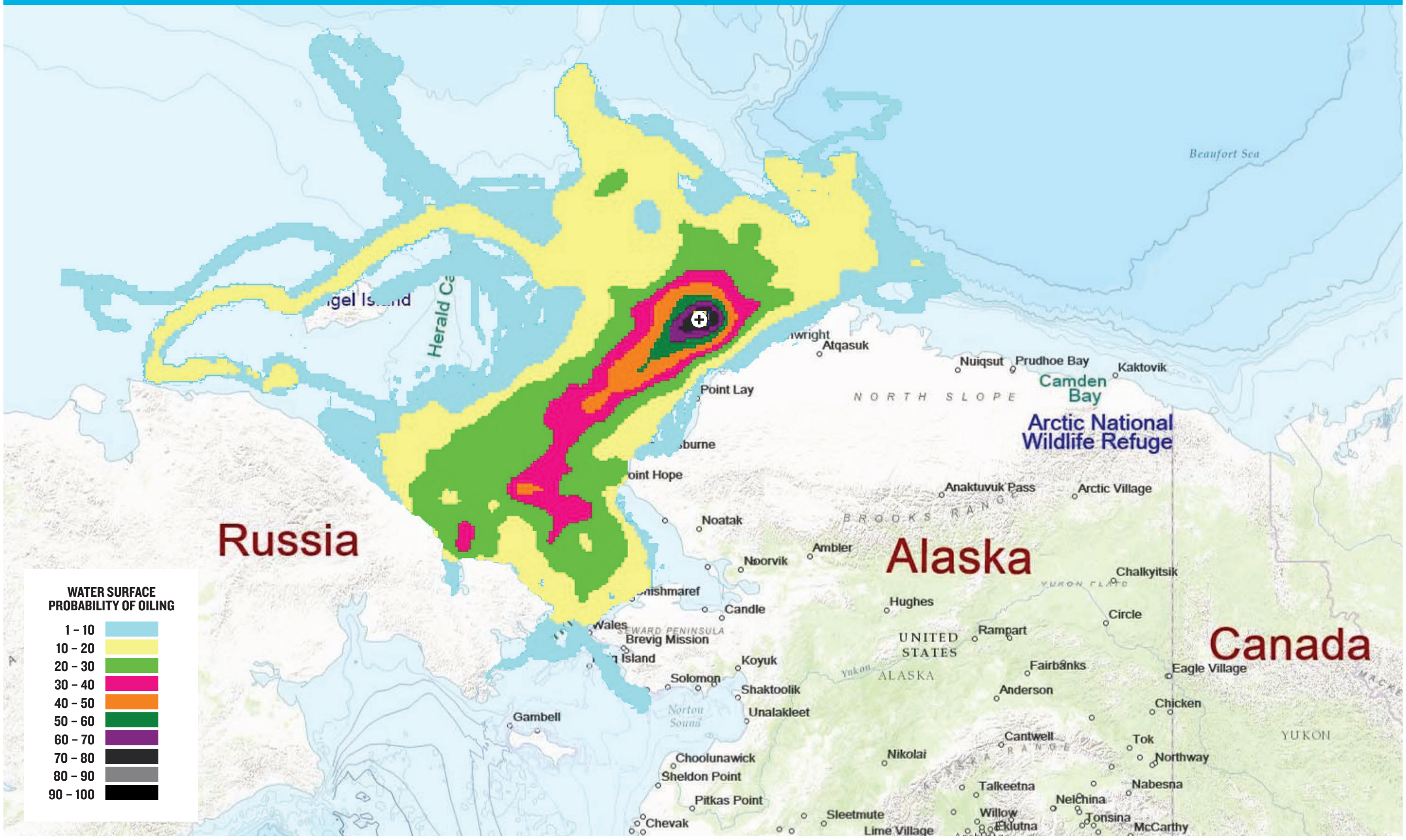
Each individual simulation begins at a time selected randomly for each given month from the five-year wind record, thus sampling the variability in the local wind and surface current forcing. The sum of each of the 100 spill trajectory simulations defines the expected footprint or reach of the spill in each monthly scenario. This footprint represents the area of water surface and linear shoreline that could reasonably be reached by crude oil in the event of a spill during the length of each scenario. Any of the individual spill trajectory simulations covers only a relatively small area of the overall footprint posed by the combination of all of the simulations.

The combined individual spill trajectory simulations also provide an indication of the shortest and average crude oil travel time from the origin of the spill to shore, as well as the maximum and average amount of crude oil that contacts the shore, for each stochastic scenario.

Each coloured range in the Figures depicts a range of probabilities of crude oil spread, increasing from the outer to the inner edge of the band. For example, the outer edge of the yellow band represents a 10 percent likelihood of spread while the inner edge represents a 20 percent likelihood. The lower end of the lowest (blue) probability range selected for the mapping was 1 percent. The highest end of the highest range selected was 100 percent.

The results of the six model scenarios are shown in Figure 3.1 through Figure 3.6. The figures do not imply that the entire colored surface area presented would be reached by crude oil in the event of a spill, and do not provide any information on the concentration of crude oil in a given area. What they show is the modelled probability of crude oil reaching a particular area. The Figures also report various statistics for each stochastic scenario, including the percentage of scenarios in which crude oil reached the shore.

FIGURE 3.1: SCENARIO 1 - CHUKCHI SEA 10-DAY RELEASE SCENARIO (AUGUST)



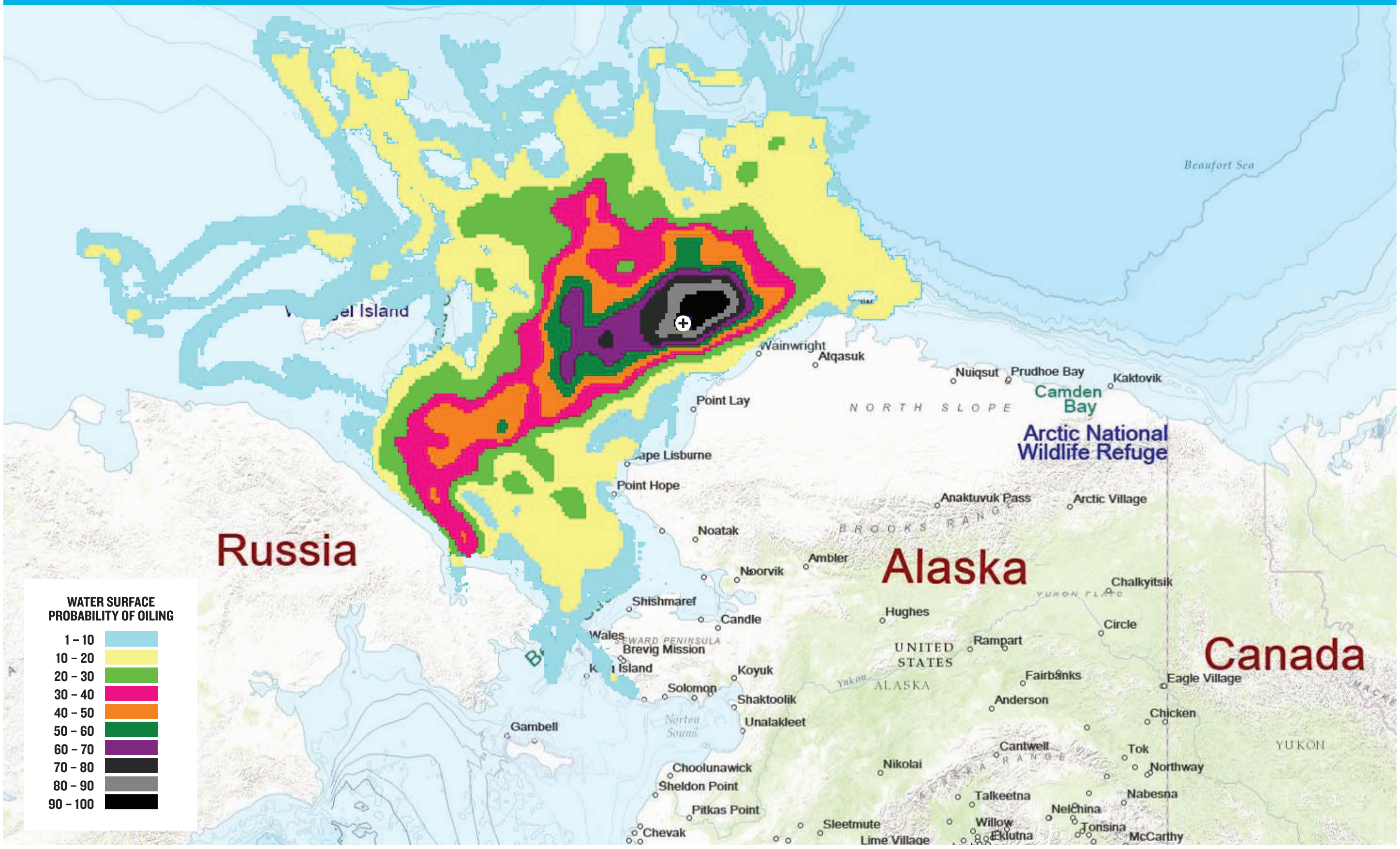
WATER SURFACE PROBABILITY					
Scenario Information		Spill Statistics		Oil Properties	
Start Month	August	% Simulations Ashore	100%	Name	ANS Crude Oil
Sea Surface Temp (°C)	2	Shortest Time to Shore	48.75 days	Density @ 15 °C (g/cm3)	0.876
Release Duration	10 days	Average Time to Shore	92. 67 days	Viscosity @ 15 °C (cP)	15
Model Run Duration	120 days	Maximum Oil Ashore	164,679 bbls		
Spill Rate	35,000 Barrels/day	Average Oil Ashore	89,388 bbls		
Spill Site	71° 15′ N, 162° 48′ W				

There is a 20 to 30 percent chance that oil would reach Russian Shores, and a 20 to 30 percent chance that oil would reach Alaskan shores from Barrow to Point Hope and to Wales on the Seward Peninsula.

There is a 50 to 60 percent chance that oil would cover portions of Hanna Shoal, and a 40 to 50 percent chance that oil would enter the East Siberian Sea. There is also a 20 to 30 percent chance that oil would reach the Bering Strait, and a 1 to 10 percent chance that oil would reach Wrangel Island. There is a 1 to 10 percent chance that oil could travel as far as 800 km (500 miles) to the south, through the Bering Strait.

In total, oil could reach more than 900 km (560 miles) of Alaskan coastline and 630 km (400 miles) of Russian coastline.

FIGURE 3.2: SCENARIO 2 - CHUKCHI SEA 33-DAY RELEASE SCENARIO (JULY)



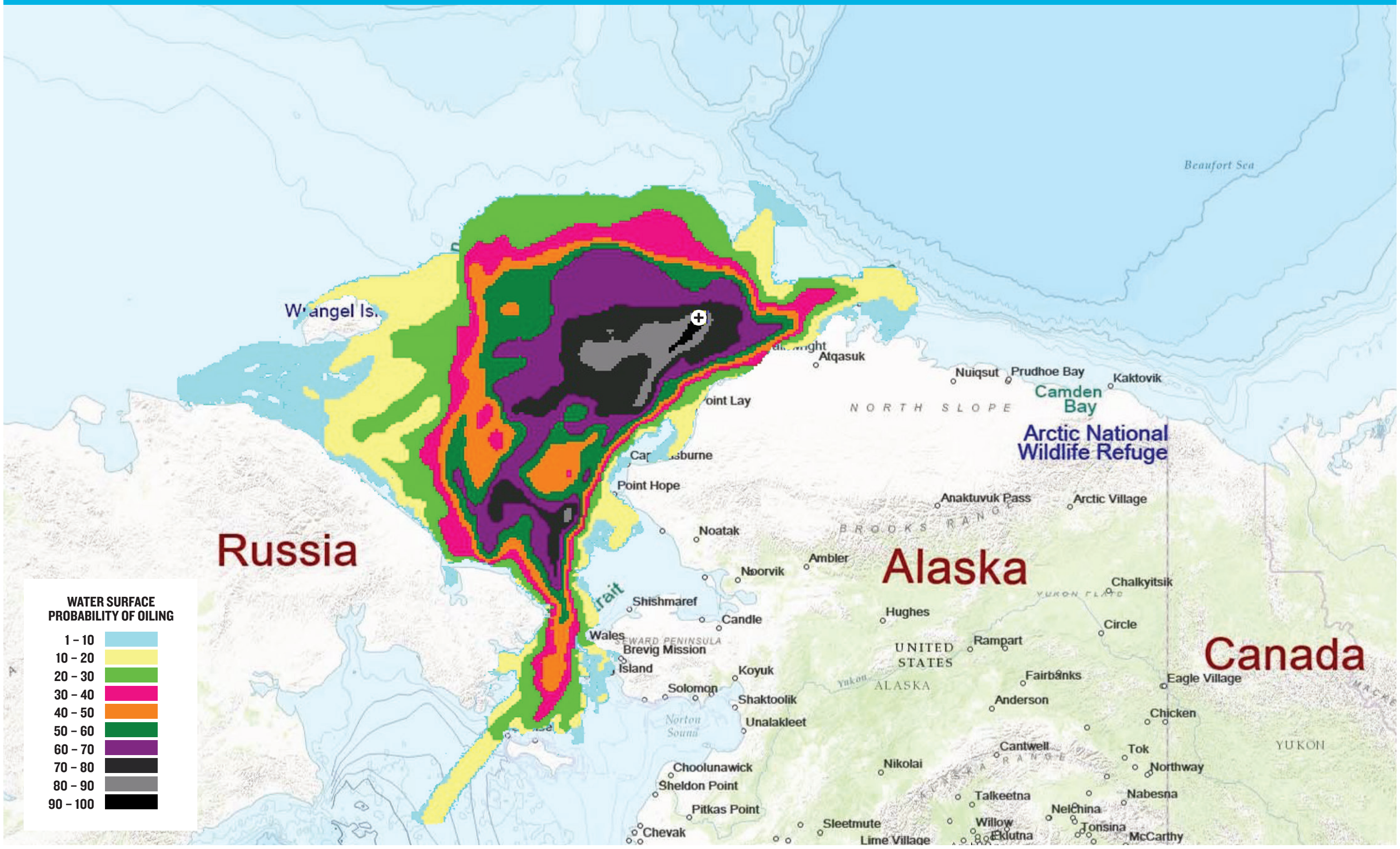
WATER SURFACE PROBABILITY					
SCENARIO INFORMATION		SPILL STATISTICS		OIL PROPERTIES	
Start Month	July	% Simulations Ashore	100%	Name	ANS Crude Oil
Sea Surface Temp (°C)	2	Shortest Time to Shore	38.7 days	Density @ 15 °C (g/cm^3)	0.876
Release Duration	33 days	Average Time to Shore	68.2 days	Viscosity @ 15 °C (cP)	15
Model Run Duration	150 days	Maximum Oil Ashore	266,060 bbls		
Spill Rate	28,000 Barrels/day	Average Oil Ashore	129,665 bbls		
Spill Site	71° 15′ N, 162° 48′ W				

There is a 40 to 50 percent chance that oil would reach Russian Shores, a 10 to 20 percent chance that oil would reach Alaskan shores from Barrow to Point Hope, and a 1 to 10 percent chance it would reach Wales on the Seward Peninsula.

There is an 80 to 90 percent chance of oil covering parts of Hanna Shoal and Barrow Canyon. There is a 50 to 60 percent chance that oil would enter the East Siberian Sea. There is also a 10 to 20 percent chance that oil would reach the Bering Strait, and a 1 to 10 percent chance that oil would reach Wrangel Island. There is a 1 to 10 percent chance that oil could travel as far as 1100 km (700 miles) to the south, through the Bering Strait.

In total, oil could reach more than 700 km (440 miles) of Alaskan coastline and 300 km (260 miles) of Russian coastline.

FIGURE 3.3: SCENARIO 3 - CHUKCHI SEA UNCONTROLLED RELEASE SCENARIO (OCTOBER)



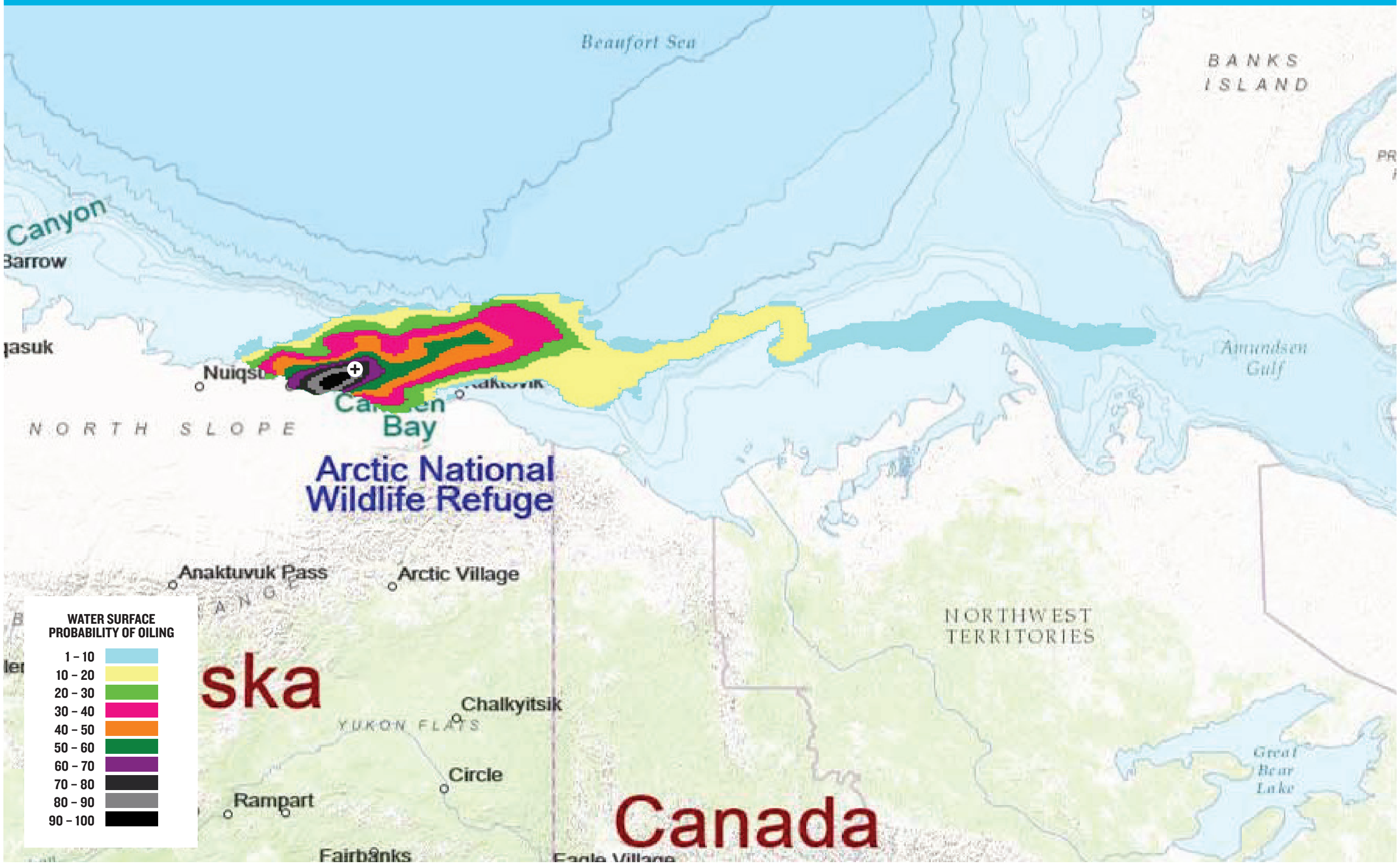
WATER SURFACE PROBABILITY					
SCENARIO INFORMATION		SPILL STATISTICS		OIL PROPERTIES	
Start Month	October	% Simulations Ashore	100 %	Name	ANS Crude Oil
Sea Surface Temp (°C)	2	Shortest Time to Shore	2.2 days	Density @ 15 °C (g/cm^3)	0.876
Release Duration	90 days	Average Time to Shore	19.4 days	Viscosity @ 15 °C (cP)	15
Model Run Duration	90 days	Maximum Oil Ashore	282,281 bbls		
Spill Rate	30,000 Barrels/day	Average Oil Ashore	174,771 bbls		
Spill Site	71° 15' N, 162° 48' W				

There is a 60 to 70 percent chance that oil would reach Russian Shores, and a 40 to 50 percent chance that oil would reach Alaskan shores from Barrow to Point Hope and to Wales on the Seward Peninsula.

There is a 60 to 70 percent chance that oil would cover parts of Hanna Shoal and Barrow Canyon. There is a 70 to 80 percent chance that oil would enter the East Siberian Sea. There is also a 40 to 50 percent chance that oil would reach the Bering Strait, and a 10 to 20 percent chance that oil would reach Wrangel Island. There is a 10 to 20 percent chance that oil could travel as far as 1100 km (700 miles) to the south, through the Bering Strait, and down the east coast of Russia.

In total, oil could reach more than 1000 km (630 miles) of Alaskan coastline and 1500 km (810 miles) of Russian coastline.

FIGURE 3.4: SCENARIO 4 - BEAUFORT SEA 10-DAY RELEASE SCENARIO (AUGUST)



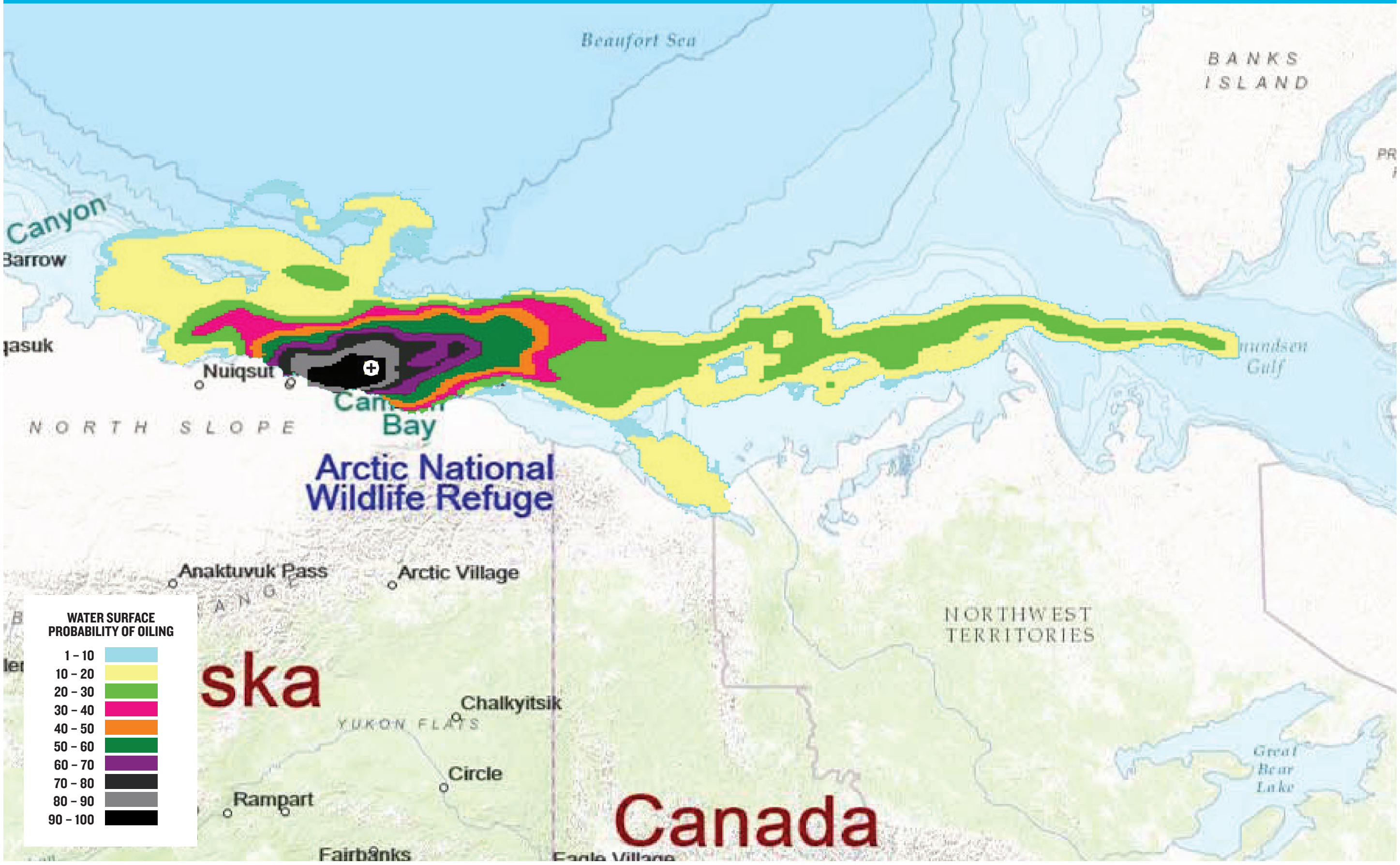
WATER SURFACE PROBABILITY					
SCENARIO INFORMATION		SPILL STATISTICS		OIL PROPERTIES	
Start Month	August	% Simulations Ashore	98%	Name	ANS Crude Oil
Sea Surface Temp (°C)	2	Shortest Time to Shore	0.5 days	Density @ 15 °C (g/cm^3)	0.876
Release Duration	10 days	Average Time to Shore	2.55 days	Viscosity @ 15 °C (cP)	15
Model Run Duration	120 days	Maximum Oil Ashore	145,404 bbls		
Spill Rate	35,000 Barrels/day	Average Oil Ashore	93,253 bbls		
Spill Site	70° 22′ N, 146° 01′ W				

There is a 90 to 100 percent chance that oil would reach Alaskan shores between Kaktovik and the bays and shores west of Nuiqsut, including a 30 to 40 percent chance it would reach the shores of the Arctic National Wildlife Refuge.

There is a 30 to 40 percent chance that oil would cover parts of Camden Bay, and a 30 to 40 percent chance it would enter Canadian waters. There is also a 1 to 10 percent chance that oil would reach the Amundson Gulf. There is a 1 to 10 percent chance that oil could travel as far as 850 km (530 miles) to the east, through The Canadian Beaufort Sea.

In total, oil could reach more than 230 km (145 miles) of Alaskan coastline.

FIGURE 3.5: SCENARIO 5 - BEAUFORT SEA 33-DAY RELEASE SCENARIO (JULY)



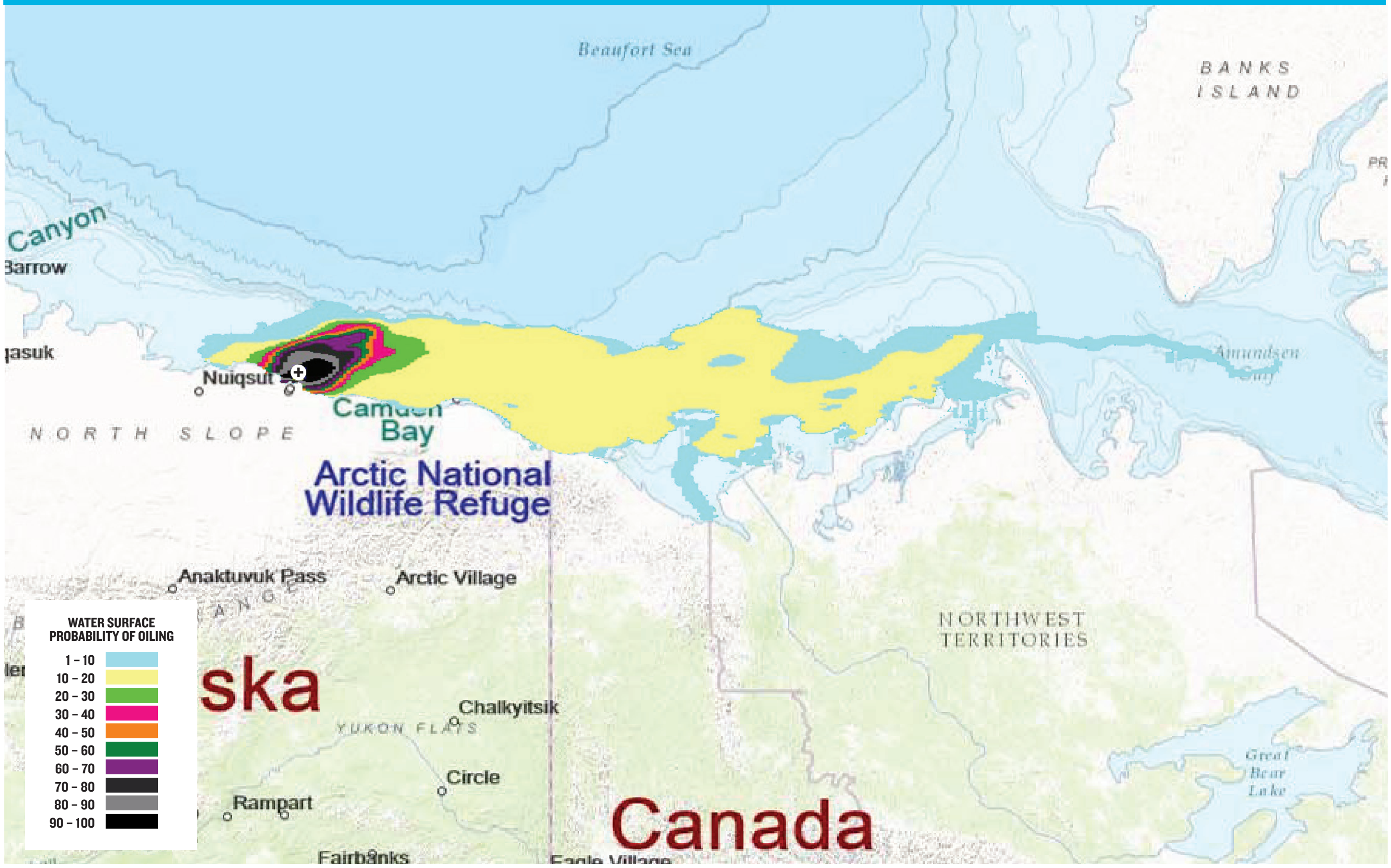
WATER SURFACE PROBABILITY					
SCENARIO INFORMATION		SPILL STATISTICS		OIL PROPERTIES	
Start Month	July	% Simulations Ashore	100%	Name	ANS Crude Oil
Sea Surface Temp (°C)	2	Shortest Time to Shore	0.54 days	Density @ 15 °C (g/cm^3)	0.876
Release Duration	33 days	Average Time to Shore	3.22 days	Viscosity @ 15 °C (cP)	15
Model Run Duration	150 days	Maximum Oil Ashore	318,519 bbls		
Spill Rate	28,000 Barrels/day	Average Oil Ashore	165,609 bbls		
Spill Site	70° 22′ N, 146° 01′ W				

There is a 10 to 20 percent chance that oil would reach Canadian Shores, and a 90 to 100 percent chance that oil would reach Alaskan shores between Kaktovik and the bays and shores west of Nuiqsut, including a 50 to 60 percent chance of reaching the shores of the Arctic National Wildlife Refuge.

There is a 40 to 50 percent chance that oil would enter Canadian waters. There is also a 20 to 30 percent chance that oil would reach the Amundson Gulf, and a 10 to 20 percent chance that oil would reach the Mackenzie Delta. There is a 20 to 30 percent chance that oil could travel as far as 980 km (610 miles) to the east, in the Canadian Beaufort Sea.

In total, oil could reach more than 550 km (345 miles) of Alaskan coastline and threaten 100s of km (60+ miles) of Canadian coastline near the Mackenzie Delta.

FIGURE 3.6: SCENARIO 6 - BEAUFORT SEA UNCONTROLLED RELEASE SCENARIO (OCTOBER)



WATER SURFACE PROBABILITY					
SCENARIO INFORMATION		SPILL STATISTICS		OIL PROPERTIES	
Start Month	October	% Simulations Ashore	100%	Name	ANS Crude Oil
Sea Surface Temp (°C)	2	Shortest Time to Shore	0.17 days	Density @ 15 °C (g/cm^3)	0.876
Release Duration	90 days	Average Time to Shore	18.6 days	Viscosity @ 15 °C (cP)	15
Model Run Duration	90 days	Maximum Oil Ashore	408,710 bbls		
Spill Rate	30,000 Barrels/day	Average Oil Ashore	18,290 bbls		
Spill Site	70° 22′ N, 146° 01′ W				

There is a 10 to 20 percent chance that oil would reach Canadian Shores, and a 90 to 100 percent chance that oil would reach Alaskan shores between the Alaska-Canada border and Nuiqsut, including a 10 to 20 percent chance of reaching the shores of the Arctic National Wildlife Refuge.

There is a 10 to 20 percent chance that oil would enter Canadian waters. There is also a 1 to 10 percent chance that oil would reach the Amundson Gulf, and a 1 to 10 percent chance that oil would reach the Mackenzie Delta.

There is a 1 to 10 percent chance that oil could travel as far as 1050 km (655 miles) to the east, through the Canadian Beaufort Sea.

In total, oil could reach more than 500 km (310 miles) of Alaskan and more than 100 km (60 miles) of Canadian coast.

4 Conclusions

The model output depicted in Section 3 shows the probability of potential spread and the impact areas from various crude oil release scenarios in the Chukchi and Beaufort Seas. The scenarios were chosen to represent plausible real world outcomes for location, oil type, and spill volume, based on industry and agency projections, and the model runs used empirically recorded data for weather and ocean conditions during the months chosen.

Modeling exercises are, as discussed above, inherently limited in terms of the factors they can account for and the inputs they are provided with. In this exercise different probability maps would have resulted from different assumptions. Moving the discharge points closer to shore, might, for instance, have resulted in more shoreline oiling, while moving them further offshore might have increased total spread, though opposite trends would also have been possible. Similarly, assuming greater or less discharge and/or control time would have increased or decreased the projected likelihood of any given area being affected.

Wherever possible, the models were based on conservative data, assumptions, and parameters. As discussed, all projected trajectories were limited because the model does not factor in oil movement in those specific areas where pack ice cover reaches 80 percent. In an actual release, continued uncontrollable movement with and under pack ice would likely substantially increase the extent of dispersal through the time of ice break-up in late spring. Additional conservative assumptions applied in various scenarios include:

- The capping of a well in seven days;
- The successful drilling of a relief well in 33 days;
- 20 percent removal of surface oil using mechanical and alternative response countermeasures.

As noted above, conditions in the Arctic Ocean make these kinds of projections optimistic. The 20 percent surface removal figure, for example, was drawn from the Deepwater Horizon blowout, where recovery operations were much less challenging than they likely would be in the Chukchi or Beaufort Seas.

In the case of the Chukchi Sea scenarios, the average time before oil reached shore varied from three months in the August release scenario to only around three weeks in the October release scenario. The average amounts of crude oil reaching shore varied from around 90,000 bbls in the August scenario to close to 175,000 bbls in the October release scenario. Oil reached shoreline somewhere in 100 percent of the scenarios modelled.

In the case of the Beaufort Sea scenarios, the average time before oil reached shore varied from 18 days in the October release scenario to only 2.5 days in the August release scenario. The average amounts of crude oil reaching shore varied from around 18,000 bbls in the October scenario to close to 165,000 bbls in the July release scenario. Oil reached shoreline somewhere in 98 to 100 percent of the scenarios modelled.

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Appendix A: OILMAP

OILMAP is a state-of-the-art, personal computer based oil spill response system applicable to oil spill contingency planning and real time response and applicable for any location in the world (Jayko and Howlett, 1992; Spaulding et al., 1992a,b). OILMAP was designed in a modular fashion so that different types of spill models could be incorporated within the basic system, as well as a suite of sophisticated environmental data management tools, without increasing the complexity of the user interface. The model system employs a Windows based graphics user interface that extensively utilizes point and click and pull down menu operation. OILMAP is configured for operation on standard Pentium PCs and can be run on laptop and notebook computers to facilitate use in the field.

The OILMAP suite includes the following models: a trajectory and fates model for surface and subsurface oil, an oil spill response model, and stochastic and receptor models. The relevant models are described in more detail below.

The trajectory and fates model predicts the transport and weathering of oil from instantaneous or continuous spills. Predictions show the location and concentration of the surface and subsurface oil versus time. The model estimates the temporal variation of the oil's areal coverage, oil thickness, and oil viscosity. The model also predicts the oil mass balance or the amount of oil on the free surface, in the water column, evaporated, on the shore, and outside the study domain versus time. The fate processes in the model include spreading, evaporation, entrainment or natural dispersion, and emulsification. As an option OILMAP can also estimate oil-sediment interaction and associated oil sedimentation. A brief description of each process algorithm is presented here. ASA (1997) provides a more detailed description for the interested reader. The oil sedimentation algorithm is described in French et al. (1994), ASA (1996) and Kirstein et al. (1985). Spreading is represented using the thick slick portion of Mackay et al.'s (1980, 1982) thick-thin approach. Evaporation is based on Mackay's analytic formulation parameterized in terms of evaporative exposure (Mackay et al., 1980, 1982). Entrainment or natural dispersion is modeled using Delvigne and Sweeney's (1988) formulation that explicitly represents oil injection rates into the water column by droplet size. The entrainment coefficient, as a function of oil viscosity, is based on Delvigne and Hulsen (1994). Emulsification of the oil, as function of evaporative losses and changes in water content, is based on Mackay et al. (1980, 1982). Oil-shoreline interaction is modeled based on a simplified version of Reed et al. (1989) which formulates the problem in terms of a shore type dependent holding capacity and exponential removal rate.

For the subsurface component, we used oil mass injection rates from the surface slick into the water column performed by oil droplet size class using Delvigne and Sweeney's (1988) entrainment formulation. The subsurface oil concentration field is predicted using a particle based, random walk technique and includes oil droplet rise velocities by size class. The user specifies the vertical and horizontal dispersion coefficients. Resurfacing of oil droplets due to buoyant effects is explicitly included and generates new surface slicks. If oil is resurfaced in the vicinity of surface spillets the oil is incorporated into the closest surface spillet. A more detailed presentation of the subsurface oil transport and fate algorithm is given in Kolluru et al. (1994).

The basic configuration of the model also includes a variety of graphically based tools that allow the user to specify the spill scenario, animate spill trajectories, currents and winds, import and export environmental data, grid any area within the model operational domain, generate mean and/or tidal current fields, enter and edit oil types in the oil library, enter and display data into the embedded geographic information system (GIS) and determine resources impacted by the spill.

The GIS allows the user to enter, manipulate, and display point, line, poly line, and polygon data geographically referenced to the spill domain. Each object can be assigned attribute data in the form of text descriptions, numeric fields or external link files.

In the stochastic mode spill simulations are performed stochastically varying the environmental data used to transport the oil. Either winds, currents, or both may be stochastically varied. The multiple trajectories are then used to produce contour maps showing the probability of surface and shoreline oiling. The trajectories are also analyzed to give travel time contours for the spill. These oiling probabilities and travel time contours can be determined for user selected spill durations. If resource information is stored in the GIS database a resource-hit calculation can be performed to predict the probability of oiling important resources.

OILMAP has been applied to hindcast a variety of spills. These hindcasts validate the performance of the model. Hindcasts of the Amoco Cadiz, Ixtoc and Persian Gulf War spills and an experimental spill in the North Sea by Warren Springs Laboratory are reported in Kolluru et al. (1994). Spaulding et al. (1993) also present a hindcast of the Gulf War spill. Spaulding et al. (1994) present the application of the model to the Braer spill where subsurface transport of the oil was critical to understanding the oil's movement and impact on the seabed. Spaulding et al. (1996a) applied the model to hindcast the surface and subsurface transport and fate of the fuel oil spilled from the North Cape barge. Integration of OILMAP with a real time hydrodynamic model and the hindcast of the movement of oil tracking buoys in Narragansett Bay are presented in Spaulding et al (1996b).

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Appendix B: HYCOM

The HYCOM consortium describes itself as a multi-institutional effort sponsored by the National Ocean Partnership Program (NOPP), as part of the U. S. Global Ocean Data Assimilation Experiment (GODAE), to develop and evaluate a data-assimilative hybrid isopycnal-sigma-pressure (generalized) coordinate ocean model (called HYbrid Coordinate Ocean Model or HYCOM). The GODAE objectives of three-dimensional depiction of the ocean state at fine resolution in real time, provision of boundary conditions for coastal and regional models, and provision of oceanic boundary conditions for a global coupled ocean-atmosphere prediction model, are addressed by a partnership of institutions that represent a broad spectrum of the oceanographic community.

The partnership members are the Florida State University Center for Ocean-Atmospheric Prediction Studies (FSU/COAPS), the University of Miami Rosenstiel School of Marine and Atmospheric Science (UM/RSMAS), the Naval Research Laboratory/Stennis Space Center (NRL/STENNIS), the Naval Oceanographic Office (NAVOCEANO), the Fleet Numerical Meteorology and Oceanography Center (FNMOC), the Naval Research Laboratory/Monterey (NRL/MONTEREY), the National Oceanographic and Atmospheric Administration/National Centers for Atmospheric Prediction/Marine Modeling and Analysis Branch (NOAA/NCEP/MMAB), the NOAA National Ocean Service (NOAA/NOS), the NOAA Atlantic Oceanographic and Meteorological Laboratory (NOAA/AOML), the NOAA Pacific Marine Environmental Laboratory (NOAA/PMEL), Planning Systems Inc., Los Alamos National Laboratory (LANL), Service Hydrographique et Océanographique de la Marine (SHOM), Laboratoire des Ecoulements Géophysiques et Industriels (LEGI), The Open Source Project for a Network Data Access Protocol (OPeNDAP), the University of North Carolina (UNC), Rutgers University, the University of South Florida (USF), Fugro-GEOS/Ocean Numerics, Horizon Marine Inc., Roffer's Ocean Fishing Forecasting Service Inc. (ROFFS), Orbimage, Shell Oil Company, ExxonMobil Corp., the NOAA/National Weather Service/Tropical Prediction Center (NOAA/NWS/TPC), the NOAA/National Weather Service/Ocean Prediction Center (NOAA/NWS/OPC), the University of Michigan, and the University of the Virgin Islands (UVI).

The academic, governmental, and commercial entities involved in the partnership support and carry out a wide range of oceanographic and ocean prediction-related research. All institutions are committed to developing and demonstrating the performance and application of eddy resolving, real-time, global, Atlantic and Pacific Ocean prediction systems using HYCOM.