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The MMS/SINTEF Oil Weathering Model, Further Development and Applications

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Abstract

The U.S. Minerals Management Service (MMS) is responsible for the development of environmental risk assessments, impact statements, review of contingency plans, and oil-spill response for offshore gas and oil leasing. An Oil-Weathering Model (OWM) is heavily used to support fulfillment of these responsibilities.

In the Alaska OCS Region, numerous estimates of oil-spill fate and behavior are derived from the OWM. The model provides analysts with a common, quantitative set of spill scenarios. The OWM is used to estimate whether State and Federal water quality standards and criteria would be exceeded by a spill, over what area, and for how long. The model calculates the thickness and persistence of a slick through time, and how long the lighter, but most toxic components remain in the oil slick. The model is used to distinguish the effects of larger and smaller spills, for example between the effects of an average tanker spill versus an average pipeline spill. The *in situ* viscosity and degree of emulsification provided by the model are used in assessing the mitigation by and effectiveness of oil spill countermeasures such as mechanical recovery, dispersants, and *in situ* burning.

In the Gulf of Mexico Region, the OWM is more frequently used in environmental assessments to evaluate oil-spill contingency plans and the reliability of associated oil-spill models. The OWM is critical to the latter evaluation because, unlike most oil-spill models, the OWM incorporates specific chemistry of individual crude oils and petroleum products.

This paper describes experience with several applications in both sub-arctic and sub-tropical regions of U.S. coastal waters.

Software availability

The SINTEF Oil Weathering Model is available from

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1. Introduction

The U.S. Minerals Management Service (MMS) is responsible for the development of environmental risk assessments, Environmental Impact Statements, review of contingency plans, and oil-spill response for offshore gas and oil leasing. The MMS/SINTEF Oil-Weathering Model (OWM) is a heavily used to support fulfillment of these responsibilities.

In the Alaska OCS Region, numerous estimates of oil-spill fate and behavior are derived from the OWM. The model provides analysts with a common, quantitative set of spill scenarios. The OWM is used to estimate whether State and Federal water quality standards and criteria would be exceeded by a spill, over what area, and for how long. The model calculates the thickness and persistence of a slick through time. How long the lighter, but most toxic components remain in the oil slick is estimated from the evaporation rate.

The model is used to distinguish the effects of larger and smaller spills, for example between the effects of an average tanker spill versus an average pipeline spill. The *in situ* viscosity and degree of emulsification provided by the model are used in assessing the mitigation by and effectiveness of oil spill countermeasures such as mechanical recovery, dispersants, and *in situ* burning.

In the Gulf of Mexico Region, the OWM is more frequently used in environmental assessments to evaluate oil-spill contingency plans and the reliability of associated oil-spill models. The OWM is critical to the latter evaluation because, unlike most oil-spill models, the OWM incorporates specific chemistry of individual crude oils and petroleum products.

The SINTEF OWM is used by Norwegian authorities and by Norwegian and international oil companies to predict the weathering behavior of crude oils and fuel oils at prevailing conditions. The weathering predictions are an useful tool in contingency analysis and planning for determining the most effective response and for Environmental Impact Assessment studies. In case of an oil spill, the weathering predictions form the basis for rapid and right decision-making during the combat operation.

2. Overview of the model

When a crude oil is spilled at sea it is subjected to several processes which rapidly alter its composition and therefore physical properties and behavior. The most important processes governing the overall characteristics of oil spilled at sea are:

- spreading,
- evaporation of the more volatile components,
- water-in-oil emulsion formation, and
- natural dispersion.

These processes occur simultaneously and the rate and extent to which they proceed depend on the chemical composition of the oil and prevailing conditions such as temperature and sea state. All these processes are inter-related. Other processes such as photo-oxidation, dissolution, bio-degradation and sedimentation also influence the fate and behavior of spilled oil in the longer term.

The chemical data generated through a SINTEF oil weathering and dispersibility study are used as input to the OWM, for predictions of the oil's behavior at sea under different weather conditions.

The weathering study will supply basic information useful for

- modeling the range of drift and spreading of potential oil spills during different seasons;
- evaluating the time window for and effectiveness of chemical dispersant application;
- planning and carrying out mechanical oil spill response actions;
- quantifying the environmental benefit of alternative response activities.

Examples of addition information coming out of the weathering studies, and useful in oil spill contingency planning, are:

- effectiveness of emulsion breakers, to assist in on-board separation of water from oil;
- establishment of exclusion zones based on the ignition point of the oil as a function of weathering time;
- changes in the viscosity of the emulsion over time, to achieve most effective oil recovery.

Oil weathering in the laboratory consists of the following sub-activities:

- Artificial evaporation (topping) and photo-oxidation of the fresh crude oil to give 4 different residues.
- Water-in-oil emulsification of the 4 residues to give a total of up to 12 different emulsified residues (Figure 1).
- Physical-chemical analyses of the artificially produced samples (oil residues and emulsions)

To isolate the influence of the different weathering processes (i.e. evaporative loss, photolysis and water-in-oil emulsification), the weathering of the oils are carried out using a systematic, step-wise procedure established at SINTEF (Daling et al., 1990, 1997). The weathering process is illustrated in Figure 1.

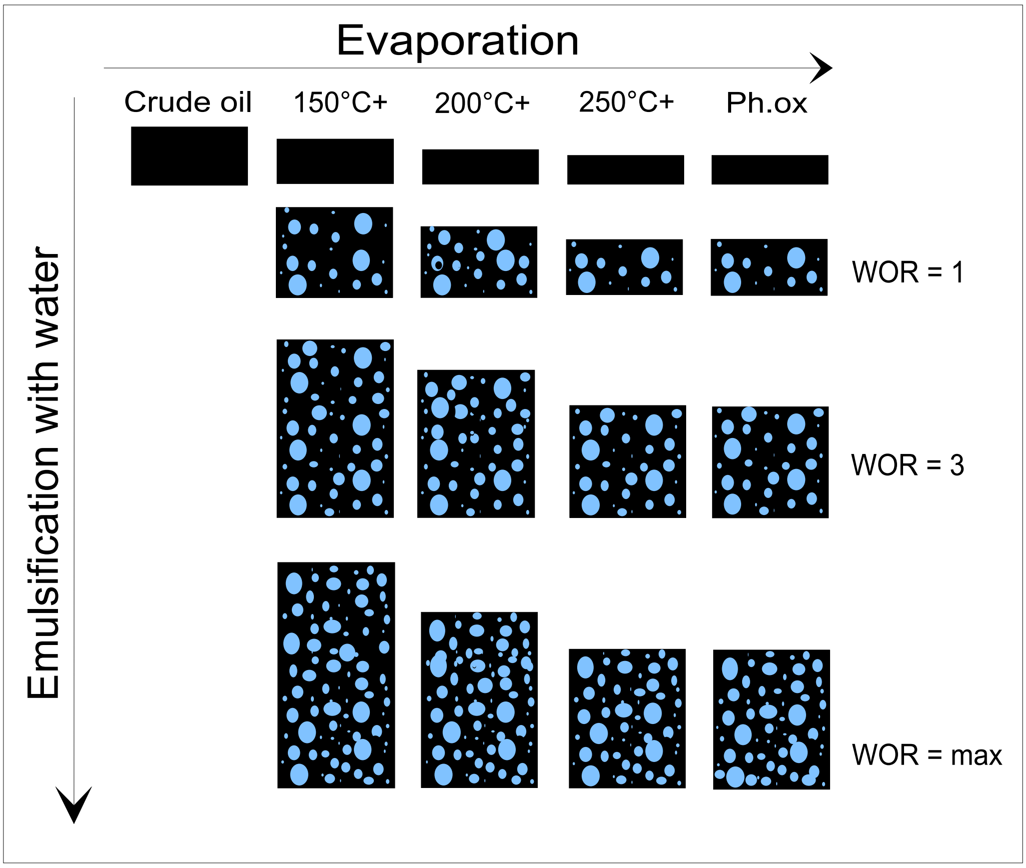

Figure 1 Flow chart for weathering of a crude oil

The OWM relates oil properties to a chosen set of conditions (oil/emulsion film thickness, sea state and sea temperature) and predicts the changes in these properties and behavior on the sea surface. The structure of the OWM is schematically shown in Figure 2.

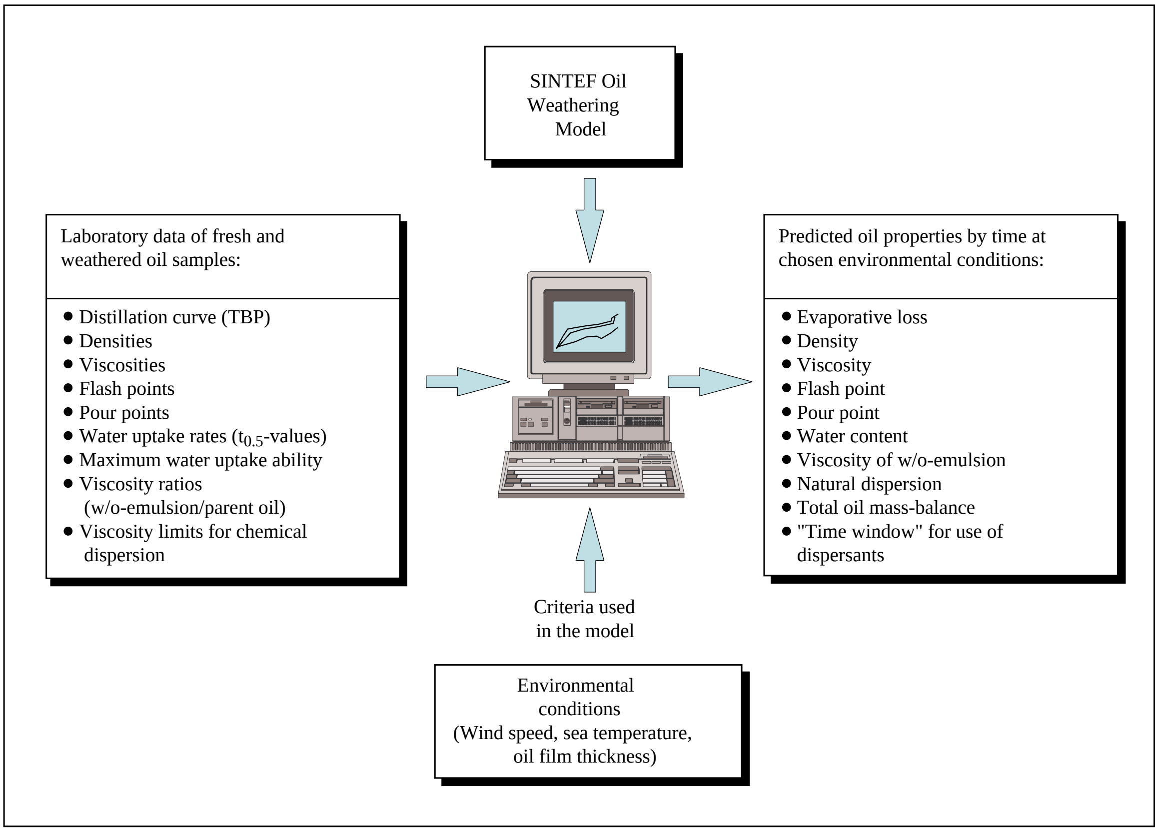

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Figure 2 Schematic diagram of the input data to the SINTEF OWM and the predicted output oil properties

User-defined Input to the SINTEF OWM

Spill scenario

A spill scenario (e.g. sub-sea or surface blowout, tanker spill, pipeline leakage etc.) is specified by entering the release rate (or total amount) and duration into the Graphical User Interface. For underwater releases the gas-oil ratio (GOR) is also required together with the discharge depth.

Terminal oil film thickness

In the SINTEF OWM the oils are categorized into condensates, low emulsifying crudes, emulsifying crudes, heavy bunker fuels or refined distillates based on experimental results obtained in the bench-scale testing. A default for the terminal w/o-emulsion film thickness is given for each category of oil in the model.

Sea temperature

The prevailing weather conditions greatly influence the weathering rate of oil on the sea surface. Two sets of predictions are given in this report, one at the average summer temperature the other at the average winter temperature for the area of interest.

Wind speed

Wind speed can be entered either as a set of constant values, for comparing situations, or as a variable time series. Wind is used in both the evaporation and natural dispersion computations, the latter being dependent on the computed wave field. The user can enter wind fetch in the four primary compass directions, such that the model computations for significant wave height and period account for the presence of land or ice fields. The relationship between the wind speed and the significant wave height is based on the US Army Corps of Engineers (1984) calculation procedures. Example values of wave heights for fully developed seas shown in Table 1.

Table 1. The relationship between the wind speed and the significant wave heights (for fully developed sea) used in the SINTEF OWM

Wind speed [m/s]	Beaufort wind	Wind type	Wave height [m]	Wave height [ft]
2	2	Light breeze	0.1-0.3	0.2-0.60
5	3	Gentle to moderate breeze	0.5-0.8	1-1.5
10	5	Fresh breeze	1.5-2.5	3-5
15	6-7	Strong breeze	3-4	6-8

Input data for the SINTEF OWM

In the bench scale laboratory testing, a systematic stepwise procedure developed at SINTEF (Daling *et al.*, 1990) is used to isolate and map the various weathering processes that take place when oil is spilled on the sea surface.

The experimental weathering data obtained in the bench-scale testing are processed and used as input for the SINTEF OWM. The following oil/emulsion properties obtained in the bench-scale testing are used in the model:

- specific gravity
- pour point
- flash point
- viscosities of fresh and water-free residues (150°C+, 200°C+ and 250°C+)
- viscosities of the 50% and 75 % w/o-emulsions
- water uptake (maximum water content, stability and half-life-time)

Weathering properties related to response

The efficiency of various oil spill combat methods (e. g. mechanical recovery, dispersion and/or burning) depends greatly on the physical and chemical properties of the oil at the time of action. When planning the most effective response the predictions charts provide important information.

Mechanical response

Past experiences from Norwegian field trials have shown that the effectiveness of many mechanical clean up operations is reduced due to a high degree of leakage of the confined oil or w/o-emulsion from the oil spill boom (especially in high current). This leakage is especially pronounced if the viscosity of the oil or the w/o-emulsion is lower than 1000 cP at a shear rate of $10s^{-1}$ (Nordvik *et al*., 1992). The **lower viscosity limit** for an optimal mechanical clean up operation has therefore been set to 1000 cP.

The **upper viscosity limit** for an optimal mechanical clean up operation depends on the type of skimmer used. For some disk-skimmers the collection capacity is reduced significantly at w/o-emulsion viscosities exceeding 10 000 cP (ITOPF, 1986), however ITOPF, 1986 does not state the shear rate.

Recent tests performed by SINTEF using a weir skimmer show that the efficiency may be reduced for semi-solidified oils, i. e. oils with a large wax content and high pour point values, and for oils with viscosities between 15000 and 20000 cP (Leirvik *et.al*.,2001).

Chemical dispersion

A dispersibility methodology, based on the viscosity increase due to weathering, was developed at SINTEF (Daling and Strøm, 1999) in order to determine the window of opportunity for the effective use of dispersants for different oils. Chemical dispersibility testing was not included in this study. General limits for dispersibility based on pour point values are given in
Table 2. These values are not valid for all oils and situations, and should only be regarded as guidelines.

Table 2 The chemical dispersibility criteria used in the SINTEF OWM based on pour points

Pour point [°C]	Chemical dispersibility
< 5°C above the sea temperature	Dispersible
5-15°C above the sea temperature	Reduced dispersibility
> 15°C above the sea temperature	Not dispersible

3. Recent model developments

Version 3.0 of the OWM was completed at the end of June, 2004. In addition to numerous improvements in the user interface, this version includes the following improvements over 2.0:

- possibility for subsurface as well as surface releases;
- internal computation of initial film thickness, based on release rate and duration;
- New spreading algorithm supporting both surface and underwater releases, with improved stability and better detection of erroneous input values;
- New oil type query filters in both OWM and the Oil Database Editor, allowing filtering on ranges of values for API gravity, specific density, and pour point;
- Capability to add/delete Data Source, Geographical Area, and Product in the Editor as documented in the User Manual how to achieve this during editing of oil information;
- New *.TX2 data results file for easy EXCEL import;
- Enabled multi-selection capability in temperature and wind lists, and made Add and Delete buttons more dynamic to facilitate clearing the entire list at once;
- Revised User's Manual for Version 3.0.

The spreading mechanisms for instantaneous releases and continuous releases are different. Instantaneous releases will spread radially, while oil released continuously will spread laterally (i.e. cross-current). This difference in spreading behaviour will affect other weathering properties e.g. evaporation and natural dispersion. Version 2.0 of the model only accounts for lateral spreading (i.e. all releases are treated as continuous), but in Version 3.0, the spreading of instantaneous and continuous spills is treated differently. Also, a calculation of the surface spreading for sub surface releases in shallow to moderate water depths (depth less than e.g. 300 m) is included. This calculation requires input of gas-to-oil ratio (GOR) and depth in addition to release rate

The user may specify a surface or underwater release, the latter presumed to be a subsea blowout, where gas is released together with oil. In the former case, the spreading of the surface slick will be governed by gravity forces, while in the latter case the spreading will be governed by the radial surface flow induced by the surfacing gas bubble plume.

Formulas for gravity spreading were established in the 1980’s by Fay and Fanneløp, but these formulas distinguish between instantaneous releases and continuous releases. Since in practice it is difficult top make a clear distinction between such cases, a unified algorithm has been derived that works in the general case. The user simply specifies the spill in terms of duration and released amounts of oil (or release rate), and the model sorts out the dominating spreading case. This is done by introducing spreading along two axes; the major axis oriented in the wind direction and the minor in the cross-wind direction. Gravity spreading is supposed to act along both axes; while wind induced drift will cause an additional elongation along the major axis. The spreading of strongly elongated slicks will approach the spreading rates determined by Fay's formula for lateral spreading, while the spreading of a circular slick will approach the spreading rates determined by Fay's formula for instantaneous releases, while more or less elongated slicks will spread at intermediate rates. This concept also produces an initial film thickness determined by the release rate, eliminating the need for a default or user specified initial thickness in the former version of the OWM.

In case of underwater releases, the user must provide water depth and Gas-to-Oil Ratio (GOR) in addition to oil release rate. This is used to calculate the velocity and radius of the surfacing gas bubble plume, and on that basis the source strength of the radial outflow of water in the surface layer. The plume parameters are computed from a non-dimensional solution of the plume equations (Fanneløp and Sjøen 1980), while the source strength is found by an equation derived by the same authors. The film thickness is determined as the ratio between the oil release rate and the source strength. This method is justified for blowouts with significant gas releases (GOR > 50) from shallow to moderate water depths (< 300 m), where the mass flow rate of gas may be assumed to be unchanged during the rise to the surface. However, blowouts with small gas flow rates or blowouts from large water depths will be more sensitive to cross currents and stratification in the water masses. Gas bubbles may consequently leak out of the deflected plume and/or dissolve in the ambient water, causing a significant reduction in the gas related buoyancy flux.

The model calculates four physical processes; spreading, evaporation, oil-in-water dispersion and water-in-oil emulsion formation.

Spreading of surface spills

Force balance

The force balance equations may be derived for an oil slick in a channel with a counter flow in the underlying water, i.e. corresponding to an oil slick confined by a boom (Figure 3). On this basis, a relationship is obtained between the density and volume of oil confined by the boom, and the strength of the counter current.

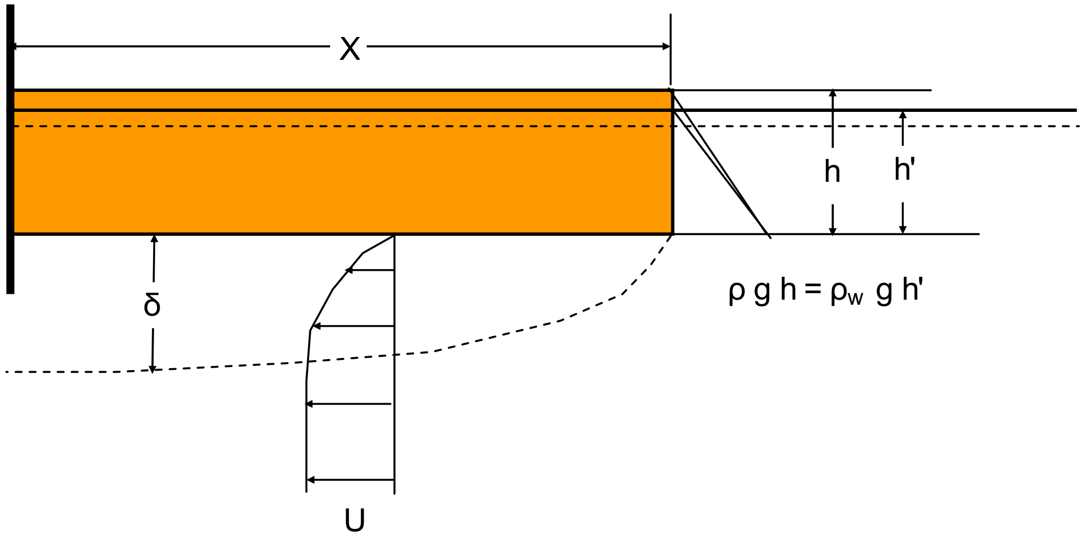

Figure 3. Idealised view of oil spreading against a counter flow in a channel

The pressure force F_p is due to the density difference between oil and water:

$$F_p = \frac{1}{2} B h^2 \rho g' \tag{1}$$

where *B* (m) is the width of the channel, *h* (m) is the oil film thickness, ρ (kg/m^3) is the oil density, and g' (m/s^2) is the reduced gravity: $g' = g(\rho_w - \rho)/\rho_w$.

The shear force F_s is due to the friction between the oil and water in motion:

$$F_s = B\, X\, \mu_w \frac{U}{\delta} \tag{2}$$

where *X* (m) is the length of the oil layer, μ_w (Ns/m^2) is the dynamic viscosity of water, *U* (m/s) is the water velocity, and δ (m) is the thickness of the boundary layer in the water. The latter may be expressed by the Blaussius formula for flow around a flat plate:

$$\delta = 3 \nu_w^{1/2} \sqrt{\frac{X}{U}} \tag{3}$$

where ν_w (m^2/s) is the kinematical viscosity of water. $\nu_w = \mu_w / \rho_w$.

Spreading equation

By taking into account that the confined oil volume is $V = B\, X\, h$, substituting for the boundary layer thickness, and equating the two forces, the following expression is derived for the equilibrium length of the oil layer:

$$X = \left[\frac{3}{2} \frac{V^2 \rho g'}{B^2} \right]^{\frac{2}{5}} \left(\rho_w \mu_w \right)^{-\frac{1}{5}} U^{-\frac{3}{5}} \tag{4}$$

If the oil is spreading on stagnant water, the velocity *U* may be presumed to represent the spreading velocity, i.e. $U = \mathrm{d}X/\mathrm{d}t$. Equation 4 will then be transformed into a separable differential equation in *t* with the solution:

$$X(t) = 1.3 \left(q^2 \rho g' \right)^{\frac{1}{4}} \left(\rho_w \mu_w \right)^{-\frac{1}{8}} t^{\frac{3}{8}} \tag{5}$$

where $q = V/B$, i.e. volume of oil per unit width of the channel.

By use of the mass conservation equation $q = X h$, equation 5 may alternatively be expressed in terms of the film thickness *h*, and be transformed into a suitable differential form which may account for changes in the oil properties with time:

$$\frac{d}{dt} X^{4/3} = 1.75 \left(h^2 \rho g' \right)^{\frac{2}{3}} \left(\rho_w \mu_w \right)^{-\frac{1}{3}} \tag{6}$$

This differential equation may be combined with any oil mass conservation equation relating *h* and *X* to the oil volume, i.e. any equation of the type $V = f(t, h, X)$. It should be noted that a conservation equation may also account for changes in the oil volume with time due to evaporation or emulsion formation. Excluding this for the moment, we may illustrate the concept by a few examples:

- For lateral spreading of a slick formed from a continuous surface leak with a discharge rate *m* (m^3/s) in a steady surface current of velocity *u* (m/s), the oil conservation equation may be written as $q = m / u = 2 h X$, where *X* represents the half width of the slick.
- For an instantaneous spill, the conservation equation may be written as $V = \pi X^2 h$, where *V* (m^3) is the spilled oil volume and *X* represents the radius of the circular slick.
- For a continuous leak on calm water, the same equation applies, but *V* will be increasing with time; $V = m\, t$, where *m* (m^3/s) is the release rate.

For a continuous leak from a point source in a steady current, the oil volume will also increase in proportion with time. In this case, gravity spreading will take place along two axis (cross-stream and downstream), but the cross-stream (lateral) component is conventionally presumed to dominate as the slick is extended downstream due to advection with the current. This assumption may be valid in cases with relatively strong currents and moderate spill rates. For weak currents and large spill rates, gravity spreading may have to be considered along both axis to get a realistic picture (see Figure 4).

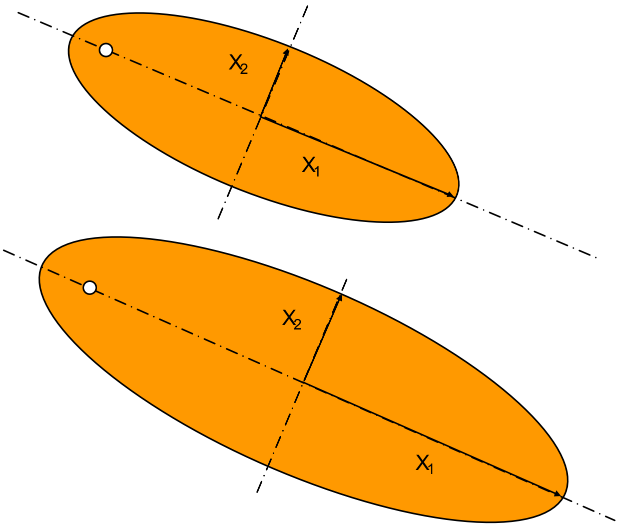

Figure 4. Spreading of an oil slick from a continuous oil leak in a steady current. The slick may be defined in terms of X_1 and X_2, representing the half-axes of an elliptical slick, with X_1 aligned in the downstream direction. The oil conservation equation may then be expressed as $V = mt = h\pi X_1 X_2$, where *m* (m^3/s) is the spill rate. The progression of X_1 and X_2 may be computed by equation 7, while including an extra downstream elongation due to the current *($dX_1 = 0.5\ u\ dt$)* in the period of time when the oil is leaking.

The approach sketched in Figure 4 is in fact unifying all the "classical" Fay spreading problems, from instantaneous spills, via continuous spills on calm water to continuous spills in a steady current. Figure 5 illustrates this concept for two cases. The same amounts of oil are released in both spills (2400 m^3), but the duration of the release is 2 hours in the first case (a), and 24 hours in the second case (b). The oil density is 850 kg/m3 in both cases, and the surface current is presumed to be moderate (10 cm/s). The results show that the calculations fro the first case approaches Fay's equation for radial spreading on calm water, while the second case approaches Fay's equation for lateral spreading of a continuous spill in a steady current.

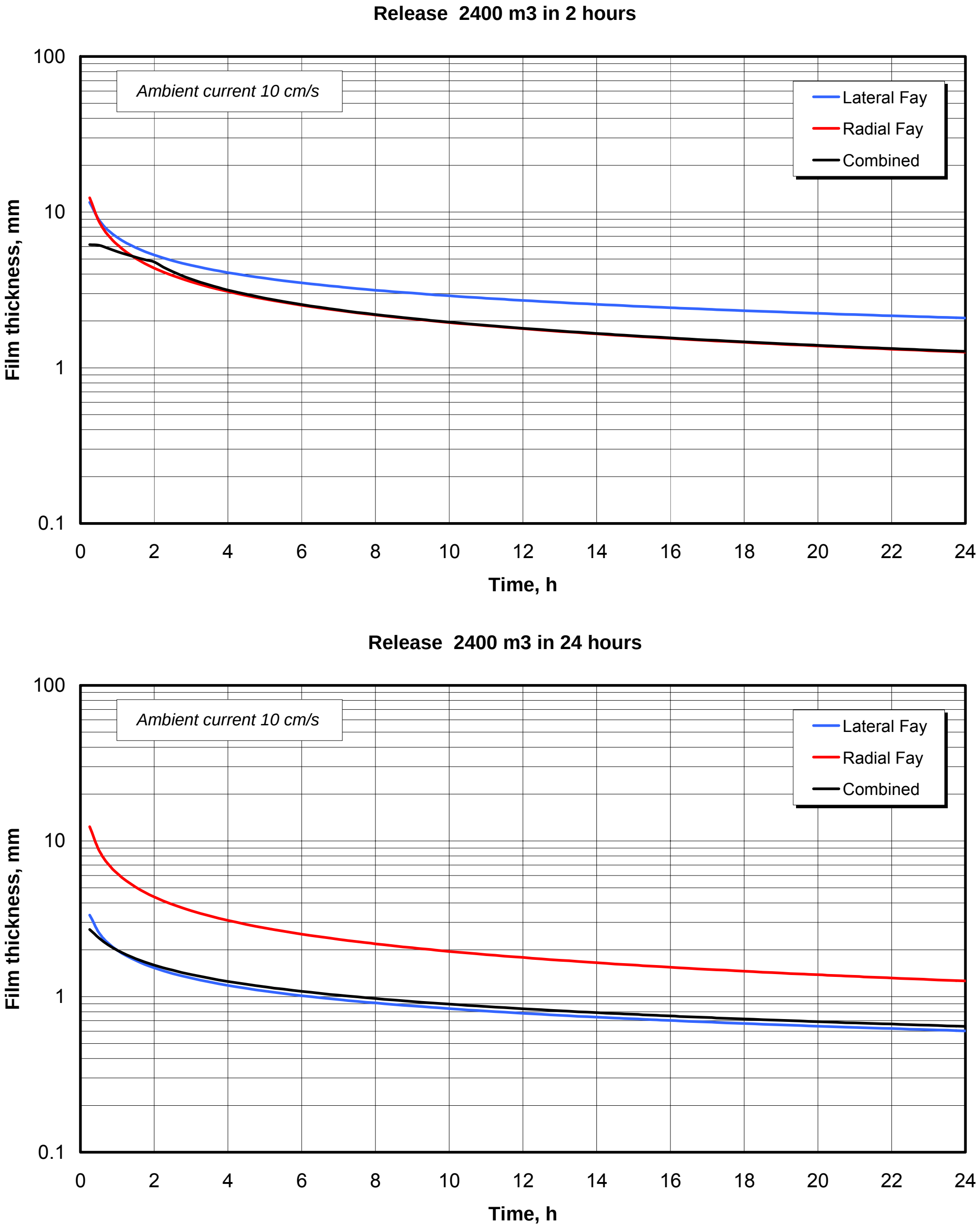

Figure 5. Gravity spreading computed with equation 7 for two cases: 2400 m^3 of oil released in 2 hours (top), and 2400 m^3 released in 24 hours (bottom). The calculations are made with an oil density of 850 kg/m^3. The coloured lines depict the corresponding results of spreading equations for instantaneous releases (“Radial Fay”), and lateral spreading for continuous releases in a steady current (“Lateral Fay”).

Surface spreading of subsea blowouts

The surface spreading of oil from a subsea blowout is governed by the generation of a rising gas bubble plume that entrains ambient water. Surfacing of the entrained water produces a radial outflow at the sea surface. The oil will be carried to the surface as fine oil droplets dispersed in the entrained water. A surface slick will form as the dispersed oil droplets settle out of the radial outflow of entrained water.

According to Fanneløp and Sjøen (1980), the surface velocity distribution in the radial outflow can be approximated by a source flow equation:

$$U(r) = \frac{S}{2\pi r} \tag{7}$$

where S (m^2/s) is the source strength.

Under such conditions – provided that all the oil comes to the surface, the oil film thickness h (m) may be estimated from the source strength and the oil spill rate m (m^3/s):

$$h = m/S \tag{8}$$

Fanneløp and Sjøen (op cit) also show that the source strength S depends on the characteristic radius b (m) and velocity w (m/s) of the surfacing plume:

$$S = k\,\pi\,b\,w \tag{9}$$

where k = 4.86 is a constant.

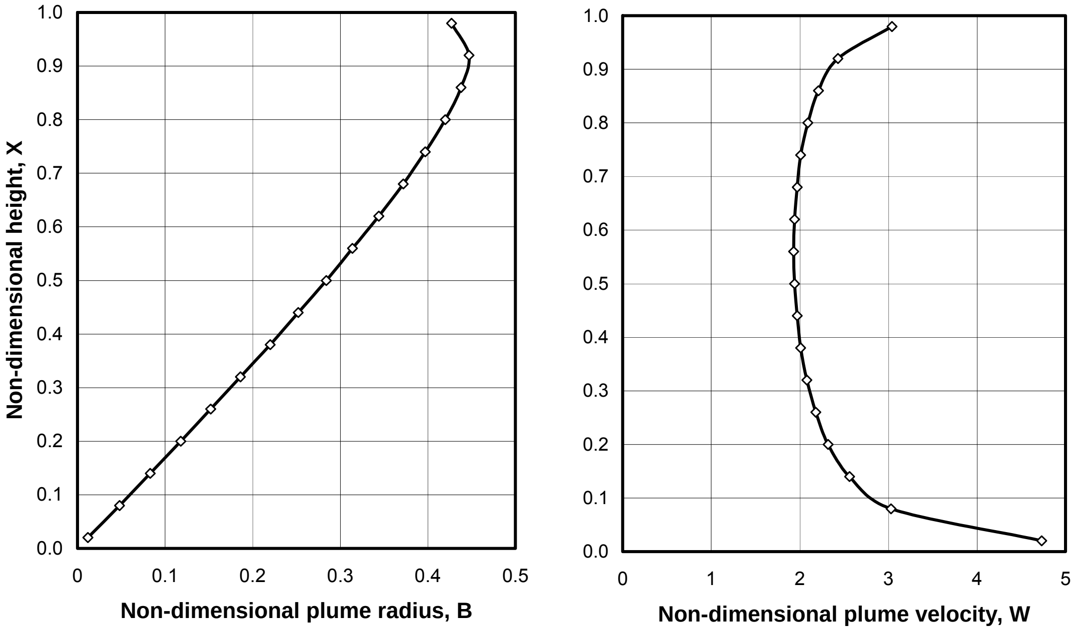

Figure 6. Non-dimensional plume radius and plume velocity computed for subsea gas blowouts (Fanneløp and Sjøen 1980). See text for definitions of the non-dimensional variables.

The same authors also presented a basis for establishing the characteristic plume radius b and velocity w in terms of a non-dimensional solution to the plume equations (Figure 6). The non-dimensional variables are defined as follows:

$$\mathrm{X} = z / H,\ \mathrm{B} = b / 2\alpha H,\ \mathrm{W} = w / \mathrm{M},$$

$$\text{where}\,\mathrm{M} = \left[\frac{\varphi_0 \left(\lambda^2 + 1 \right)}{2\alpha^2 H} \right]^{1/3} \tag{10}$$

In these equations, H (m) is the pressure height, $H = H_0 + H_a$, where H_0 is the water depth and H_a is the pressure height corresponding to 1 atmosphere (10 m), $\varphi_0 = g\dot{V}_0 / \pi$ ($\mathrm{m}^4/\mathrm{s}^3$) is the buoyancy flux at the exit, where $\dot{V}_0$ (m^3/s) is the exit gas volume flow rate, while $\alpha = 0.1$ and $\lambda = 0.65$ are parameters related to plume dynamics.

The basic blowout specific variables in these equations are water depth H_D and the exit gas volume flow rate $\dot{V}_0$. The latter may usually be derived from the oil discharge rate m (m^3/s) and the Gas-to-Oil Ratio, GOR, representing the ratio between the released gas volume and oil volume at normal conditions (1 atmosphere and 15°C). Neglecting the minor correction due to the temperature difference, the ideal gas law gives:

$$\dot{V}_0 = m\,GOR\,H_a / H \tag{11}$$

The non-dimensional variable X is defined from the actual water depth. The corresponding non-dimensional values B and W may then be found from the graphs shown on Figure 6, or from curve-fitted functions based on the original data. The actual plume variables (*b* and *w*) may then be determined by rescaling B and W with known X and M, the latter calculated from the exit volume flux (see equation 10).

It should be noted that this approach is valid under certain conditions that in general implies that effects of cross flow and stratification can be neglected. In practice, the concept should be applied to cases with significant gas volume fluxes (GOR > 50) from moderate water depths (< 300 m).

4. Example applications within MMS

The Alaska OCS Region uses the oil weathering model to set up generalized weathering scenarios in environmental impact statements to guide the impact assessment. To judge the effect of an oil spill, the model is used to estimate information regarding how much oil evaporates, how much oil is dispersed, and how much oil remains after a certain time period. Weathering estimates are derived from modeling results from the SINTEF Oil Weathering Model (OWM) for time periods up to 30 days. Below are presented the assumptions used to set up the weathering scenario, the uncertainties and the results from an oil spill scenario for the Cook Inlet Planning Area Oil and Gas Lease Sales 191 and 202 Environmental Impact Statement (USDOI, MMS 2003;).

The following assumptions are made regarding oil weathering in a Cook Inlet crude-oil spill:

- The crude oil properties will be similar to Cook Inlet crude.
- The size of the spill is 1,500 or 4,600 barrels.
- The wind, wave, and temperature conditions are as described.

- Melt-out spills occur into 50% ice cover.
- The properties predicted by the model are those of the thick part of the slick.
- The spill occurs over a short period of time.

Actual conditions in a real spill event will of course be different from those assumed, but these scenarios provide our best estimate of the behavior and fate of potential releases.

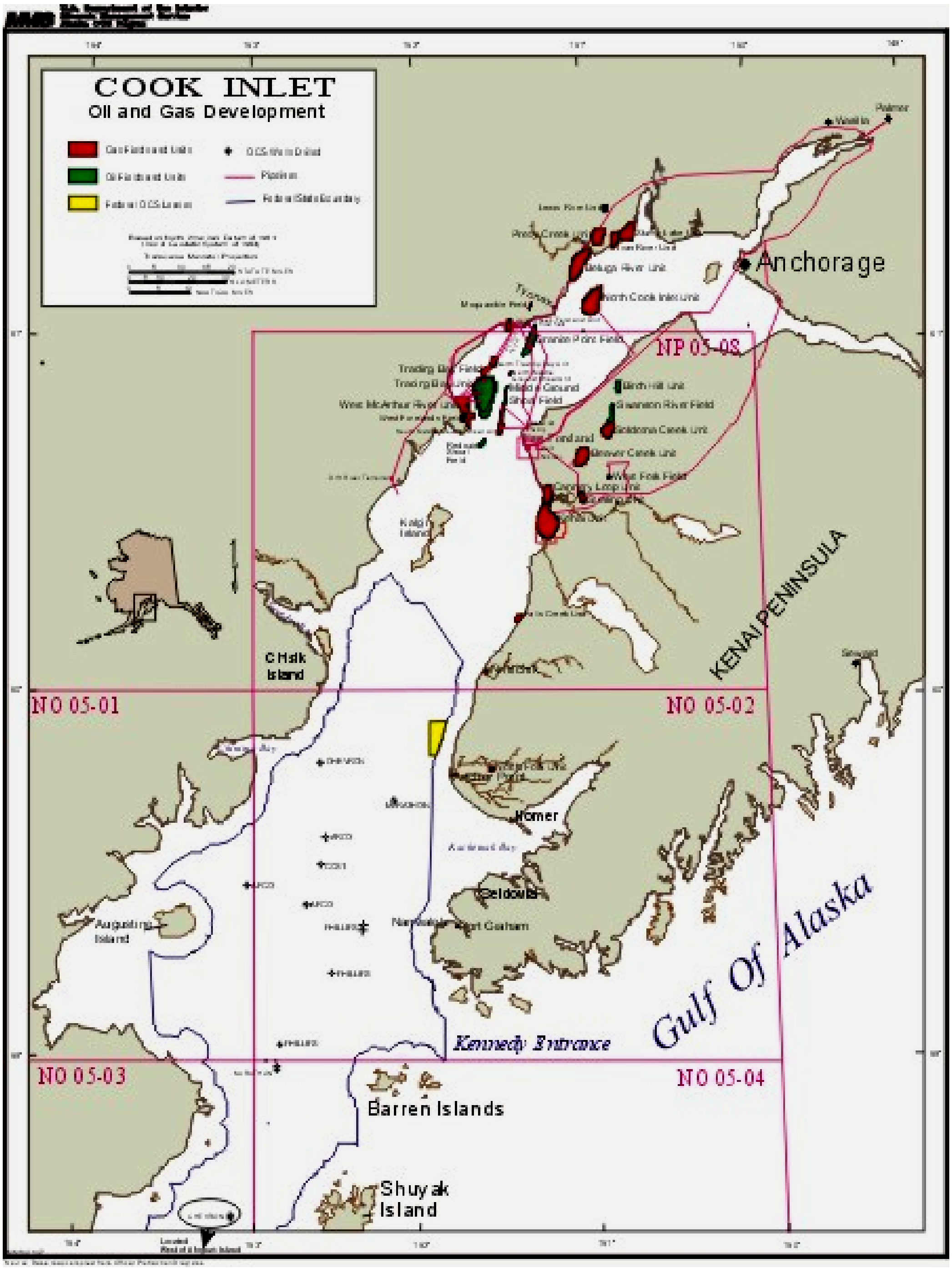

Figure 7 Map of Cook Inlet in the Gulf of Alaska

Table 3 through Table 6 show the results for Cook Inlet crude-oil spills using the SINTEF model. The SINTEF OWM changes both oil properties and physical properties of the oil. The oil properties include density, viscosity, pour point, flash point, and water content. The physical processes include spreading, evaporation, oil-in-water dispersion, and water uptake. The SINTEF OWM Version 2.0 performs a 30-day time horizon on the model-weathering calculations but with a warning that the model is not verified against experimental field data for more than 4-5 days. The SINTEF OWM has been tested extensively with results from three full-scale field trials of experimental oil spills (Daling and Strom, 1999).

The SINTEF OWM does not incorporate the effects of the following:

- beaching,
- containment,
- photo-oxidation,
- microbiological degradation,
- adsorption to particles, and
- encapsulation by ice.

We simulated three general scenarios: two in which the oil spills into open water during summer or winter and one in which the oil spills into 50% ice cover during winter. We assume open water can occur year-round depending on the area of lower Cook Inlet, and we also assume that winter occurs October to April. For open water and ice, we model the weathering of the 1,500- or 4,600-barrel spill as if they are instantaneous spills. We report the results at the end of 1, 3, 10, and 30 days. Table 3 through Table 6 summarize the results we assume for the fate and behavior of Cook Inlet crude oil in our analysis of the effects of oil on environmental, economic and socio-cultural resources. In our analysis, we assume the following fate of the crude oil without cleanup. After 30 days in open water or ice: 33-36% evaporates, 13-62% disperses, and 5-52% remains.

Table 3 Fate and Behavior of a Hypothetical Open-Water Oil Spill, 1,500 Barrels in Size, from a Platform in Lower Cook Inlet

Description	Summer Spill[1] (Time after spill in days)				Winter Spill[2] (Time after spill in days)			
	1	3	10	30	1	3	10	30
Oil Remaining (%)	76.9	69.3	53.4	29.2	73.1	59.5	29.8	5.4
Oil Dispersed (%)	1.4	4.0	15.1	35.7	4.0	13	38.8	61.5
Oil Evaporated (%)	21.7	26.7	31.5	35.1	22.9	27.5	31.4	33.1
Thickness (mm)	2.3	1.3	1.0	1.0	1.8	1.1	1	1
Discontinuous Area (km^2)[3]	8	32	150	621	8	31	77	618
Estimated Coastline Oiled (km)[4]	23				17			

Notes:

Calculated with the SINTEF oil-weathering model Version 2.0 of Reed et al. (2000) and assuming a Cook Inlet Crude (S.L. Ross, 2001).

[1] Summer (April-September), 11.5 knot wind speed, 8.8 °C, 1-meter-wave height. Average Weather Marine Area A, Brower et al. (1988).

[2] Winter (October-March), 16-knot wind speed, 4.76 °C, 1.8-meter-wave height. Average Weather Marine Area A, Brower et al. (1988).

[3] Calculated from Equation 6 of Table 2 in Ford (1985) and is the discontinuous area of a continuing spill or the area swept by an instantaneous spill of a given volume.

[4] Calculated from Equation 17 of Table 4 in Ford (1985) and is the result of stepwise multiple regression for length of historical coastline affected.

Table 4 Fate and Behavior of a Hypothetical Broken-Ice Oil Spill, 1,500 Barrels in Size, from a Platform in Lower Cook Inlet

Description	Winter Spill[1] (Broken Ice) (Time after spill in days)			
	1	3	10	30
Oil Remaining (%)	77.4	71.1	61.6	48
Oil Dispersed (%)	0.9	2.6	6.7	15.8
Oil Evaporated (%)	21..7	26.3	31.7	36.2
Thickness (mm)	3.2	1.9	1	1
Discontinuous Area (km^2)[2]	8	31	77	618
Estimated Coastline Oiled (km)[3]	17			

Notes:

Calculated with the SINTEF oil-weathering model Version 2.0 of Reed et al. (2000) and assuming a Cook Inlet Crude (S.L. Ross, 2001).

1Winter (October-March), 16-knot wind speed, 4.76 oC, 1.8-meter-wave height. Average Weather Marine Area A, Brower et al. (1988).

2 Calculated from Equation 6 of Table 2 in Ford (1985) and is the discontinuous area of a continuing spill or the area swept by an instantaneous spill of a given volume.

3Calculated from Equation 17 of Table 4 in Ford (1985) and is the result of stepwise multiple regression for length of historical coastline affected.

Table 5 Fate and Behavior of a Hypothetical Open-Water Oil Spill, 4,600 Barrels in Size, from a Offshore Pipeline in Cook Inlet

Description	Summer Spill[1] (Time after spill in days)				Winter Spill[2] (Time after spill in days)			
	1	3	10	30	1	3	10	30
Oil Remaining (%)	77.8	70.6	55.4	30.2	74.3	62.2	32.2	5.8
Oil Dispersed (%)	1.1	3.3	13.4	34.7	3.3	10.8	36.6	61
Oil Evaporated (%)	21.1	26.1	31.2	35.1	22.4	27	31.2	33.2
Thickness (mm)	2.9	1.6	1	1	3.4	1.6	1	1
Discontinuous Area (km^2)[3]	13	56	265	1100	13	55	263	1094
Estimated Coastline Oiled (km)[4]	38				28			

Notes:
Calculated with the SINTEF oil-weathering model Version 2.0 of Reed et al. (2000) and assuming a Cook Inlet Crude (S.L. Ross, 2001).
1Summer (April-September), 11.5 knot wind speed, 8.8 oC, 1-meter-wave height. Average Weather Marine Area A, Brower et al. (1988).
2Winter (October-March), 16-knot wind speed, 4.76 oC, 1.8-meter-wave height. Average Weather Marine Area A, Brower et al. (1988).
3 Calculated from Equation 6 of Table 2 in Ford (1985) and is the discontinuous area of a continuing spill or the area swept by an instantaneous spill of a given volume.
4 Calculated from Equation 17 of Table 4 in Ford (1985) and is the result of stepwise multiple regression for length of historical coastline affected.

Table 6 Fate and Behavior of a Hypothetical Broken-Ice Oil Spill, 4,600 Barrels in Size, from a Offshore Pipeline in Cook Inlet

Description	Winter Spill[1] (Broken Ice) (Time after spill in days)			
	1	3	10	30
Oil Remaining (%)	79.3	73.6	65.9	52
Oil Dispersed (%)	0.6	1.6	4	12.5
Oil Evaporated (%)	20.1	24.8	30.1	35.5
Thickness (mm)	5.6	3.3	1.1	1
Discontinuous Area (km^2)[2]	13	33	263	1,094
Estimated Coastline Oiled (km)[3]	28			

Notes:
Calculated with the SINTEF oil-weathering model Version 2.0 of Reed et al. (2000) and assuming a Cook Inlet Crude (S.L. Ross, 2001).
1Winter (October-March), 16-knot wind speed, 4.76 oC, 1.8-meter-wave height. Average Weather Marine Area A, Brower et al. (1988).
2 Calculated from Equation 6 of Table 2 in Ford (1985) and is the discontinuous area of a continuing spill or the area swept by an instantaneous spill of a given volume.
3Calculated from Equation 17 of Table 4 in Ford (1985) and is the result of stepwise multiple regression for length of historical coastline affected.

5. Conclusions and possible future extensions

In general, the MMS has a relatively long timeframe of interest regarding oil weathering, through at least 30 days or as long as a slick persists. Furthermore, there is surprisingly little empirical data for how long a spill persists as an identifiable slick. We would like to see this end point better tracked and reported in real spill events.

MMS is working to improve data and algorithms for cold climate weathering. Using a range of Alaska oil types, looking at:

- Evaporation rates down to very cold temperatures (-40).
- Evaporation rates in snow cover
- Spreading of oil under and above ice and equilibrium thicknesses
- Brine channel migration
- Water-in-Oil emulsification in broken ice wave field

These and other improvements are anticipated in future versions of the oil weathering model described here.

6.References

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