The OILMAP Family
...and a few relatives

- Environmental Data Server (EDS)
- Met-Ocean Forecasts
- Environmental Data

- OILMAPDEEP
  Deepwater Blowout Model (Near-Field)

- OILMAP
  Trajectory and Fate Model (Far-Field)

- AIRMAP
  Atmospheric Dispersion Model

- SIMAP
  Far-Fiield Oil Fate, Exposure and Biological Effects Models

- CHEMMAP
  Chemical Trajectory and Fates Model (Far-Field)

- OILMAPLAND
  Trajectory and Fates Model (Far-Field)

- Response Planning
- Environmental Impact Assessment
Modeling of the Near-field Blowout and Far-field Phases of an Oil and Gas Blowout

OILMAP or SIMAP Oil Transport and Fate Modeling

Droplet Release from Intrusion at Trap Height

OILMAP-Deep Blowout Modeling
OILMAP: Trajectory & Fate Model for Response Planning
CHEMMAP Trajectory and Fate Model and AIRMAP
OILMAPLand - 2D Trajectory and Fate

Modeled Processes – Overland Flow

Modeled Processes – Surface Water Network
Chemical Spills (e.g., from a Chemical Plant) Potential Effects: Air, Land, and Estuary

- Vapor Cloud
- Downstream Transport
- 3D Plume in Water
Physical Fate and Exposure Modeling
Approach & Discretization

- Movements of oil/chemical & organisms tracked in space and time as parcels (Lagrangian elements, LEs, ‘spillets”)
  - Floating slicks, weathered oil
  - Droplets/particulates &
  - Organisms in the water
  - Dissolved
  - In/on sediments & shorelines

- Model uses grids to define
  - Bathymetry
  - Habitats
  - Temperature, Salinity
  - Current vectors
  - Mobile ice cover & vectors
  - Landfast Ice cover

- Results also gridded
Volatile Components of Oil Modeled Separately; In SIMAP: Soluble and Semi-Soluble vs Insoluble

**Monoaromatic Hydrocarbons (MAHs)**
- Benzene, Toluene, Ethylbenzene and Xylenes = BTEX
  - highly soluble, highly volatile, moderately toxic
- Alkyl-substituted Benzenes
  - soluble, less volatile, more toxic

**Polynuclear Aromatic Hydrocarbons (PAHs)**
- Naphthalenes (2-ring PAHs)
  - soluble, less volatile, more toxic
  - with more alkyl chains, less soluble but more toxic
- 3 ring PAHs – semi-soluble, most toxic fractions
  - Phenanthrenes
  - Fluorenes
  - Dibenzothiophenes
- 4-ring PAHs – fluoranthenes, pyrenes, chrysenes
- larger PAHs insoluble

**Aliphatics:**
- Alkanes – C12-C23 – volatile, negligible solubility
- Alkanes ≤ C12 & Cyclics – volatile & soluble
Response Modeling

- Model accounts for
  - Surface dispersant application
  - Booming
  - Mechanical removal (off water and shorelines)
  - In situ burning
  - Subsea dispersant use via OILMAP-Deep

- User specifies
  - Location of response actions (GIS polygon)
  - Time window
  - Efficiency/Amount per time
  - Failure thresholds (wind, waves, minimum thickness)
Floating Oil & In-Water Concentrations

Horizontal cross section of LEs with Gaussian distributions of mass around each LE, projected into a grid
- Calculate area swept by oil > threshold thickness
- French McCay (2009, 2016) developed surface oil thickness thresholds based on experimental and field data:
  - Lethal threshold: 10 g/m²
  - Sublethal threshold: 1 g/m²
- Probability of Exposure
  - Habitats occupied
  - Behavior – likelihood of intersection oil at water surface
Activity-based Exposure Model: Fish and Invertebrates

- Organisms classified by behavior
  - Swimming
    - Vertical zone
    - Diel migration
  - Speed
  - Drift with currents
  - Stationary (benthic)

- Movements of organisms are tracked using Lagrangian Elements to calculate exposure of individuals

Acute toxic effects a function of dose
- Exposure duration – while concentration > threshold
- Mean concentration during exposure duration
Mortality by behavior group, species and life stage, as:

- Equivalent area or volume of 100% loss = \( \Sigma \) (Fractional loss in each area/volume)
- Percentage of population in defined area
- (If pre-spill abundance known)
  - Numbers
  - Biomass (kg)

Future impacts

- Production forgone = growth that would have been produced over remaining lifetime if there had not been a spill
- Catch loss (yield foregone) for fished species
SIMAP Model Validation

- Developed over 3 decades, several peer reviews, validation studies
- Derived from CERCLA Type A model (French et al. 1996); also referred to in OPA 90 NRDA regulations
- *Exxon Valdez* Oil Spill (French McCay 2004)
- *North Cape* Oil Spill (French McCay 2003)
- 20 spills (French McCay and Rowe, 2004)
- Test spills designed to verify algorithms (French and Rines 1997; French et al. 1997; Payne et al. 2007; French McCay et al. 2007)
- Deepwater Horizon (DWH) oil spill in support of the Natural Resource Damage Assessment (NRDA) – NOAA (Spaulding et al. 2015, 2017; French McCay et al. 2015, 2016, 2018) and as part of validation study for BOEM risk assessment project (French McCay et al., 2018a,b,c)
North Cape Oil Spill

- USA, Rhode Island coast, 19 January 1996
- 828,000 gal (2,682 tonnes) of No. 2 (light) fuel oil
- Entrained by heavy surf causing large impact to aquatic organisms
Surface Oil at 16 Hours After Spill

Observed – Modeled
Surface Oil at 36 Hours After Spill

Observed – Modeled
Dissolved Aromatic Concentrations at 40 Hours After Spill

Model Agreed with Measured Concentrations
Dissolved Aromatic Concentrations at 138 Hours After Spill
Model Agreed with Measured Concentrations
Total Hydrocarbons in Sediments at 10 Days After Spill

Model Agreed with Measured Concentrations
Biological Model

- **Validation: Lobsters**
  - Field-based estimate 9 million
  - Model estimate 8.3 million
    - (using best estimate of toxicity)
  - Stranded dead lobsters on beaches: 3 million (so at least this many killed)

- Used validated model for injury quantification for fish and invertebrates

North Cape Bird Injury

- Diving ducks
- Loons
- Grebes
- Small alcids
- Cormorants
- Murrens
- Gulls
- Gannets
- Sandpipers, plovers
- Total diving ducks & loons
- Total, all species

log10 (# killed)

Exxon Valdez (Prince William Sound)

- Total Birds
- Eagles
- Murrels
- Puffins
- Guillemots
- Murrelets
- Other alcids
- Gulls
- Cormorants
- Procellariids
- Sea ducks
- Grebes
- Loons

Model vs Field (log10 (# killed))

French McCay 2004 Envir. Tox & Chem
Deepwater Horizon Oil Spill

- April 22 – July 15, 2010 in NE Gulf of Mexico
- ~205 million gallons (government estimate)
- Response:
  - Mechanical removal and In-Situ Burning
  - Surface and subsea application of dispersants
Daily Oil Flow Rate to Environment & Dispersants by Date (Lehr et al. / Government Estimates)
Droplet sizes – Volume Fraction by Day
Overall Mass Balance – DWH

Reflects discharged amount over time, dispersant application at depth, winds
Validation Against Surface Oil Estimates Based on Remote Sensing
Uncertainties in Transport: Currents and Winds Used

- **Hydrodynamics (all very different)**
  - ADCPs – measured currents, interpolated – best trajectory below 40 m
  - NGOM (NOAA, real time) – not correct directions below 40 m
  - NCOM (US Navy, NRL, real time) – not correct directions below 40 m
  - HYCOM (US Navy, NRL, real time) – not correct directions below 40 m
  - HYCOM (US Navy, NRL, reanalysis) – similar to FSU version
  - HYCOM (FSU, reanalysis) – best above 40 m, OK below
  - SABGOM (ROMS) – too fast below 40 m
  - IAS ROMs (ROMS) – too fast below 40 m

- **Winds (all fairly similar)**
  - NOAA: NARR, NAM, CFSR
  - NOGAPS
Surface Oil Distribution – SAR Based
Surface Oil Distribution – Modeled
Surface Oil Area Covered by Oil

The graph illustrates the area covered by oil on the surface over time, with different lines representing various thresholds of oil concentration per square meter (g/m²). The x-axis represents dates ranging from 4/12/2010 to 9/19/2010, and the y-axis represents the area in millions of square meters (km²). The lines show the progression of oil coverage over the specified dates, with distinct colors and markers for each concentration level.
Shoreline Oil Distribution – HYCOM FSU

Resolution: 5 x 5 km

False Negative (Observed Only)

Match

False Positive (Modeled Only)

No Oil

False Positives: 115
False Negatives: 114
No Oil Observed: 230
Comparison of the Modeled Concentrations to Field Measurements

- Due to differences between modeled and actual field conditions and patchiness of observed chemistry – displacement between modeled and observed concentrations in both space and time.
- Thus, direct overlay of chemistry measurements on the model was insufficient for evaluating if the concentrations produced by the model are reasonable.
- Results were plotted as probability distributions within a spatial (25 km by 25 km box centered on the wellhead) and time window, containing a population of chemistry samples.
  - Most sampling targeted deep plume within 12 km of wellhead.
- Good agreement of magnitudes of concentrations.
Comparison of ADCP Modeled Concentrations to Field Measurements: AR1 = BTEX, 800 – 1000 m

April 22 - May 26

May 26 – June 6

June 6 – July 15
Comparison of ADCP Modeled Concentrations to Field Measurements: AR6, 800 – 1000 m

April 22 - May 26

May 26 – June 6

June 6 – July 15
Risk = (probability of spill) X (consequences)

Spill Probability
- Oil or hazardous material type
- Spill size and duration
- Location
- Season/environmental conditions

Spill consequences
- Shorelines/Habitats
- Wildlife (birds, mammals, turtles)
- Fish and invertebrates
- Socioeconomic resources
Stochastic Modeling

- Quantifies
  - Probability of contamination above threshold of concern
  - Mean (50th) and other (e.g., 99th) percentile degrees of contamination by location around the spill site

- Uses
  - Response planning
  - Environmental / Ecological Risk Assessment
  - Identification of worst case scenario for
    - Floating oil exposure
    - Shoreline oiling
    - Water column exposure
Composite of hundreds of individual simulations by randomly changing the spill starting date which – randomising the winds & currents conditions.
US Fish and Wildlife Service (USFWS) evaluated potential overlaps of oil spill trajectories from hypothetical spills with polar bear and other marine mammal distribution, habitat and usage maps (with Ryan Wilson, USFWS and Craig Perham, now @ BOEM)

Publications:
Oil Spill Scenarios: Spill Sites, Discharge Rates, Durations, Oil Type

- **Beaufort Sea** (6-day pipeline discharges at sea floor)
  - Spy Island; 4,800 bbl/day (Prudhoe Bay, medium crude)
  - Spy Island; 110 bbl/day (Prudhoe Bay, medium crude)
  - Northstar Island; 4,800 bbl/day (light crude)
  - Liberty; 4,800 bbl/day (heavy crude)

- **Chukchi Sea** (blowouts: medium crude, 25,000 bbl/day for 30 days)
  - Burger
  - Klondike
  - Crackerjack
  - Wrangel

- **Spill Start in October**
Probability of Surface Oiling & Time of First Arrival for $\geq 1 \text{ g/m}^2$ (Left) or $\geq 10 \text{ g/m}^2$ (Right) Oil Cover at Spy Island

28,000 bbl spill
28,000 bbl spill
Probability of Surface Oiling & Time of First Arrival for
≥1 g/m² (Left) or ≥10 g/m² (Right) Oil Cover at Liberty
75,000,000 bbl spill
Probability of Surface Oiling & Time of First Arrival for
≥1 g/m² (Left) or ≥10 g/m² (Right) Oil Cover at Burger

750,000 Barrel Blowout Release of Prudhoe Bay Crude in October

Minimum Time to Surface Oiling (Days)
- <1
- 1-5
- 5-10
- 10-15
- 15-20
- 20-25
- 25-30
- 30-35
- >30

Monthly Ice Coverage
- Burger Spill Location
- October
- November
- December

0 670 1340 KM
Consider These are Worst Case Discharges

- Hypothetical spills modeled here were very large, worst case scenarios.
- Also, worst conditions for persistence of surface oil in the environment were evaluated: a spill occurring or to continuing into the ice freeze up season (i.e., occurring during October).
- The probability of such a spill occurring would be extremely low.
- Results from smaller spills and in other seasons would result in much less surface oil exposure.
- Need to consider Risk: These results should be considered in view of the joint probabilities of such a spill occurring and of the projected consequences.
Comparative Risk Assessment (CRA) Study

- Oil Fate and Exposure – Deep Sea Blowout With and Without Subsea Dispersant Injection Treatment (SSDI)
- Compared various response options
  - No intervention
  - Mechanical only
  - Mechanical & In-Situ Burning & Surface Dispersant (MBSD)
  - MBSD & SSDI
  - SSDI-only
- 3 papers in press Marine Pollution Bulletin
- API Sponsored
- Included a Technical Advisory Committee (TAC) of Responders and Subject Matter Experts (SMEs)
### Comparative Risk Assessment (CRA)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<tbody>
<tr>
<td>Oil Release Rate</td>
<td>45,000 bbl/day</td>
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<tr>
<td>Release Duration</td>
<td>21 days</td>
</tr>
<tr>
<td>Release Depth</td>
<td>1400 m</td>
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<tr>
<td>Crude oil density</td>
<td>API = 34.2</td>
</tr>
</tbody>
</table>

- **Currents** – Naval Research Lab
  - HYCOM
- **Winds** – NOAA NCEP
  - CFSR hourly

![Map showing oil spill and distances](attachment:image)
No Intervention – 5th Surface & 97th Shoreline Oil of 100 Runs Starting at Randomly-Selected Dates:
Maximum Exposure on Water Surface (at any time)

Run 36: Spill Start: 2008 Dec 5, 12:08 UTC

Averaged g/m² in ~1km² grid cells
Uncertainty – Environmental Conditions:
Summary of Exposure Metrics for 100 Model Runs, Randomizing Start Date and Time

Mean (Coefficient of Variation = SD/Mean)
Due to Environmental Conditions

Results of CRA Study

[Bar chart showing comparisons between No Intervention, MBSD, and MBSD+SSDI for Maximum surface oil mass, Maximum surface oil volume, Cumulative oil volume on shore, Cumulative oil mass evaporated, Maximum oil mass in water column, and Cumulative oil mass degraded.]
Conclusions of CRA Study

The Model-Predictions Show

- Mechanical and *in situ* burning only removed a small fraction of the oil that would otherwise have been floating or evaporate.
- Compared to the No-Intervention and MBSD cases, SSDI has the potential to substantially
  - Reduce the amount of oil and mousse on the water surface and on the shoreline
  - Increase dissolution rate of soluble & semi-soluble hydrocarbons (BTEX, PAHs and soluble alkanes) and so their degradation rate
  - Increase weathering rate of rising oil such that floating oil contains much less soluble & semi-soluble aromatics (BTEX, PAHs)
  - Decrease VOC emissions to and concentrations in the atmosphere and human and wildlife exposure
  - Reduce the concentrations of PAHs in surface waters
  - Increase the concentrations of PAHs in deep water; however, densities of biota at depth are << than near surface
Spill Scenario
- 45,000 bbl/day over 30 days decreasing by 113.1 bbl/day
- Total Release = 1,300,802 bbl
- Simulation Length = 75 days

Parameters Considered
- 4 Release Locations (680 – 2,950 m depth)
- 2 GOR’s (100 and 1,500 scf/stb)
- 2 Crude Oil types (light and medium)
- 3 Dispersant Options: none, 50% and 100% effectiveness
- 3 Hydrodynamic/wind model pairs
  - POM/ECMWF
  - ROMS/NARR
  - HYCOM/NARR

144 possible spill scenarios distilled to 72

Risk Assessment for BOEM: Similar Results & Conclusions

<table>
<thead>
<tr>
<th>Physical Parameters</th>
<th>Mars TLP 2004</th>
<th>Ship Shoal Block 269</th>
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</thead>
<tbody>
<tr>
<td>Oil Type</td>
<td>Medium</td>
<td>Light</td>
</tr>
<tr>
<td>Pour Point (°C)</td>
<td>-28°</td>
<td>-42°</td>
</tr>
<tr>
<td>API Gravity</td>
<td>26.8</td>
<td>38.7</td>
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<tr>
<td>Density at 25°C (g/cm³)</td>
<td>0.8817</td>
<td>0.8236</td>
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<tr>
<td>Viscosity (cP) @ 25°C</td>
<td>24</td>
<td>4</td>
</tr>
</tbody>
</table>
Modeling results are useful to:
- Inform response planning
- Assess risks
- Scale the expected level of impact

May use conservative assumptions to be protective of resources at risk

Quantitative, based on best information

Allows evaluation of alternatives and tradeoffs
- Response options
- Regulatory approaches
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