ADAC Project: Arctic Oil Spill Modeling

Project Principal Investigator(s):
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Supporting Team:
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Student Participation:
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Project Champion:
Kristen Trego, CG-MER

Project Advocates:
Chris Barker, NOAA Office of Response and Restoration
Project Description:

The team is supporting the USCG marine oil spill response mission through the development of arctic-capable oil spill models and the transfer of model algorithms to the GNOME model where they can be used operationally. We are focusing on near-surface spills accounting for ice concentration as well as under-ice spills accounting for under-ice roughness and under-ice storage capacity.

Baseline:

The USCG relies on the General NOAA Operational Modeling Environment ( GNOME) oil spill model and NOAA for expert guidance when responding to an oil spill. At the time our project started, NOAA’s GNOME oil spill model was not arctic-capable (e.g., it did not account for sea ice). Also, the GNOME oil spill model did not yet include an oil plume module so it could not readily address sub-surface well blowouts and subsurface pipeline ruptures. A new NOAA GNOME model, under development, deals with ice by assuming if the coverage is 20% or less, the oil moves with winds and currents. If the coverage is 80% or more, then it moves entirely with the ice. For concentrations between 20% and 80%, it interpolates linearly.
Arctic Oil Spill Modeling: Relevance and Method

Relevance to DHS and USCG:

The research being conducted to develop and transfer arctic-capable oil spill algorithms to the GNOME model supports the USCG operational needs in the event of an oil spill.

Research Methods:

ADAC developed an in-house test bed for arctic-capable oil spill modeling referred to as the Arctic Oil Spill Calculator (AOSC). AOSC was designed to mirror GNOME so algorithms developed within AOSC could be readily transferred to GNOME.

AOSC oil spill algorithms were validated with oil spill data to the extent possible, and a number of oil spill scenarios were examined.

To address subsurface spills in arctic settings, the Texas A&M Oil spill Calculator (TAMOC) was modified so input data formats were compatible with GNOME, and output from TAMOC was used to drive far-field calculations within AOSC.

The under-ice oil storage capacity is being determined based on ice stage data and it will be a new variable included in the GNOME model.
Arctic Oil Spill Modeling: Relevance and Method

Developed in Years 1-3

Arctic Oil Spill Calculator (AOSC)

Texas A&M Oil spill Calculator (TAMOC)

ADAC Models to Predict Oil Spills in Arctic Conditions

Included in GNOME in Year 4

General NOAA Operational Modeling Environment (GNOME)

AOSC
TAMOC

Operational in GNOME and used by NOAA in Year 5

NOAA Operational Forecasting Model

→ Provides Oil Spill Domain Awareness to USCG

(We are here)
• To develop the AOSC and TAMOC models for Arctic oil spills, we have defined four canonical Arctic Oil Spills:
  • Utqiagvik, Alaska surface release simulation: vessel rupture
  • Utqiagvik, Alaska sub-surface release simulation: vessel rupture
  • Northstar Island sub-surface release simulation: pipeline breach
  • Burger sub-surface release simulation: blowout

• We have also aided NOAA R&R to simulate a real petroleum release in the Arctic:
  • Gas pipeline leak in Cook Inlet
Arctic Oil Spill Modeling: Progress during Year 4

• Current (where we are now):
  • Engaging with Chris Barker, NOAA Office of Response and Restoration, to include AOSC and TAMOC in GNOME
  • 3D oil spill modeling in support of LRAUV
  • Improving integration of TAMOC with GNOME to include all oil fate processes
  • Training NOAA staff to use TAMOC within GNOME
Arctic Oil Spill Modeling: Progress during Year 4.

- Roadmap to include AOSC and TAMOC within GNOME

<table>
<thead>
<tr>
<th>Element of AOSC / TAMOC to add to GNOME</th>
<th>Programmer</th>
<th>Time Line</th>
</tr>
</thead>
<tbody>
<tr>
<td>Include <em>shorefast ice</em> by implementing time-dependent shoreline boundaries</td>
<td>NOAA</td>
<td>Mar. 2018</td>
</tr>
<tr>
<td>Create a GNOME variable for <em>ice storage capacity</em></td>
<td>NOAA</td>
<td>Jan. 2018</td>
</tr>
<tr>
<td>Develop algorithms to determine ice storage capacity based on <em>ice stage</em></td>
<td>NOAA / UAA</td>
<td>Feb. 2018</td>
</tr>
<tr>
<td>Transport the oil in GNOME according to AOSC algorithms</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>• Smooth Ice:</strong> Mover is ice or water flow (if vel. Threshold exceeded)</td>
<td>NOAA / UAA</td>
<td>Mar. 2018</td>
</tr>
<tr>
<td><strong>• Rough Ice:</strong> Mover is ice or storage overflow</td>
<td>NOAA / UAA</td>
<td>Apr. 2018</td>
</tr>
<tr>
<td>Transfer <em>particle properties</em> from TAMOC to GNOME</td>
<td>TAMU</td>
<td>Jan. 2018</td>
</tr>
<tr>
<td>Transport the oil in GNOME according to AOSC algorithms</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Train NOAA to <em>simulate our four Arctic spill scenarios in GNOME</em> using the updated AOSC / TAMOC capabilities</td>
<td>UAA / TAMU</td>
<td>May 2018</td>
</tr>
</tbody>
</table>
3D oil spill modeling in support of LRAUV

Location: Chukchi Sea, Burger site, 46 m depth

Modeling: Delft3D
- smooth ice, moving at 5 cm/s
- particle tracking approach
- particles emitted from underside of ice

Figure: 2D conc. of particles
Data: 3D conc. of particles (a proxy for 3D conc. of dissolved chem.)
Arctic Oil Spill Modeling: Progress during Year 4.

- Incorporate AOSC algorithms in GNOME and test them

Working with NOAA to develop a new variable within GNOME: under-ice storage capacity.

Ice storage capacity has been estimated at several locations in the Chukchi and Beaufort Seas, based on ice draft data.

Ice storage will be inferred based on NWS ice stage data.
Arctic Oil Spill Modeling: Progress during Year 4.

- Incorporate AOSC algorithms in GNOME and test them

Analysis of ice draft data at locations to determine ice storage capacity.
Arctic Oil Spill Modeling: Progress during Year 4.

- Incorporate AOSC algorithms in GNOME and test them

Using ice stage data at locations to determine relationship between ice stage (predicted) and ice storage capacity (needed).
Arctic Oil Spill Modeling: Progress during Year 4.

- Incorporate AOSC algorithms in GNOME and test them

Converting far-field density current oil spill model output into particle tracking format used by GNOME.

Integration of other AOSC algorithms into GNOME

Case 3: Moving ice, with rough bottom

Assumptions:
- fluid velocity = 0
- ice velocity = \( U_{\text{ice}} \)
- \( d \) = ave. oil thickness under ice.

Stagnation point analysis:
- \( U_{\text{fluid}} = U_{\text{ice}} = \frac{Q}{2\pi rd} \)
- \( b = \frac{Q}{2\pi d U_{\text{ice}}} \)
- \( L = \frac{Q}{d U_{\text{ice}}} \)
Arctic Oil Spill Modeling: Progress during Year 4.

- Transition TAMOC to operation within GNOME

Developed methods to estimate TAMOC
Inputs from data available in GNOME

\[ \Delta H_{\text{gas} \rightarrow \text{water}} \]

\[ r^2 = 0.97 \]

\[ K_{\text{salt}} \]

\[ r^2 = 0.83 \]

Gros et al., *ES&T*, 2016.
Arctic Oil Spill Modeling: Progress during Year 4.

- **Transition TAMOC to operation within GNOME**

  TAMOC operates in GNOME –
  Initiate a TAMOC simulation, get the results, and pass TAMOC particles to GNOME.
Arctic Oil Spill Modeling: Progress during Year 4.

- Conduct laboratory experiments for spill / surface interaction
Arctic Oil Spill Modeling: Progress during Year 4.

- Coordinate with NOAA to run Arctic oil spill scenarios with TAMOC inside GNOME

Cook Inlet gas pipeline leak

- Percentage of gas dissolved during ascent = 16%
- Volume of water brought to sea surface = 11 m³/s
- Predicted pipeline hole size agreed with observation during repairs
### Arctic Oil Spill Modeling: Schedule and Metrics

<table>
<thead>
<tr>
<th>UAA Schedule</th>
<th>Progress</th>
<th>Metrics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Develop roadmap to transition AOSC and TAMOC to operation within GNOME</td>
<td>Complete</td>
<td>TAMOC and AOSC run in GNOME</td>
</tr>
<tr>
<td>Program AOSC in Python</td>
<td>Ongoing</td>
<td>AOSC runs in GNOME</td>
</tr>
<tr>
<td>Incorporate AOSC algorithms in GNOME and test them</td>
<td>Ongoing</td>
<td>Run 3 of 3 scenarios</td>
</tr>
<tr>
<td>Train personnel from NOAA R&amp;R to use AOSC within GNOME</td>
<td>Pending</td>
<td>Train 2 persons</td>
</tr>
<tr>
<td>Generate and format inputs for use in AOSC (ice dispersion, HIOMASS)</td>
<td>Ongoing</td>
<td>Accomplish</td>
</tr>
<tr>
<td>Develop protocols to provide data to GOODS website</td>
<td>Pending</td>
<td>Provide 3 data feeds</td>
</tr>
<tr>
<td>Update Arctic coastline on GOODS website</td>
<td>Pending</td>
<td>Complete for 500 km</td>
</tr>
<tr>
<td>(Conduct laboratory experiments)</td>
<td>(Optional)</td>
<td>(Conduct 1 experiment)</td>
</tr>
</tbody>
</table>
## Arctic Oil Spill Modeling: Schedule and Metrics

<table>
<thead>
<tr>
<th>TAMU Schedule</th>
<th>Progress</th>
<th>Metrics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Develop roadmap to transition AOSC and TAMOC to operation within GNOME</td>
<td>Complete</td>
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<td>Conduct laboratory experiments for spill / surface interaction</td>
<td>Ongoing</td>
<td></td>
</tr>
<tr>
<td>Coordinate with NOAA to run Arctic oil spill scenarios with TAMOC inside GNOME</td>
<td>Ongoing</td>
<td>Sample scripts included in GNOME distribution</td>
</tr>
<tr>
<td>Validate TAMOC and AOSC to new laboratory data</td>
<td>Pending</td>
<td>Match measured flow rate, depth, and mean density</td>
</tr>
<tr>
<td>Establish protocols to maintain TAMOC within GNOME</td>
<td>Pending</td>
<td>TAMOC included with GNOME</td>
</tr>
<tr>
<td>Train personnel from NOAA R&amp;R to use AOSC within GNOME</td>
<td>Pending</td>
<td>2 persons trained</td>
</tr>
</tbody>
</table>
Arctic Oil Spill Modeling: Planned Research Outcomes

• Include all of the AOSC algorithms within GNOME
• Include the TAMOC model as the subsurface element of GNOME
• Include sample simulations within the GNOME distribution for all four Arctic Oils Spill Scenarios used within ADAC to test and develop AOSC and TAMOC
• Train the NOAA R&R Personnel to use the AOSC and TAMOC products within GNOME during Arctic Oil Spill Response.

After these outcomes are complete, NOAA will use ADAC products within GNOME to forecast oil fate and transport during Arctic Oil Spills, giving USCG domain awareness during oil spills using Arctic capable products.
Arctic Oil Spill Modeling: Transition Plans

- **Code** the AOSC algorithms in the GNOME programming environment
  - The team led by Chris Barker (NOAA R&R) is doing this under guidance of PI Ravens and his research staff

- **Simulate** subsurface aspects of oil spills in GNOME using TAMOC
  - TAMOC has already become part of GNOME
  - PI Socolofsky and his research staff are improving and testing the integration of TAMOC with GNOME

- **Use** the updated GNOME model to simulate our four canonical Arctic Oil Spill Scenarios

- **Train** NOAA R&R staff to utilize ADAC algorithms when running GNOME

Once complete, the NOAA GNOME model, which provides USCG oil trajectory forecasts during oil spills, will operate using the complete ADAC-developed modeling components
Feedback...

- What are we missing?
- What can we improve?
- Who should we connect with to improve odds of research success?
Prior guidance / suggestions to NOAA:

**On movement of oil on surface:**

Oil moves with winds and currents if ice concentration is less than 20%

Oil moves with ice if ice concentration is greater than 80%

For ice concentrations between 20% and 80%, linearly interpolate.

**On spreading of oil on surface with different concentrations of ice:**

Rate of oil spreading decreases linearly with increasing ice coverage.

The graph compares the total area of a spill in open water as it increases over time for different spill volumes. To calculate the spill area when ice is present, the open water area of the spill is multiplied by the fraction of open water.

Ex: for a 1,000 m² spill, after 30 hrs (roughly 1 day) the open water spill area is 10 km². If the ice concentration is 6/10, the actual area of the spill is $10^*0.6 = 4$ km²
Prior validation of AOSC random walk algorithms (for predicting movement and spreading):

Random-walk algorithms for spreading of oil on the surface based on the Arctic Oil Spill Calculator (AOSC) and based on GNOME.

AOSC output

 GNOME output

Agreements indicates that ADAC was able to reproduce the GNOME spreading projections (case shown assumes no ocean current, no wind, and a diffusion coefficient of $10^6$ m$^2$/s)
Prior validation of AOSC performance for surface releases:

Comparison of AOSC output with observations from a 2009 experimental spill in the Barents Sea in marginal ice conditions (~80%):

- Spill volume 7 m³
- Duration of experiment: 6 days
- Mover was ice drift

![Observed Trajectory vs AOSC Calculated Trajectory](image)
Prior validation of AOSC performance for surface releases:
Prior density current modeling based on output of TAMOC plume model:

Case 1 (shown on left):
- Stagnant water and ice,
- Smooth ice

Case 2:
- Stagnant water and ice,
- With under-ice roughness

Case 3:
- Moving water and ice,
- With smooth and roughened ice
Arctic Oil Spill Modeling: Relevance and Method

Case 1: stagnant water/ice and smooth ice

\[ g' = \frac{\Delta \rho}{\rho} g \]

\[ \frac{U}{\sqrt{g' h}} = Fr \approx 0.7 \]

\[ Q = U A = U 2\pi r h \]

\[ h(r) = \left[ \frac{Q}{2\pi r (0.7) \sqrt{g'}} \right]^{2/3} \]

assuming:
\[ g' = 0.0054 \text{ m/s}^2, \]
\[ Q = 300 \text{ m}^3/\text{s} \]
Arctic Oil Spill Modeling: Relevance and Method

Prior density current modeling based on output of TAMOC plume model:

Case 2: Stagnant water and ice with under-ice roughness

**Assumptions:**
- Density current moves radially from its center, filling the cavities in the under-side of the ice.
- Effective depth of under-side of ice subject to oil flow:
  \[ d = \frac{V_{\text{void}}}{\text{Area}} \]
- Effective fluid velocity:
  \[ U = \frac{Q}{2\pi rd} \]
- If \( d < h \), calculate \( U \) based on \( h \) instead.
Case 3: Moving ice, with rough bottom

Assumptions:
- Fluid velocity = 0,
- Ice velocity = \( U_{ice} \),
- \( d = \text{ave. oil thickness under ice.} \)
- Stagnation point analysis:
  - \( U_{fluid} = U_{ice} = \frac{Q}{2\pi rd} \)
  - \( b = \frac{Q}{2\pi d U_{ice}} \)
  - \( L = \frac{Q}{d U_{ice}} \)

View of under-side of ice from below:
- Plume source
- Stagnation point
- \( U_{ice} \)
Prior case studies using AOSC

Utqiagvik, Alaska surface release simulation: vessel rupture
- 120,000 m³ (750,000 barrels) released in 1 day
- Release depth 0 m (0 ft)
- Oil only
- Immediate slick formation

Utqiagvik, Alaska sub-surface release simulation: vessel rupture
- 120,000 m³ (750,000 barrels) released in 1 day
- Release depth 45.7 m (150 ft)
- Oil only
- Maximum stable droplet size
Prior case studies using AOSC

Northstar Island sub-surface release simulation: pipeline breach
- 10,000 bbl per day
- Release depth 14.9 m (49 ft)
- Oil only
- Jet droplet size distribution

Burger sub-surface release simulation: blowout
- 23,100 bbl per day
- Release depth 45.7 m (150 ft)
- GOR of 450
- Jet droplet size distribution
Gas leak in Cook Inlet

- Simulated real scenario of a natural gas leak
- 0.0714 m³/s
- Pure gas
- Estimate leak hole size -> agreed with measurements during repair
- Predicted that 16% dissolved; 84% released to atmosphere/ice cover
Arctic Oil Spill Modeling: Relevance and Method

Current (where you are at):

- 3D oil spill modeling in support of LRAUV,
- Engaging with Chris Barker, Office of Response and Restoration, to implement transfer of AOSC algorithms into GNOME,
- Conversion of TAMOC data input format so that it is compatible with GNOME
- Training of NOAA staff in the use of TAMOC within GNOME