First Annual Partners' Meeting

Oil Spill Modeling for the Bering, Chukchi, and Beaufort Seas

Arctic Domain Awareness Center (ADAC)
A DHS Center of Excellence

ADAC
ARCTIC DOMAIN
AWARENESS CENTER
A DEPARTMENT OF HOMELAND SECURITY CENTER OF EXCELLENCE
at UAA UNIVERSITY *of* ALASKA ANCHORAGE

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Overview:

- The Coast Guard relies on the GNOME oil spill model and NOAA for expert guidance when responding to an oil spill.
- The existing GNOME oil spill model is not arctic-capable (e.g., it does not yet account for ice).
- ADAC has engaged with NOAA’s leading oil spill modelers (Glen Watabayashi and Catherine Berg) and has begun to give guidance on ways to incorporate ice into GNOME.

Accomplishments:

1. Review of 30 relevant research publications on oil spill – with a focus on research on oil spills in the Arctic.

2. Engagement and communication with NOAA experts on recommended approaches to account for the presence sea ice in oil spill modeling.

3. Mastery of GNOME oil spill model and communication of its use for oil spill and ship drift.

4. Identification of a suitable MS Thesis topic in the general area of arctic oil spill modeling.

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Accomplishment 1 *[review of publications]*

ASCE, 1996: ASCE Task Committee on Modeling of Oil Spills of the Water Resources Engineering Division. ASCE Journal of Hydraulic Engineering, 122, 594-609.

Beagle-Krause, C.J., H. Simmons, M. McPhee, R. Lundmark Daae, M. Reed. 2013. Fate of Dispersed Oil Under Ice, Report 1.4. Prepared for the American Petroleum Institute and the Joint Industry Program on Oil Spill Recovery in Ice. p58

Berger, D. and D. Mackay, 1994. The Evaporation opf Viscous or Waxy Oils – When is a Liquid Phase Resistance Significant? In Proceedings of the Seventeenth AMOP Technical Seminar. Environment Canada, Ottawa. Pp 77-92.

Brandvik, P.J., and L.-G. Faksness. 2009. Weathering processes in Arctic oil spills: Meso-scale experiments with different ice conditions. Cold Regions Science and Technology 55: 160-166.

Buist, I., Belore, R., Guarino, A., Hackenberg, D., Dickins, D., & Wang, Z. (2009). Empirical weathering properties of oil in ice and snow. Proceedings of the 32 AMOP technical seminar on environmental contamination and response Volume 1, (p. 940). Canada: Environment Canada.

Buist, I., and D. Dickins. 1987. Experimental spills of crude oil in pack ice. Proceedings 1987 International Oil Spill Conference. American Petroleum Institute. Washington.

Chen, E., B. Keevil and R. Ramsier, 1976. Behaviour of Crude Oil Under Fresh Water Ice. Journal of Canadian Petroleum Technology. Vol. 15, pp 79-83.

Cox, J.C. and L.A. Schultz, 1980.The Transport and Behaviour of Oil Spilled Under Ice. Proceedings of the Third Arctic Marine Oilspill Program Technical Seminar, Environment Canada, Ottawa, pp 45-61.

Cox, J.C. and L.A. Schultz, 1981.The Containment of Oil Spilled Under Rough Ice. Proceedings of the 1981 International Oil Spill Conference. API. Washington. Pp 45-61.

Dickins. D.F., Brandvik, P.J., Bradford, J., Faksness, L-G., Liberty, L. and R. Daniloff, May 2008. Svalbard 2006 Experimental Oil Spill Under Ice: Remote Sensing, Oil Weathering Under Arctic Conditions and Assessment of Oil Removal by In-situ Burning. Paper accepted for presentation at the 2008 International Oil Spill Conference, Savannah, Georgia.

Drozdowski, A., S. Nudds, C.G. Hannah, H. Niu, I. Peterson, and W. Perrie. 2011. Review of Oil Spill Trajectory Modelling in the Presence of Ice. Canadian Technical Report of Hydrography and Ocean Sciences 274. Fisheries and Oceans Canada and Bedford Institute of Oceanography, Dartmouth, NS.

Fay, J.A. 1969. The spread of oil slicks on a calm sea. Fluid Mechanics Laboratory, Department of Mechanical Engineering, Massachusetts Institute of Technology, Cambridge,Massachusetts.

Fingas, M.F. & Hollebone, B.P. 2003, "Review of behaviour of oil in freezing environments", Marine pollution bulletin, vol. 47, no. 9, pp. 333-340.

Gjøsteen, J. K. Ø., and Løset, S. (2004). "Laboratory experiments on oil spreading in broken ice," *Cold Regions Science and Technology*, 38(2-3), 103-116.

Gjøsteen, J. K. Ø. (2004). "A model for oil spreading in cold waters," *Cold Regions Science and Technology*, 38(2-3), 117-125.

Glaeser, J.L., Vance, G., 1971. A study of the behavior of oil spills in the arctic. Report Number 714/08/A/001,002, United States Coast Guard, Washington, DC.

Kawamura, P., D. Mackay and M. Goral. 1986. Spreading of chemicals on ice and snow. Report to Environment Canada, EETD, Ottawa.

McMinn, T.J. (1972). "Crude oil behaviour on arctic winter ice," *Project 734108*, United States Coast Guard, Washington, DC, 1-75.

NORCOR Engineering & Research. 1975. The Interaction of Crude Oil with Arctic Sea Ice. Beufort Sea Technical Report #27.

Potter, S., I. Buist, K. Trudel, D. Dickins, and E. Owens. 2012. Spill Response in the Arctic Offshore, edited by D. Scholz. Prepared for the American Petroleum Institute and the Joint Industry Program on Oil Spill Recovery in Ice. American Petroleum Institute, Washington, DC, 157 pp.

Puskas, J., McBean, E., and Kouwen, N. (1987). "Behaviour and transport of oil under smooth ice," *Canadian Journal of Civil Engineering*, 14, 510-518.

S. L. Ross Environmental Research Limited, and D. F. Dickins Associates Limited (1987). "Field Research Spills to Investigate the Physical and Chemical Fate of Oil in Pack Ice," *Report No. 062*, Environmental Studies Revolving Funds, Environment Canada.

Stiver, W. and D. Mackay. 1983. Evaporation rate of spills of hydrocarbons and petroleum mixtures. Environmental Protection Service, Environment Canada, Report EE-8. Ottawa.

Tebeau, P.A., T.M. Meehan and J.C. Myers. 1982. A laboratory experiment on oil weathering under Arctic conditions. U.S. Coast Guard Report CG-D-34-82. Washington.

Uzuner, M.S., Weiskopf, F.B., Cox, J.C., and Schultz, L.A. (1979). "Transport of oil under smooth ice," *EPA-600/3-79-041*, Environmental Protection Agency, Corvallis, OR, 1-62.

Venkatesh S., El-Tahan, H., Comfort, G., and Abdelnour, R. (1990). "Modelling the Behavior of Oil Spills in Ice-infested Water," *Atmosphere-Ocean*, 28(3), 303- 329.

Weerasuriya, S.A., and Yapa, P.D. (1993). "Unidirectional spreading of oil under solid ice," *Canadian Journal of Civil Engineering*, 20(1), 50-56.

Word, J., M. Pinza, W. Gardiner. 2008. Literature Review of the Effecs of Dispersed Oil with Emphasis on Cold Water Environments of the Beufort and Chuckhi Seas. Prepared for Shell Global Solutions. 117 pp.

Yapa, P.D., and Chowdhury, T. (1990). "Spreading of oil spilled under ice," *Journal of Hydraulic Engineering*, ASCE, 116(12), 1468-1483.

Yapa, P.D., Dasanayaka, L.K., Shen, H.T., and Shen, H.H. (2006). Modeling oil transport and spreading in icy waters. Report Submitted to CRRC, December 2006, Department of Civil and Environmental Engineering, Clarkson University, Potsdam, NY, 119 pp.

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Accomplishment 2 [engagement with NOAA]

Semester-long review of oil spill modeling with focus on the Arctic

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Presentation to NOAA Office of Emergency Response and Restoration [Glen Watabayashi and Catherine Berg

Review of GNOME and preliminary discussion of oil spill modelling of the Bering, Chukchi, and Beaufort Seas

The frequency, area, and duration of open waters in the arctic is increasing as has the ability to navigate and prospect oil in the region. The potential for oil spills requires the ability to model oil spills in the region to aid in oil recovery. One such tool used by National Oceanographic Association, NOAA, is the oil trajectory model Global NOAA Operational (or Oil) Modeling Environment, GNOME, and fate model Automated Data Inquiry for Oil Spills, ADIOS2, which is being integrated into GNOME.

GNOME does an excellent job modelling the trajectory of oil in open waters. The model has been used successfully in hundreds of spills across the United States; however, in Alaska, its capabilities are limited by the lack of local knowledge, sparse data, and knowledge of how spills behave in the Arctic.

Local knowledge of the environmental conditions such as the location of local seeps, the quantity of bacteria available in a given season, the salinities, sediment loads, and coastlines are all important factors understanding what will happen during a spill.

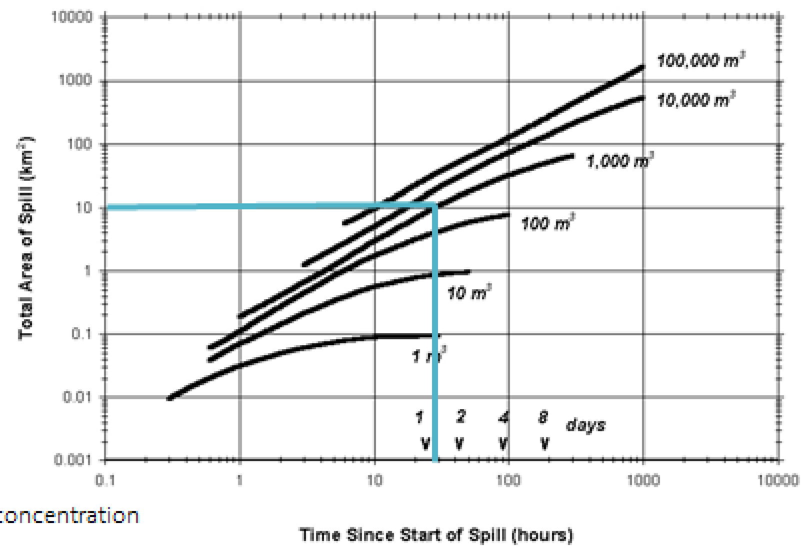
While Alaska is the largest state geographically, it does not have a corresponding quantity of data. GNOME is heavily reliant on input data, real-time and forecast. Alaskan data sources need to be fully understood so that in the event of a spill the best data can located, be input into the model, and the results properly interpreted. Accurate and up-to-date surface currents of oceans, lakes, and rivers, winds, and ice conditions are important factors in modelling oil spills in the Arctic.

Finally, the trajectory and fate of oil will be influenced by Arctic conditions. The cold climate and the presence of ice will affect how oil behaves, weathers, and moves. The effects of climate and ice and oil need to be understood. A summary of some of these processes can be seen in figure 1.

Converting GNOME to an arctic capable model

Accomplishment 2 [engagement with NOAA, *continued*]

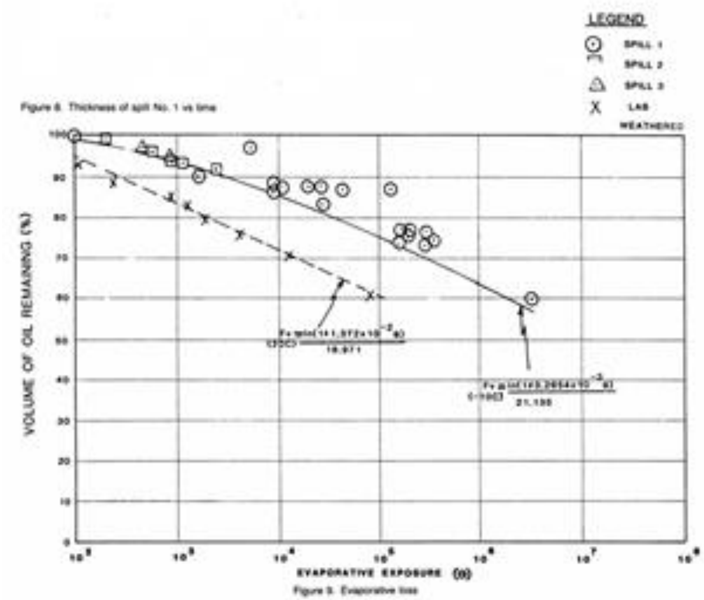
Spreading in pack ice: empirically



0-30% Open water
30-90% Linear decrease with increasing ice concentration
90+ Oil in ice

Accomplishment 2 [engagement with NOAA, *continued*]

Evaporation in drift Ice



Mass transfer coefficients

Evaporation on Ice, Under Snow and Among Drift Ice after Stiver and Mackay (1983)

$$F_v = \ln\left[1 + \frac{BT_G}{T}\theta \exp\left(A - \frac{BT_0}{T}\right)\right]\frac{T}{BT_G}$$

Where: F_v ≡ volume fraction of the oil evaporated
T_0, T_G ≡ the intercept and slope of the modified ASTM distillation [°K]
T ≡ environmental ambient temperature [°K]
B, A ≡ dimensionless, oil-specific constants equal to the least-squares slope and intercept of a plot of the natural logarithm of the Henry's Law constant (H = Pv/RT, which is numerically equal to the slope of the tangent to the curve of a plot of F_v vs. θ at the given point) vs. T_b/T
T_b ≡ boiling point of weathered crude oil at atmospheric pressure [°K]
P ≡ vapor pressure of the weathered crude oil [Pa]
v ≡ liquid's molar volume [m^3/mol]
R ≡ gas constant 8.314 [Pa m^3/mol °K]
$\bar{\theta}$ ≡ dimensionless evaporative exposure
= kAt/V_0 = kt/x
k ≡ mass transfer coefficient [m/s]
A ≡ area of slick [m^2]
t ≡ elapsed time since oil release [s]
V_0 ≡ initial volume of oil released [m^3]
x ≡ slick thickness [m]

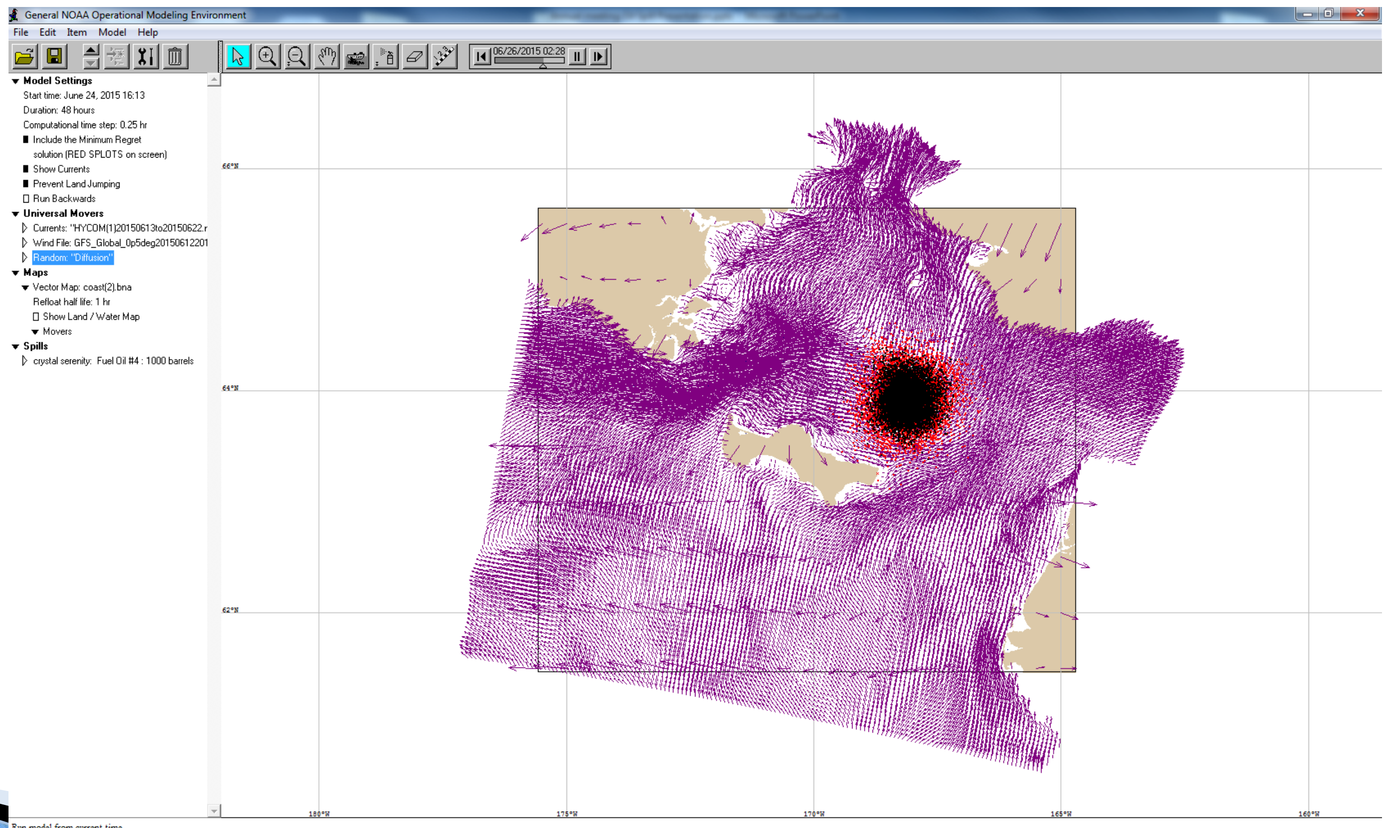
And, for the mass transfer coefficient used to calculate θ:

$$\frac{1}{k_T} = \frac{1}{k_a} + \frac{K_{oa}}{k_o} + \frac{z}{D_s}$$

Where: k_T ≡ overall mass transfer coefficient [m/s]
k_a ≡ air side mass transfer coefficient [m/s]
k_o ≡ liquid phase mass transfer coefficient [m/s]
K_{oa} ≡ air-oil partition coefficient
k_o/K_{oa} = 0.001 m/s
D_s ≡ diffusivity of oil vapor in snow [m^2/s]
= 2×10^{-5} m^2/s
z ≡ thickness of snow [m]

Accomplishment 3 [Mastery of GNOME Oil Spill model]

- Here, add snap shot of video of GNOME model in action.



Accomplishment 4 [identification of a suitable topic for a MS Thesis]

Simulation of an under ice release of oil – accounting for under-ice roughness

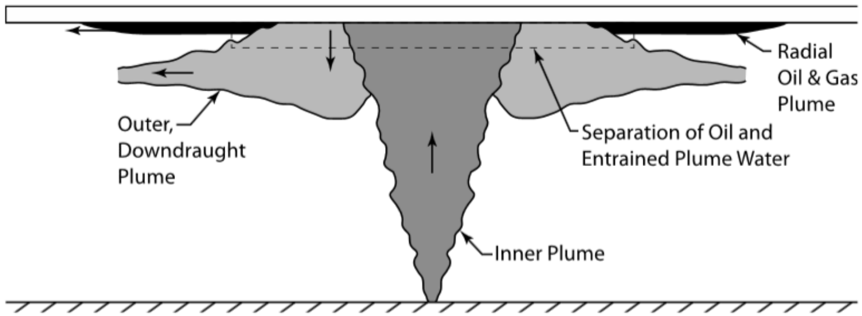
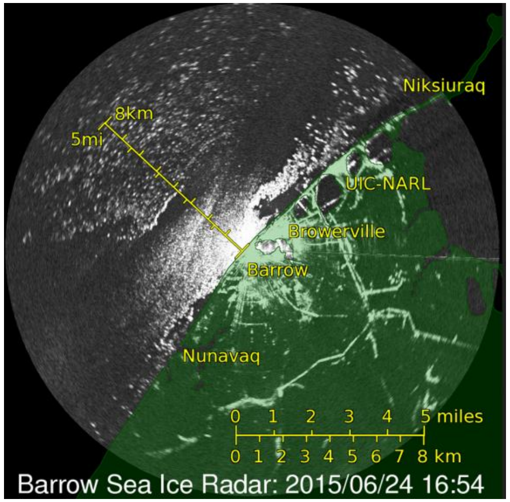
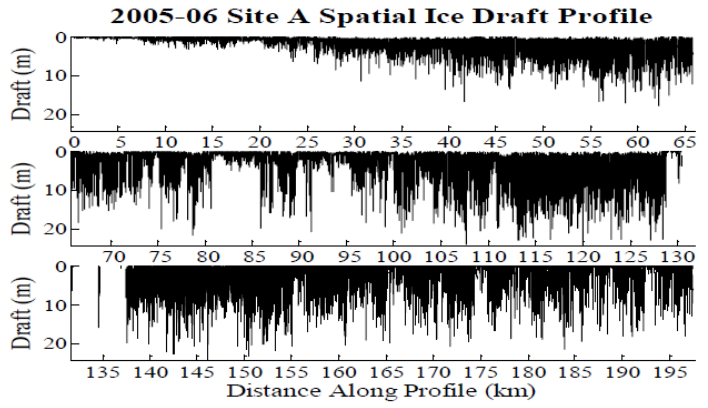
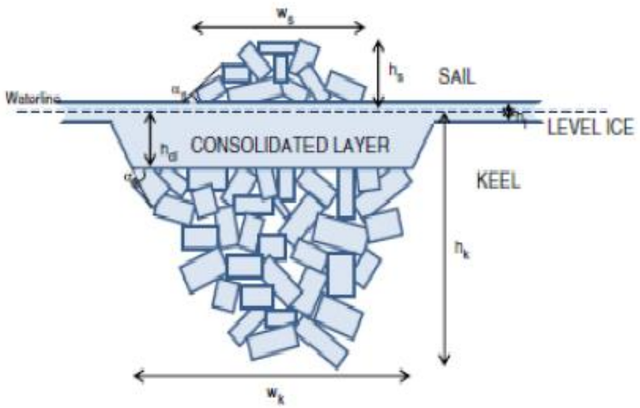


Figure 1. Schematic of a subsea blowout in shallow water under ice cover. Oil and gas rise through the inner plume and impact the ice surface, which deflects the oil and gas laterally, eventually forming a radial plume of oil and gas at the water and ice interface. A separated plume of dissolved hydrocarbons forms an intrusion (outer plume) below the surface.







Metrics:

- **Metrics**
- Number of reviews of studies on oil fate and transport in the arctic; incorporation of arctic oil fate and transport data within GNOME. Range: 10 studies reviewed to 30 studies reviewed.
  - **30 studies reviewed**
- Level of improvement in resolution of GNOME model relative to conventional GNOME model. Resolution will go from 4 km to a target of 2 km.
  - **To be covered in year 2 in partnership with Jinlun Zhang UW**

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Milestones achieved

- Completed review of studies of oil fate and transport in the arctic. Provide guidance to NOAA on how to incorporate oil weathering, bio-degradation, dispersion, etc. within the arctic GNOME model. Identify gaps in knowledge. Also provide guidance to NOAA Office of Response Restoration on how to incorporate ice conditions within GNOME. Years 1 and 2.
- **ACHIEVED in year 1 – will continue in year 2.**
- Completed development of the "Diagnostic Save Files" (or location files) using the high-resolution ocean currents and sea ice conditions generated from the Univ. of Washington ocean/sea ice modeling effort. Year 2.
- **Year 2.**
- Perform successful runs of GNOME model using the high resolution Diagnostic Save Files and compare output with that generated with conventional Diagnostic Save Files. Year 2.
- **Year 2.**

Stakeholders

Key Stakeholder Engagement

- Mr. Kurt Hansen and Mr. Richard I Hansen from the USCG R&D Center, Mr. James Robinson and Mr. Mark Everett (US Coast Guard, 17th Coast Guard District), and Glen Watabayashi (NOAA Office of Response and Restoration).
- **Have identified and engaged with Glen Watabayashi. Have reached out to Mr. Hansen and Mr. Hansen. TO DO!**

Gaps and lessons learned.

- **Lessons Learned:**
- **It is extremely valuable to reach out to stakeholders.**
- **It is extremely valuable to engage with researcher outside of the inner ADAC circle.**

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Next steps

- Continue to engage with NOAA Office of Response and Restoration.
- Provide additional suggestions on how to make GNOME Arctic-capable.
- Assist NOAA with GNOME development by trying out the new version of GNOME underdevelopment.
- Continue to engage with USCG R&D Center.
- Support NOAA by pursuing the under-ice oil spill modeling work.