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May 16, 2014

Tanker Safety Panel Secretariat
330 Sparks Street, Place de Ville Tower C (AAM)
Ottawa, ON K1A 0N5

To the Tanker Safety Panel Secretariat,

On Behalf of the Arctic Oil in Sea Ice Group, Centre for Earth Observation Science (CEOS), I am pleased to submit the analysis below entitled "Research Gaps in Scientific Understanding of Oil in Sea Ice" to the Tanker Safety Expert Panel. This submission presents what we identify as a gap in the science required to create world-leading regulations for safe tanker transportation in Canada's Arctic. It reviews the current state of knowledge surrounding the detection, impacts and mitigation of oil in sea ice, and discusses areas where further research is required to inform regulations. It is suggested that oil spill detection research center around satellite remote sensing, particularly using synthetic aperture radar (SAR) techniques. Innovative approaches to mitigation and remediation of oil spills should include research into bioremediation and the use of cold-adapted microbes. Centering research efforts in these areas are suggested in order to ensure minimal impacts from an oil spill in Arctic waters. You are welcome to post this submission.

Our research group would welcome the opportunity to discuss this issue further with your Panel.

Sincerely,

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Research Gaps in Scientific Understanding of Oil in Sea Ice

Submitted to the Tanker Safety Expert Panel – Phase 2

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Executive Summary:
The University of Manitoba is host to a sea ice research group with expertise in the detection, impacts and mitigation of oil in sea ice. The CEOS group interacts with several other Arctic research teams both nationally and internationally and has worked extensively with the oil and gas and marine transportation industry in the Canadian Arctic. This submission presents what we identify as a gap in the science required to create world-leading regulations for safe tanker transportation in Canada's Arctic. It reviews the current state of knowledge surrounding the detection, impacts and mitigation of oil in sea ice, and discusses areas where further research is required to inform regulations. It is suggested that oil spill detection research centre around satellite remote sensing, particularly using synthetic aperture radar (SAR) techniques. Innovative approaches to mitigation and remediation of oil spills should include research into bioremediation and the use of cold-adapted microbes. Centering research efforts in these areas are suggested in order to ensure minimal impacts from an oil spill in Arctic waters.

Overview of Oil in Sea Ice Research:

In the context of a changing climate, the industrial development of the Arctic, and in particular the shipping, exploration or development of hydrocarbon resources have created an urgent need to advance scientific and societal ability to monitor and react to a potential release of oil, natural gas, and other contaminants in Arctic waters. Whether it occurred in Canadian or International waters, a "worst-case" spill such as a tanker rupture or well-head blowout will negatively affect the pan-Arctic marine ecosystem. Large scale circulation of the Arctic means that it is likely that oil or contaminants associated with an oil spill would eventually reach Canadian waters (Figure 1). However, there is very limited knowledge of how marine ecosystems will be affected by the presence, composition, and dispersion of contaminants such as petroleum hydrocarbons, and chemicals used for clean-up such as dispersants and herding agents. Further, development of technologies that would be able to help detect oil in ice, and cold-adapted bioremediation technologies are in their infancy.

Figure 1 – Schematic representation of sea ice extent and motion. (Barber et al., *in review*)

To date, much of what we know about the behavior of oil in Arctic waters under varying ice conditions and response operations for any large spill or worst-case spill scenarios has been the result of our ability to conduct experimental oil spills field trials. Canada has benefited from this work even though a majority of it has been conducted in other Arctic countries (Dickins, 2011; http://www.arcticresponsetechnology.org). However, acquiring permits for further field experiments has become increasingly difficult both in Canada and abroad. For example, after hosting the three most recent major oil spill field experiments, Norway has cooled to the idea of conducting any further studies in its waters at least in the near future. Canada must continue or increase its participation in the Arctic oil spill research and development for there is an urgent need for further develop oil spill field demonstrations, trials and tests in order to determine key response operations and to establish our national capacity.

Over the years, limited tank trials have been conducted at national and international facilities such as the US Army Cold Regions Research and Engineering Laboratory (CRREL), Ohmsett, and Stiftelsen for industriell og teknisk forskning (SINTEF) to study everything from the development of remote sensing based detection technologies, effectiveness of herding agents, to the effective burning of crude oil between ice blocks and the effects of emulsification of burning (http://www.arcticresponsetechnology.org). While these studies have all provided extremely valuable information, the results have not been thoroughly tested in real Arctic oil spill conditions as they lack Arctic ambient conditions.

Understanding the fate of oil in sea ice and in the surrounding seawaters and biota is essential for the conduct of environmental risk assessments, the development of oil spill countermeasures, detection using under-ice, within ice and above ice remote sensing technologies, apportioning responsibility, and the monitoring of habitat recovery in the event of a spill. Under lower temperatures, oil becomes highly viscous and does not spread as easily as it would in warmer, ice-free water. Depending on the timing of a spill, oil may become encapsulated as ice grows (Bobra and Fingas, 1986), creating new vectors for spill movement, weathering, and fate. The movement of oil on or under ice is largely dictated by the roughness of the ice interface and can be tracked using the buoys deployed on the ice floes (Goodman, 1978). Furthermore, oil weathering rates are slower due to lower evaporation losses and, for oil spilled under sea ice, a decrease in the rate of emulsification stemming from reduced wave-action compared to open-water conditions. Snow and ice tend to reduce oil spreading and weathering. Figure 2 illustrates possible scenarios for the presence of oil in ice and snow.

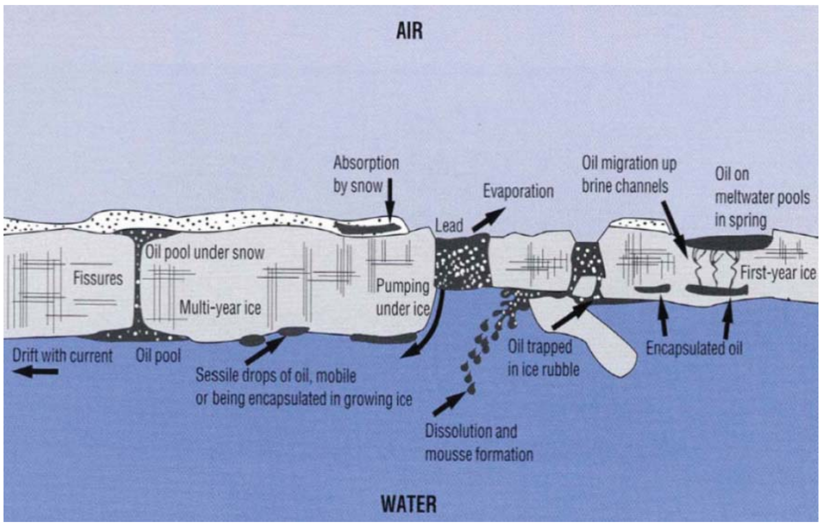

Figure 2: Oil behavior in ice-affected water (Allen (2008) adapted from Bobra and Fingas (1986)).

The thickness of oil spilled on ice depends on the surface roughness, with thicker oil being retained in depressions and irregularities in the ice (Fingas, 2011). The resulting oil layer is typically about 2 cm thick, but can be over 30 cm thick in areas where the oil is contained by ice deformation features such as rafting and pressure ridges (Dickins and Buist, 1999; Fingas and Hollebone, 2003). Oil may spread along the ice-snow interface and approximately 25% of the oil may be absorbed into dry snow cover. Under high wind conditions the oil-snow mixture may be distributed over large distances. We also expect that oil will affect both the thermodynamic and complex dielectric constant of the snow covered sea ice system (Barber, 2005)

For accidental release under ice, the nature and fate of the oil depends on ice conditions within the water column and at the surface. Under solid ice cover, oil forms a relatively thick layer (on the order of a few centimeters), which pools in undulations on the underside of the ice. Oil movement is impeded by the interface roughness and may remain relatively localized. Studies have found that a current with an approximate speed of 0.5 m/s is required to force the oil out of undulations (Dickins and Buist, 1999; Fingas and Hollebone, 2003). If the oil is accompanied by an abundance of natural gas, the buoyant force resulting from gas build-up may crack the ice cover allowing oil to flow onto the ice surface (Fingas and Hollebone, 2003). The ultimate fate of the oil is dictated by ice behavior. If the ice breaks up, the oil will be carried along with the floes (Deslauriers *et al*. 1977). The oil may then be distributed into the water through tidal and wind action on the broken ice.

Spilled oil during winter freeze-up becomes encapsulated in the growing ice sheet within approximately two days (Buist *et al*. 1983), occurring more quickly under first-year ice than under multi-year ice. Oil migrates to the surface in spring when the ice warms and brine channels open (Potter *et al*. 2012). Once at the surface, oil floats on the melt pools and, due to the low rate of weathering, it is relatively “fresh”. Under conditions where atmospheric temperatures are reasonably warm (>-15°C) and a thick snow cover exists, brine drainage channels can form (Barber, 2005), thereby creating the potential for oil entrainment into the sea ice even in winter.

Not surprisingly, the behavior and fate of oil in pack ice is heavily influenced by the concentration of ice cover. The presence of close-pack ice (i.e., an ice-to-surface ratio greater than 6/10) reduces the spread of oil and the spill will be thicker. This contained oil moves with the ice floes. As ice concentration decreases the oil behavior changes, approaching that of an open-water spill for ice concentrations less than 3/10. Oil spreads more freely as ice concentration decreases (Dickins and Buist, 1999). Oil spreading between broken ice is influenced by slush and brash ice. While light hydrocarbons surface to the water-air interface, heavier components will incorporate into the slush and brash ice (Dickins, 2011). In turn, lighter hydrocarbons are more readily evaporated than the heavier components, which are suspended in the slush. Local, regional and hemispheric circulation of sea ice (Barber et al. 2014) promotes the trajectory of oil spills in sea ice and the presence/absence of ice changes the wave climatology of the marine system affecting dispersion modeling.

Areas Requiring Additional Research

While we have some understanding of how oil behaves in ice-affected waters, we have a very limited knowledge of how we would detect it if it was released into this environment. Optical remote sensing techniques are of limited utility in the Arctic due to limited light for much of the year, and the frequent presence of cloud. Underwater sonar and hyperspectral techniques (using autonomous underwater vehicles), as well as synthetic aperture radar (SAR) and ultraviolet techniques (using satellite remote sensing) show promise as technologies for oil spill detection in the Arctic, but further study is necessary to understand how these technologies could be deployed to detect oil in a variety of ice conditions.

Currently, there is very limited study of chemical fate, partitioning and associated toxicity of fresh, evaporated, emulsified crude oils, distillate, fuel oils, herding agents, dispersants and residues generated in, and across the sea ice environment. There is a need to examine the potential toxic effects of these contaminants to determine thresholds for impairment and severity of impacts on natural assemblages of biota and to capture the myriad of possible ecological mechanisms (e.g., predator-prey interactions, trophic interactions) of adverse effects (i.e., indirect effects of contaminants) and recovery. Results of studies into these areas would inform decision-making through the development of an oil spill Environmental Sensitivity Index (ESI) to assess, forecast, and mitigate oil spill impacts, as well as predicting oil and oil dispersant fate, food web bioaccumulation, and acute and chronic toxicity from the individual to the ecosystem level in Arctic systems.

For any worst-case spill scenario, dispersants are considered by industry to be a primary countermeasure. Dispersants provide environmental protection from spilled oil by dispersing oil slicks into the water column, where they can then be more quickly diluted and degraded. Since the early 1980's, a significant amount of research has been conducted into studying dispersant effectiveness (DE) in cold and brackish waters (ESRF NE22-4/177E-PDF). In general, it was found that chemical dispersion in cold marine environments did not impair DE unless temperatures were less than the spill oil's pour point. It has also been reported that DE is highest when water salinity lies between 25 and 40 (Figas et al., 2011). Ice cover < 50% is thought to affect DE primarily through its ability to generate and then diffuse oil droplets once the dispersant has been applied. Ice cover exceeding 50% significantly dampens the wave field and surface mixing conditions (Asplin et al. 2012) resulting in declining dispersion efficiencies.

Unfortunately, Canada has no written policy on dispersant use. Current guidelines that provide direction on dispersant testing, effectiveness standards, toxicity standards, and considerations for use were developed in 1984 are deemed to be out of date by the responsible Canadian Government agencies. Thus, there is an urgent need to develop an overarching strategy to provide science-based credible information and to engage in dialogue with decision makers and other stakeholders to address risk perceptions, concerns and questions regarding the use of dispersants and ultimately to expedite the approval process for use of dispersants, including at least a limited policy authorizing dispersant use in specific ice affected areas and potentially pre-approval for specific projects.

In Situ Burning (ISB) has been, and continues to be a primary spill response option in ice covered Arctic waters. Experiments have been designed and conducted to study everything from slick thickness to winds and water currents on burning rates and efficiency (residues) on various types of fresh, evaporated, emulsified crude oils, distillate and residue fuel oils. Studies of various ignitions systems and herders (e.g. ThickSlick 6535 and SilTech OP-40) have also been conducted (ESRF NE22-4/177E-PDF;

http://www.arcticresponsetechnology.org). In general, the natural containment, reduced wave generation and weathering in drift ice concentrations ranging from 3/10 to 6/10 can significantly extend the “window of opportunity” for response operations such as burning or the use of dispersant. Conversely, ice concentrations < 3/10 or > 6/10 represents a “response gap” (Dickins, 2011) as too little ice negates the benefits of natural containment while too much ice limits accessibility. Despite our understanding of ISB in the presence of various types and extent of sea ice, there is still much to be learned before full acceptance of ISB as a primary response option for oil spill mitigation in Arctic marine waters can be accomplished and specific Canadian guidelines regarding ISB can be developed.

Mitigation approaches and technologies are also required for the special conditions of the Arctic. The ability of microbes to degrade hydrocarbons is well known (Hazen et al. 2010) and is an example of the ‘ecosystem services’ that microbial communities can potentially provide to Canadian society and Canadian industries that produce and transport hydrocarbon resources such as crude oil and bitumen. To fully realize these benefits the chemistry, physiology and ecology of crude oil biodegradation in Arctic environments need to be better understood. In the event of large spill or worst-case spill scenarios in fall or winter under heavy ice conditions, ISB, use of dispersants or other clean-up efforts may not be possible until the spring melt period. This could result in crude oil persisting for months where the only remediation potential rests with marine microbial communities in the Canadian Arctic, whose inherent potential for hydrocarbon biodegradation at low temperature remains poorly understood. In principle, natural attenuation by resident microorganisms may not require intervention, particularly in cold or deep waters that are rich in inorganic nutrients (Nitrogen, Phosphorus) that are essential for microbial growth. As such, Arctic microbes might indeed represent invaluable first responders in the event of a cold Arctic oil spill. However, we know very little about this potential in polar seas, and how temperature, oil chemistry and marine microbial population structure might influence intrinsic bioremediation in the Canadian Arctic. A comprehensive understanding of the natural degradation of petroleum by marine microbial communities in Arctic ice-laden waters will contribute significantly to remediation of future oil spills. This awareness will allow Canada and other regions affected by and/or at-risk from marine oil pollution to incorporate strategies to promote the efficient microbial attenuation of petroleum.

A New Approach to Studying Oil in Ice?

Together with colleagues at 6 universities across Canada, CEOS (University of Manitoba) is currently leading a proposal to the Canadian Foundation for Innovation (CFI) to build a facility called the Churchill Marine Observatory (CMO) (Figure 3). The CMO will directly address technological, scientific and economic issues pertaining to marine transportation and oil and gas development throughout the Arctic. CMO is envisaged as a state-of-the-art Arctic marine observatory, technology incubation and commercialization centre that will revolutionize our ability to directly observe variability and change in complex natural systems and support cutting-edge research. It will explore and develop approaches and technologies desperately needed to detect, quantify and mitigate impacts in ice-laden Arctic waters should accidental release of various forms of crude oil, liquefied natural gas, and transportation related contaminants occur.

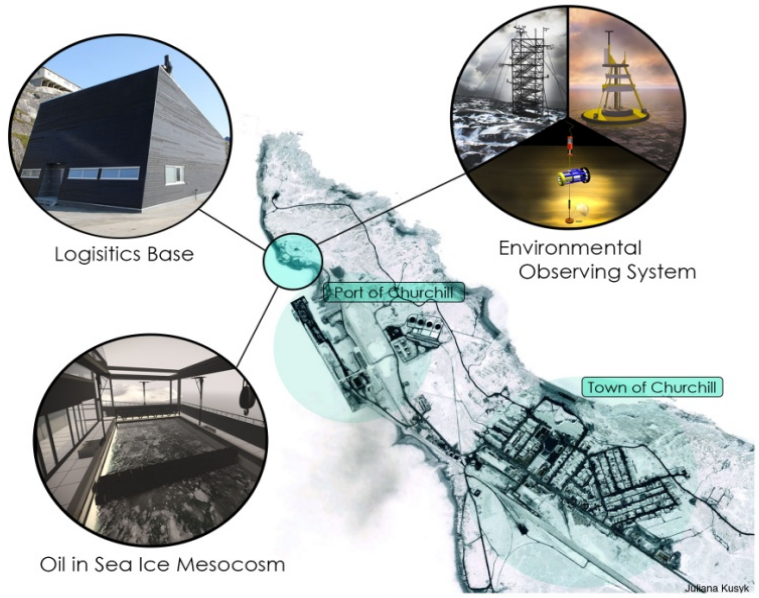

Figure 3: The central components of the CMO and its location relative to the Town and Port of Churchill.

CMO is specifically designed to investigate a variety of contaminants both under landfast first-year sea ice and mobile ice types in the marginal ice zone (MIZ). Three mutually supporting core research and technology elements are proposed: 1) the Oil in Sea Ice Mesocosm (OSIM); 2) a fully integrated Environmental Observing (EO) system; and 3) a Logistics Base (Figure 3). CMO will dramatically advance knowledge of oil spills in sea ice and ice-covered waters, impacts of these contaminants on the marine ecosystem, and development of environmental technologies designed for detection and mitigation of oil in ice-covered waters. Controlled conditions of the OSIM tanks will allow for research into the detection, impacts and mitigation issues described above.

CMO will contribute to national policy making and technology development, advancing science to detect, monitor and mitigate oil spills in sea ice. Data from the EO system will be used to scale process studies conducted in OSIM to Hudson Bay and throughout the Arctic through field observations and satellite remote sensing. The CMO will help position Canada as a leader in contaminant detection, impacts and mitigation in sea ice covered waters. Partnerships with indigenous organizations will ensure transparent knowledge exchange, while the private sector will provide market driven uptake of the technology developed and various levels of government will ensure effective transfer of knowledge into policy and regulatory requirements for marine transportation, oil and gas exploration and development in the Artic. CMO is a proposal which will be submitted to CFI in June, 2014. We provide this information to the panel simply for your information (FYI).

Conclusions:

A lack of scientific knowledge underlying the development of sound policies and regulations could potentially hamper the development of Canada's Arctic oil and gas industry, put at risk a very sensitive Arctic marine ecosystem, and adversely affect northern peoples cultural and economic use of the Arctic. Conversely, development of a detailed scientific knowledge base about the distribution, behavior and persistence of hydrocarbons in the Arctic environment will help build confidence among Canadians that increased shipping activities and exploration/exploitation of Arctic offshore oil reserves can safely proceed. Currently there are few regulatory controls that are suited to increased Arctic development and shipping, and a very limited capacity to respond in the event of a spill. In conjunction with preparing new regulations, or advancing plans to develop in the Arctic, additional research is required to better understand how hydrocarbons would behave when accidentally released into the Arctic marine system.

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