BEAUFORT REGIONAL ENVIRONMENTAL ASSESSMENT

Assessment Report on the Potential Effects of Climate Change on Oil and Gas Activities in the Beaufort Sea

Canada

July 2013

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Project Number: 123510815

July 2013

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Environment Canada & Aboriginal Affairs and
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NCR#5609911 - v2

Executive Summary

This report summarizes and assesses the state of knowledge of climate change as it relates to the potential effects on standard operating activities of the oil and gas industry in the Canadian Beaufort Sea region. The need for this information was identified by the Beaufort Regional Environmental Assessment (BREA) Climate Change Working Group and was funded by Aboriginal Affairs and Northern Development Canada. This assessment is based on a preliminary report prepared for a workshop held in Inuvik, Northwest Territories, November 19-23, 2012. The preliminary report was used to support and focus discussions at the workshop; and, feedback from the workshop and comments from reviewers not able to attend were incorporated here. The assessment does not discuss greenhouse gas emissions produced by oil and gas activities nor is it an environmental assessment.

Science and traditional knowledge reports pertinent to climate change in the Beaufort Sea region were reviewed and analyzed with a focus on how that information might relate to oil and gas activities. In addition, environmental assessment reports, regulations and guidelines which address climate change in the context of oil and gas exploration and development were reviewed. The information gathered was synthesized to describe and assess climate change effects on the environment and how these changes may affect, positively or negatively, oil and gas operations in the Beaufort Sea.

There is clear evidence that the physical properties of the Beaufort Sea are being affected by climate change. Ice and water conditions in the Southern Beaufort Sea (SBS) are strongly influenced by oceanic and sea ice exchanges with neighboring regions. Sea ice thickness and concentrations of multi-year ice are decreasing especially along the slope and deeper offshore waters of the Beaufort Sea and adjacent regions. These reductions are mainly a result of losses of older multi-year ice. There is also an increasing presence of glacial ice features. In contrast to the deeper offshore waters, there have been no significant changes observed in ice thickness along the Mackenzie shelf and the reductions in ice concentrations are smaller. A later freeze-up and earlier break-up of ice along the inner shelf has resulted in a reduction in duration of days of ice cover for this area. The offshore waters are warming and freshening with more open water and ice melt. Models suggest that these trends will continue for at least the next couple of decades.

Mean air temperatures within the assessment area have been increasing over the past 50 years. Precipitation has also been increasing but at a lower rate than air temperature. Over the past 14 years, wind patterns have been dominated by anticyclonic systems. Prior to 1977, these large-scale wind patterns shifted between anticyclonic and cyclonic every 5-8 years. Storm activity has increased in strength (depth of the low pressure) but not in frequency. Storms appear to have a strong control on sea ice break-up, motion and resulting thickness distributions.

Seven climate and ice variables considered to be of high importance in this study are; wave height, wind speeds, sea temperature and heat content, sea level, coastal erosion rates, sea ice (distribution, type, concentration, and thickness) and presence of glacial features within the sea ice pack.

Changes in sea ice and water conditions such as currents, wave height and sea temperatures will likely have the greatest effects both positive and negative on oil and gas activities in the Beaufort Sea.

Key Positive Effects include:

- longer operating seasons for seismic and drilling activities due to reduced ice cover and thickness
- earlier mobilization and later demobilization of vessels both to and from the Beaufort Sea as well as from overwintering anchorages and offshore areas
- reduced icebreaking requirements

Key Negative effects include:

- increased threats to drilling and production platforms due to increased ice velocities and the increased presence of glacial ice features
- larger wave heights may cause delays in ship support activities and seismic operations
- increased sea surface temperatures which may increase degradation of permafrost in coastal areas with implications for coastal oil and gas infrastructure
- reduced use of ice roads and ice spray islands in nearshore areas
- increased coastal areas affected by storm surge potentially affecting infrastructure

Additional positive and negative effects to oil and gas activities from ice and waves are discussed in the body of the report.

Climate change effects on oil and gas activities are expected to be greatest for longer term projects such as production activities which can span 30 years or more, and where changes affecting operations may change over the lifespan of the project. Due to the large year to year variations which can occur in weather or ice conditions, oil and gas companies will need to plan and prepare for extreme events in all phases of a project.

Information gaps were identified that need to be addressed to improve the understanding of the effects of climate change on oil and gas activities. Most of these gaps pertained to either climatology or ice, although gaps were also identified in other areas including, but not limited to; contaminants, marine ecology and the seabed. Based on gaps identified, recommendations for future research were developed.

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Abbreviations

AEAU	alternative energy and alternate use
ASTIS	Arctic Science and Technology Information System
BG	Beaufort Gyre
BREA	Beaufort Regional Environmental Assessment
CAA	Canadian Arctic Archipelago
CEAA	Canadian Environmental Assessment Agency
CFL	circumpolar flaw lead
CIS	Canadian Ice Service
CNLOPB	Canada – Newfoundland and Labrador Offshore Petroleum Board
CNSOPB	Canada – Nova Scotia Offshore Petroleum Board
DFO	Fisheries and Oceans Canada
EBSA	Ecologically and Biologically Significant Area
EGU	European Geosciences Union
EIRB	Environmental Impact Review Board
EIS	environmental impact statement
EISC	Environmental Impact Screening Committee
ESRF	Environmental Studies Research Fund
FY	first year
ICES	Ice, Cloud and Land Elevation Satellite
IPCC	Intergovernmental Panel on Climate Change
IPY	International Polar Year
IRIS	Integrated Regional Impact Study
LRTAP	Long-Range Transport Air Pollution
MMS	Minerals Management Service
NOAA	National Oceanic and Atmospheric Agency
NW	northwest
NWT	Northwest Territories
OC	organochlorines
OCS	Outer Continental Shelf
PAH	polycyclic aromatic hydrocarbon
PERD	Program of Energy Research and Development
SAR	search and rescue
SBS	Southern Beaufort Sea
SDL	Significant Discovery Licence
SST	sea surface temperature
UK	United Kingdom
UNFCCC	United Nations Framework Convention on Climate Change
US DOI	United States Department of the Interior

1 INTRODUCTION

Oil and gas exploration began in the Canadian Beaufort Sea in the early 1970s and the first well was drilled in 1972. Ninety wells were drilled between 1972 and 1989 with over half these located in water depths of 20 m or less (Callow 2012). The most intense period of exploration drilling occurred between 1982 and 1985 with an average of eight wells drilled per year in water depths ranging from 1.4 m to 67.4 m. Exploration drilling ceased in the Beaufort Sea in 1989 and no drilling was conducted again until the winter of 2005/2006 when Devon drilled a single well in a water depth of 13 m. Of the 90 wells drilled in the Canadian Beaufort Sea 38 resulted in the application and approval of Significant Discovery Licences (SDL) for either gas or oil. Although no drilling has occurred since 2006, interest still exists in exploring for hydrocarbon resources in the Beaufort Sea, as evidenced by the number of exploration licences acquired in the deeper waters offshore since 2007. In recent years, one or more ship-based seismic surveys have been conducted in the Canadian Beaufort Sea every year. Although exploration drilling in the past has focused in water depths less than 70 m, oil and gas companies are now expanding their search to include potential drilling sites in deeper waters, including those over 1,000 m in depth.

Offshore oil and gas activities for exploration, production or decommissioning require significant infrastructure in terms of vessels, drilling platforms, docks, and land based camps or offshore warehouses. Tuktoyaktuk Harbor, McKinley Bay and Herschel Basin provided important support bases for offshore exploration activities in the 1970s and 80s. Tuktoyaktuk was also used by Devon in 2005/2006. A variety of drilling platforms have been used in the Canadian Beaufort Sea including ice spray, islands, artificial islands, caissons and floating drill ships (Timco and Frederking 2009). Ice management and ice breaking support are required for most oil and gas activities in the Beaufort Sea.

The resurgence of oil and gas interests in the Beaufort Sea has led to the establishment of the Beaufort Regional Environmental Assessment (BREA). BREA is a four-year, multi-stakeholder initiative that includes Inuvialuit, territorial and federal governments, academia and industry. The key goal for BREA is to produce relevant scientific and socio-economic information that simplifies project-level environmental assessment and regulatory decision-making for oil and gas activities, while strengthening the relationship between environmental assessment and integrated management and planning in the region (BREA 2012). Information is gathered in specific areas of interest through the implementation of work plans established by BREA working groups, including; climate change, regional waste management, information management, cumulative effects assessment, oil spill preparedness and response, and socio-economic indicators.

This assessment was identified in the work plan of the BREA Climate Change Working Group. The objectives of the Climate Change Working Group are to identify and recommend actions to fill information and data gaps related to climate change effects of relevance to offshore oil and gas activities in the Beaufort Sea. The assessment is focused on oil and gas activities presented in the Oil and Gas Exploration and Development Activity Forecast: Canadian Beaufort Sea 2012–2027 (Callow 2012). Existing significant discovery licences (SDL) and current exploration licences (EL) are shown on Figure 1. Recent oil and gas exploration in the Beaufort Sea has expanded further into offshore and deeper waters

(> 1000m) than previously (1960s to 2000s). Exploration Licences issued in the Beaufort Sea in 2012 include exploration blocks off the western coast of Banks Island (Figure 2).

The Intergovernmental Panel on Climate Change (IPCC) defines climate change as ***"a change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forcings, or to persistent anthropogenic changes in the composition of the atmosphere or in land use."*** Regardless of the definition used, effects will occur, positive or negative, on oil and gas activities as a result of climate change.

This study complements other research and assessments being conducted in the Beaufort Sea Region. These include:

- The International Polar Year (IPY) circumpolar flaw lead (CFL) system study
- ArcticNet's Integrated Regional Impact Study (IRIS 1) assessment report which assess the effects of climate change on the marine and coastal environment
- BREA supported research
- Research conducted by various federal agencies such as Natural Resources Canada, Fisheries and Oceans Canada and Environment Canada
- Program of Energy Research and Development (PERD) funded studies
- Environmental Studies Research Fund (ESRF) studies
- International and Canadian studies of the southern Beaufort Sea and coastal Canadian Arctic as made available through cruise reports and the peer reviewed literature

This report will support efficient and effective environmental assessment and regulatory decision-making by managers, regulators and policy makers pertinent to the potential impacts of climate change related to oil and gas activities in the Beaufort Sea.

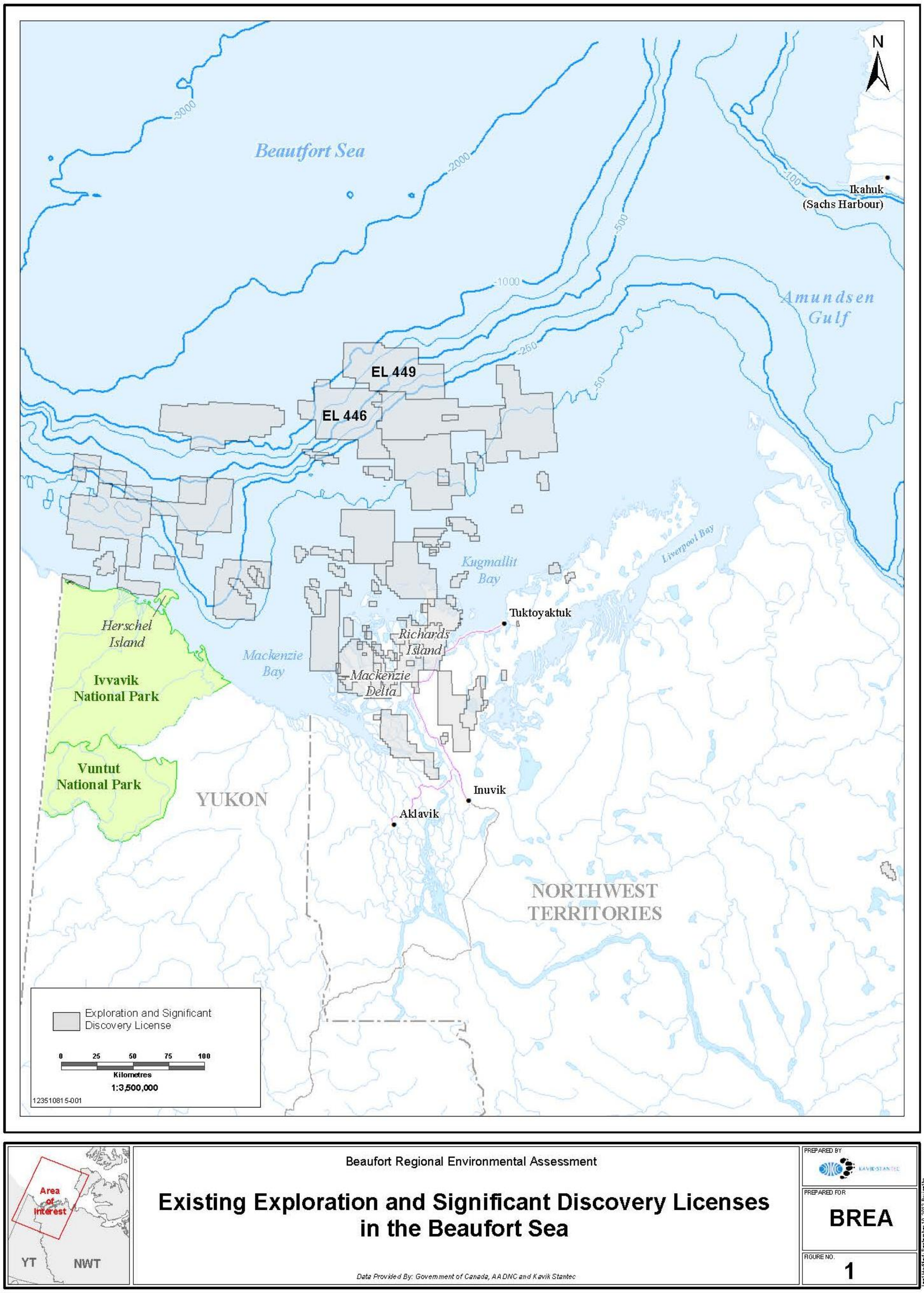


Figure 1 **Existing Exploration and Significant discovery Licences in the Beaufort Sea**

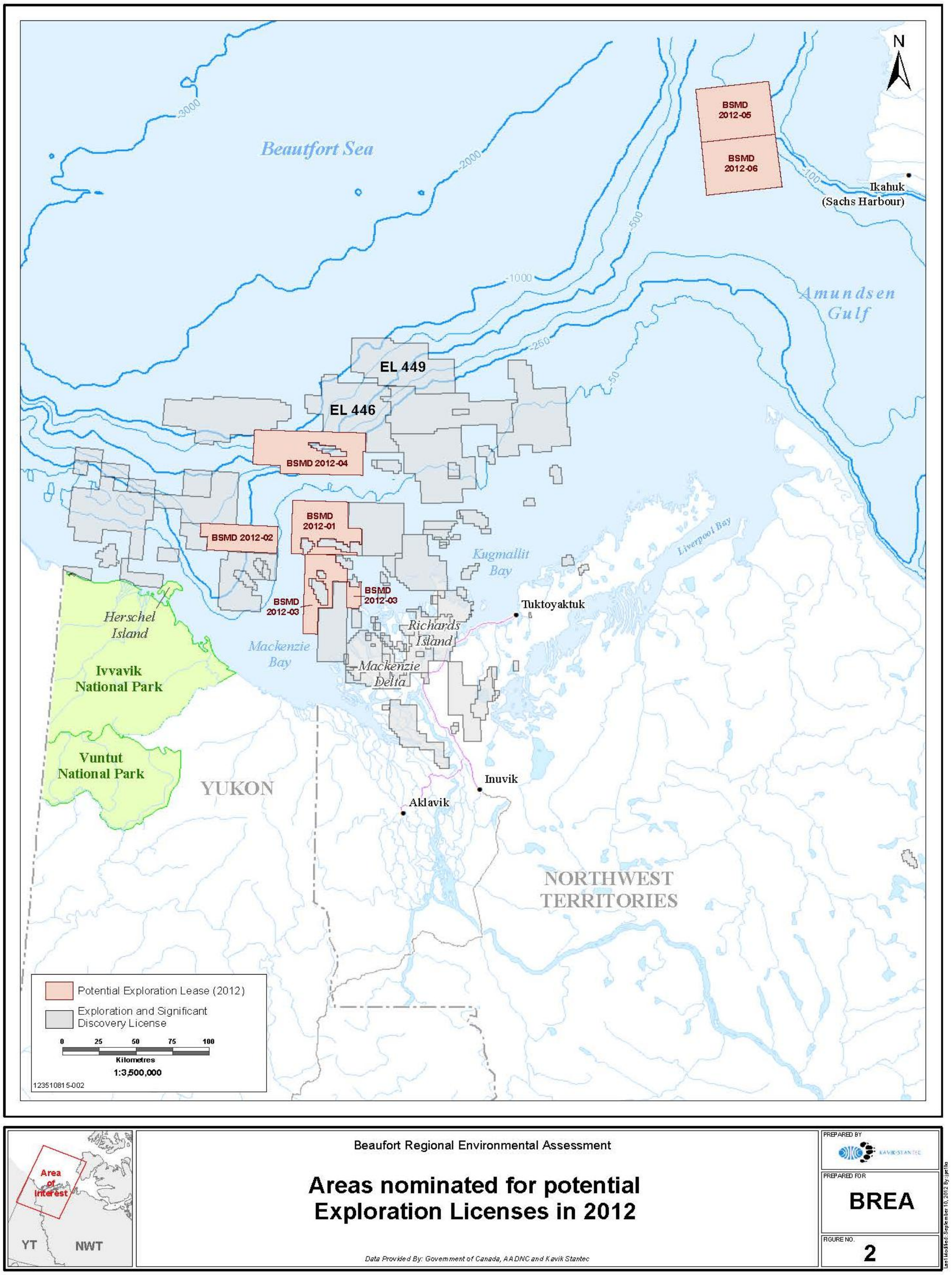


Figure 2 Areas nominated for potential Exploration Licences in 2012

2 METHODS

2.1 Literature Search and Review

Literature pertinent to potential climate change effects on oil and gas activities in the Beaufort Sea was identified and reviewed.

The literature review included information on:

- Climate change science, including; baseline data, monitoring, analyses of trends and periodicities of climatic variables, and modeling as these relate to the potential effects of climate change on oil and gas activities.
- Climate impacts, including; baseline data, monitoring, modeling, data/information management, prediction capability, impacts/effects and adaptation as these relate to the potential effects of climate change on oil and gas activities.
- Traditional knowledge pertaining to climate change in the Beaufort Sea and coastal areas.
- Past and current environmental assessments and impact statements for Canadian and Alaskan Beaufort Sea oil and gas exploration and development related activities.
- National (e.g., Newfoundland and Nova Scotia) and international (e.g., Norway, Greenland, and Alaska) literature pertinent to potential climate change impacts on oil and gas activities in the Canadian Beaufort Sea including guidance on climate change considerations in environmental assessment.

Identification and review of relevant information and literature included the use of database searches, review of bibliographies, review of Stantec's and subcontractor's extensive in-house libraries, review of agency records, and consultation with climate change experts.

Databases searched included:

- Arctic Science and Technology Science Information System (ASTIS) held by the Arctic Institute of North America which also includes:
    - Refereed ArcticNet publications
    - Canadian IPY Publications Database (Polar Data Catalogue)
    - Hydrocarbon Impacts Database
    - Inuvialuit Settlement Region Database
- Department of Fisheries and Oceans, online catalogue WAVES
- Beaufort Sea Project Technical Papers and Synthesis Reports (41 Technical Reports and 5 Overview Synthesis Reports, available at http://www.restco.ca/BSP_Tech_Papers.shtml)
- Natural Resources Canada bibliographic database Geoscan
- U.S. National Snow and Ice Data Center (NSDIC)
- Environment Canada Canadian Ice Service Data Archive

- National Oceanic and Atmospheric Agency (NOAA) Arctic Report Card
- Offshore Oil and Gas environmental baseline studies for the Canadian Beaufort Sea conducted since the late-2000's (in particular, the extensive baseline data collection programs of Imperial Oil Resources Ventures Ltd., BP Exploration in collaboration with ArcticNet and DFO from 2009-2011)
- Polar Data Catalog (operated by ArcticNet and the Canadian Cryospheric Information Network, available at http://polardata.ca/)

Literature searched was divided into 12 different categories in the bibliography:

- Climate change research and monitoring
- Sea ice
- Atmosphere
- Physical oceanography
- Coastal processes
- Biological (fish, zooplankton, etc.)
- Marine mammals
- Arctic contaminants
- Traditional knowledge
- Climate driven impacts
- Regulations/guidelines/best practices
- Environmental assessments

The results of the literature search are presented in this report in Section 3 "Changes from Baseline Conditions: Present and Future" and Section 4 "Traditional Knowledge on Climate Change". The bibliography is located in Appendix A.

2.2 Climate and Sea-ice Variables

Climate and ice variables used for monitoring, modeling, and impact prediction were identified. Climate and ice variables selected as relevant and potentially important to this study were required to inform on the effects of climate change on oil and gas activities and on the mitigation or adaptation applied to reduce the severity of that effect.

Two matrices were developed to aid in the selection of the most relevant climate and ice variables. The first matrix (Table B-1) identifies the effects and their severity by life-cycle phase and operation of oil and gas activities in the Beaufort Sea.

The second matrix (Table 3) assesses climate and ice variables to determine key variables. The following questions were used in the assessment process;

- Does the climate state variable inform on an opportunity (e.g., reduced ice allowing longer drilling or shipping season) or hazard (e.g., increased wave height affecting ship safety) to oil and gas activities and its severity?
- What type of oil and gas activity is potentially affected, either in a positive or negative manner, by the climate state variable (see Effect in Table 3)?
- Is the climate state variable measurable (see Measured/Modeled in Table 3) and to what level of accuracy (see Measurable/Accuracy in Table 3)?
- What is the practicality (see Practical in Table 3) of measuring the climate state variable?
- What temporal scales (see Temporal Scale in Table 3) apply to the climate state variable?
- What is the spatial or geographic scope applicable to this climate state variable (see Spatial Scope in Table 3)?
- What is known of the frequency of an event related to this climate state variable (see Frequency of Effect in Table 3)?
- What is known of the long-term trends (see Long-term trend data available in Table 3) related to this climate state variable?
- What is the urgency (see Urgency in Table 3) in understanding or predicting the effect of the climate state variable?
- How relevant (see Relevance of Effect in Table 3) is the measurement of the climate state variable to understanding the effect on oil and gas activities?

Based on the analysis provided through the use of the second matrix, climate/ice state variables rated as high are identified as “key” climate variables.

2.3 Synthesis of Predicted Climate Change and Potential Effects on the Oil and Gas Industry

Climate change scenarios have been described and published for the Beaufort Sea and adjoining areas of the Arctic (e.g., the IPCC4 findings [Christensen et al. 2007; Anisimov et al. 2007], Bonsal and Kochtubajda 2009). In this study these scenarios were reviewed and assessed based on the most current information and predictions available and the levels of uncertainty or model confidence in the various predictions. This review is based on recent scientific publications (e.g., for sea ice: Wang and Overland 2009; Zhang et al. 2010; Perovich et al. 2011) and analyses carried out as part of the present study. The assessment is based on an examination of the range of possible changes to climatic patterns which, in turn, influences the range and extent of possible effects on oil and gas activities. Based on the review and assessment, short (5 years), medium (up to 15 years) and long-term (up to 30 years) climate change scenarios are described. These climate change scenarios are then applied and assessed by time scale (short, medium and long) as to the potential effects on oil and gas activities or compilation of activities provided for this project (Callow 2012).

2.4 Review and Synthesis of Existing Guidelines and Best Practices

National and international literature regarding guidance and best practice relating to climate change considerations in environmental assessment and regulatory decision-making was identified and reviewed.

The guidelines and best practices considered relevant to oil and gas activities in the Beaufort Sea and climate change were synthesized.

2.5 Identification and Analysis of Key Data Gaps

Based on the results of the literature review, identification of climate state variables and the associated synthesis, key data gaps were identified and analyzed. Although data gaps will always exist, not all data gaps are key or important to an understanding of effects and any particular level of risk or opportunity.

A mini-workshop was held by project team members to identify key data gaps. The following factors were considered:

- Can the data gap be addressed and is it reasonable to do so?
- Is there sufficient information currently available to address effects?
- Biophysical components in which climate change may most likely affect oil and gas activities (e.g., sea ice).
- What are the changes in the biophysical environment that may affect oil and gas activities?
- Is the direction of a change in the biophysical environment known?
- Data gaps can be in the form of regulations and guidelines.
- Data gaps can be related to both direct and indirect effects on oil and gas activities. Indirect effects have the potential for strong consequences on oil and gas activities but are far more difficult to predict.

2.6 Recommendations

Recommendations on research/discussion questions and means to address information gaps were developed. Recommendations include field programs, analysis of existing information (i.e., new analytical approaches or re-analysis of previously analyzed data), traditional knowledge studies, engineering studies or new approaches in exploration and development of oil and gas resources. Recommendations focus on those gaps of knowledge that have the highest priority.

Recommendations developed are based on the following considerations:

- Applicability and practicality in addressing a key knowledge gap identified in this study.
- Opportunity provided to oil and gas activities by climate change effects on the environment, or risk and severity of risk posed by climate change on oil and gas activities.
- Urgency in addressing climate change effects in early phases of oil and gas exploration and development scenarios

- Data availability or requirements
- Data analysis or new approaches required

2.7 Development of List of Experts

A list of climate change experts was compiled through our network of contacts (ArcticNet, Universities, government, and industry) and through the literature. Experts include those located in Canada, the United States of America and other countries conducting Arctic climate change research (e.g., Norway, Russia, Denmark, UK,). The list of experts (Appendix C) includes name, affiliation, and area of expertise.

2.8 Workshop

A facilitated workshop was held over a three day period in Inuvik, NWT, from November 19-21, 2012. A small group of select experts on climate change including Inuvialuit Traditional Knowledge holders and western scientists in conjunction with oil and gas industry representatives participated in the workshop. A preliminary draft of this report was prepared and distributed to participants prior to the workshop. It provided background information and acted as a framework to focus discussion.

The workshop consisted of a balance between presentations and open forum discussions. Open forum discussions were used instead of break-out groups to allow for everyone to participate and hear what was being discussed. The small group of workshop participants (<25) facilitated this approach.

The objectives of the Workshop were to:

- validate the findings contained in the draft assessment and report,
- review information gaps related to current knowledge of the Beaufort biogeophysical environment, regional climate change, and effects on oil and gas activities,
- propose research initiatives to improve the state of knowledge,
- identify current climate change information and its value to inform near-future (i.e., the next 13-30 years) oil and gas exploration and development, and
- identify uses of this information in regulatory decision-making and environmental assessments.

Workshop Proceedings are provided in (Appendix D).

3 CHANGES FROM BASELINE CONDITIONS: PRESENT AND FUTURE

3.1 Sea Ice: Areal Extent and Concentration

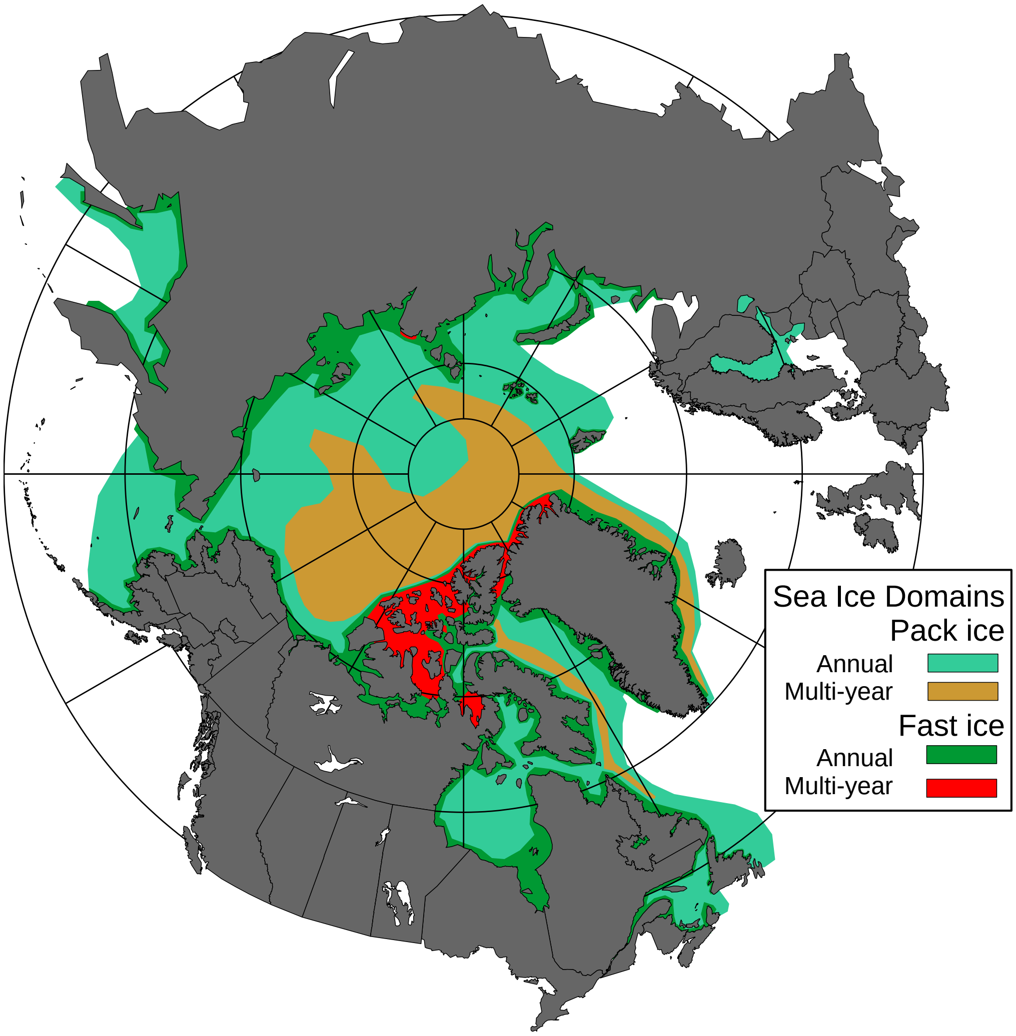
Sea ice areal extent and concentration is fundamentally important to the Beaufort Sea ecosystem and to human activities in this area. As the intermediate layer between the atmosphere and the ocean, the presence of sea ice alters the fluxes between the atmosphere and the ocean. Its presence or absence has important effects on many biophysical variables including weather patterns, generation of ocean waves, light penetration into the ocean and the timing and usage of areas by various types of marine life. Sea ice represents an impediment, and under some circumstances, a hazard to offshore oil and gas operations. On the other hand, stable landfast ice is important for transportation in inshore regions.

Because of its importance, summaries of the changing sea ice environment are presented below, derived from analysis of long-term data sets available from the Beaufort Sea including the digital sea ice charts published by the Canadian Ice Service of Environment Canada and passive microwave satellite data coverage for the Arctic Ocean. The earliest baseline studies of sea ice were those of the Beaufort Sea Project conducted in the early to mid- 1970’s as discussed in Section 2.1.

SEA ICE CHANGES OVER THE ARCTIC OCEAN

The ice cover in the Beaufort Sea is best understood within the context of the sea ice conditions of the Arctic Ocean itself, where dramatic changes in ice areal extent have been occurring over the past decade and longer (AMAP 2011). The ice conditions in the Canadian Beaufort Sea are strongly influenced by oceanic and sea ice exchanges with neighbouring regions and, ultimately, by the underlying atmospheric, oceanic and cryospheric circulations of the Polar Ocean.

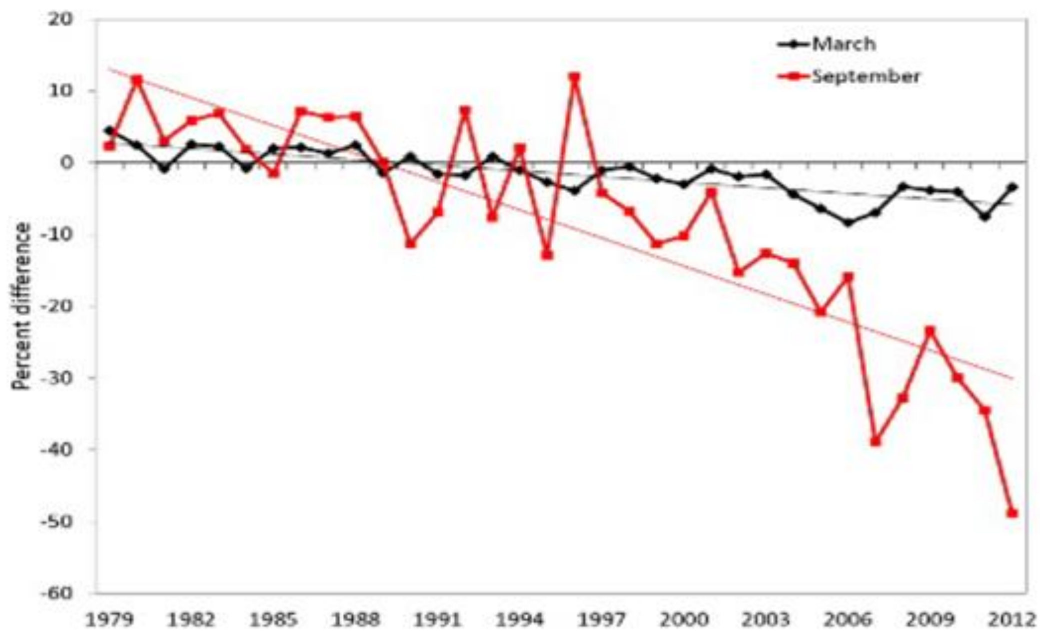
The sea ice within the Arctic Ocean primarily consists of four different types classifiable in terms of age, thickness and mobility (Figure 3). Pack ice in the annual and multi-year categories is mobile (although occasionally “fast” or immobile during usually brief periods of negligible large-scale movement). Distinctions are made with respect to whether the ice is multi-year ice, having survived at least one summer, or is annual ice having been formed since the end of the previous summer. Fast ice is also classifiable into multi-year and annual varieties using the same age criteria. Annual fast ice is usually seasonally present (late-autumn through early summer) in shallow (typically depths < 20 m in the Beaufort Sea) coastal waters until it melts away in place or has its remnants mixed into adjacent fields of melting and dispersing pack ice. Multi-year fast ice, on the other hand, may undergo numerous mobilization/immobilization cycles in the more restricted environment offered by the channels of the Canadian Arctic Archipelago.



SOURCE: H. Melling, pers. comm.

Figure 3 Major ice type domains of the Arctic sea ice cover

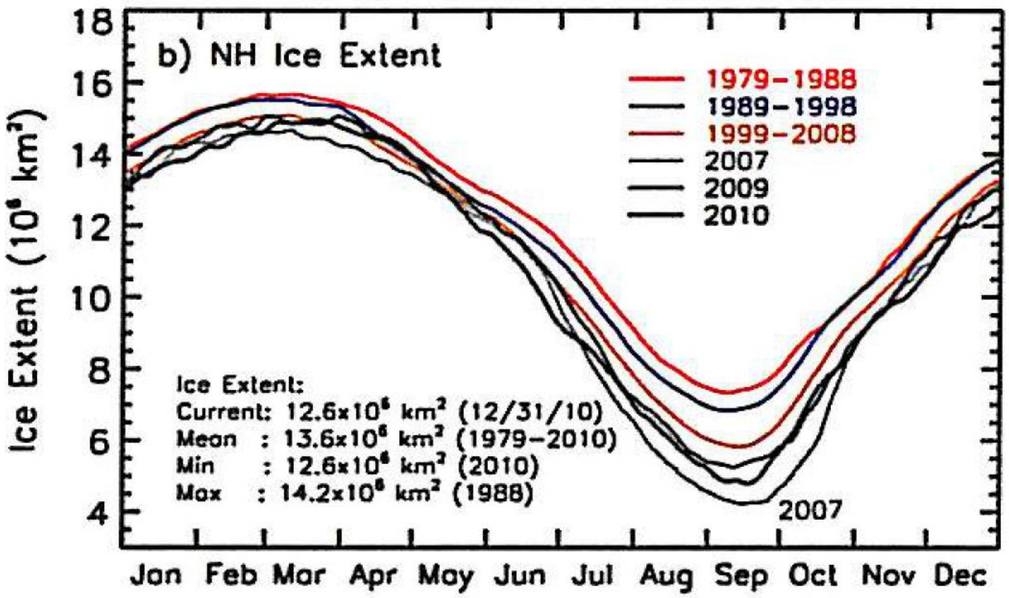
Passive microwave data on the annual areal coverage of all types of ice for the Arctic Ocean and adjoining areas, dating back to 1979, provides the best measure of changes over the intervening decades in, at least, the spatial extent of ice coverage. These changes are most evident in the annual extents as estimated at seasonal extreme points: March when coverage is maximal; and, September when it reaches minimum extent. The March ice extent (Figure 4) showed minimal decreases of approximately 3% per decade relative to the indicated 1979–2000 average, arising largely from reduced extents of ice moving out of the Arctic Basin to lower latitudes. On the other hand, the much larger decrease in the September ice extents (Figure 4) of approximately 13% per decade is suggestive of underlying major changes in the Basin corresponding to progressive decreases in the fractional occupation of the Basin surface by thicker, harder, multi-year pack ice. The magnitudes of these changes, particularly in September at times of minimum ice extent and in the post-1999 and post-2006 years, are illustrated by the decadal average and individual year data sets plotted in Figure 5 (Comiso 2012).



SOURCE: Perovich et al. 2012

Figure 4 Time series of the percent difference in ice extent in March (the month of ice extent maximum) and September (the month of ice extent minimum) for the years 1979-2012 relative to the mean values for the period 1979–2000. Note that in September 2012 a new record low occurred with a 49% reduction from the 1979-2000 mean values.

The percentage changes in the March and September ice extents (Figure 4) were only marginally significant prior to the early 1990s but by the middle of the latter decade, the weak negative trend in the September extents had strengthened dramatically and established new normal levels which were 30% to 40% below those typical of the early historical record. Additional, very recent analyses of passive microwave satellite datasets (Comiso 2012; Figure 5) has separately tracked changes in the spatial extent of both overall multi-year ice content and its included fraction of perennial ice (defined as multi-year ice which has not survived two annual melt seasons). The distinction between perennial and older multi-year pack ice components is of considerable relevance to the evolution of future ice covers due to the longer lifetimes usually characteristic of the older ice forms. Comiso's estimates were that the actual areal coverage of all multi-year ice forms was decreasing at a rate of –17.2% per decade as opposed to a rate of –13.5% for the thinner, perennial variant. This implies that the above-noted trend toward lower multi-year ice coverage is preferentially occurring in its oldest and thickest portions of this major component of the ice cover. If this tendency is sustained, the rates of disappearance of this ice cover component's spatial extent (which is by definition equal to the entire areal extent of the ice cover just prior to the start of the freezing season) may very well be expected to accelerate over time.



SOURCE: Comiso 2012

Figure 5 Plots of 10-year-averaged and selected annual values of daily Northern Hemisphere ice extent as deduced from passive microwave data.

Sea Ice Changes in Areas of Hydrocarbon Activities in the Canadian Beaufort Sea

Within the area of hydrocarbon activities in the Canadian Beaufort Sea, the consequences of these larger scale trends in ice extents, thicknesses and topographies are likely to be controlled by both the basic distribution of ice types (Figure 3) and the underlying circulations of the lower atmosphere and the upper layers of the Arctic Ocean. On average, a very large high pressure atmospheric system produces an anti-cyclonic circulation, known as the Beaufort Sea Ice Gyre (Lukovich and Barber 2006) which moves elements of the multi-year polar pack ice south-westward past the edge of the Canadian Arctic Archipelago before gradually turning westward at latitudes south of 72^0N and moving into the Alaskan Beaufort Sea and then into the Chukchi Sea (Figure 6). The usual seasonal melts of landfast and annual pack ice shoreward of the Beaufort Gyre flow, produces large but annually highly variable areas of low ice concentrations and/or open water south and east of the contiguous polar pack ice. Annual ice re-growth in these areas results in a distinct Transition Zone ice regime during the period of November to June (Figure 6). This regime is characterized by ice thickness, topography, and movement intermediate to the extensive peripheral zone of annual fast ice, and the circulating Arctic Ocean pack ice including multi-year types. The ice movements generally follow those prevailing in more offshore areas but tend to be more irregular due to strong interactions with the outer edges of the fast ice in the denoted "shear zone" regime. In fact, it is the grounding of the deep keels of the deformed ice produced by these interactions that is responsible for the seasonal stability of a relatively well-defined fast ice zone with an outer boundary which approximately tracks the 20 m bathymetric contour in the southeastern Beaufort Sea. Given the dramatic reductions in total extent of sea ice in the polar pack zone since 2007, the transition zone is becoming significantly larger than depicted in Figure 6.

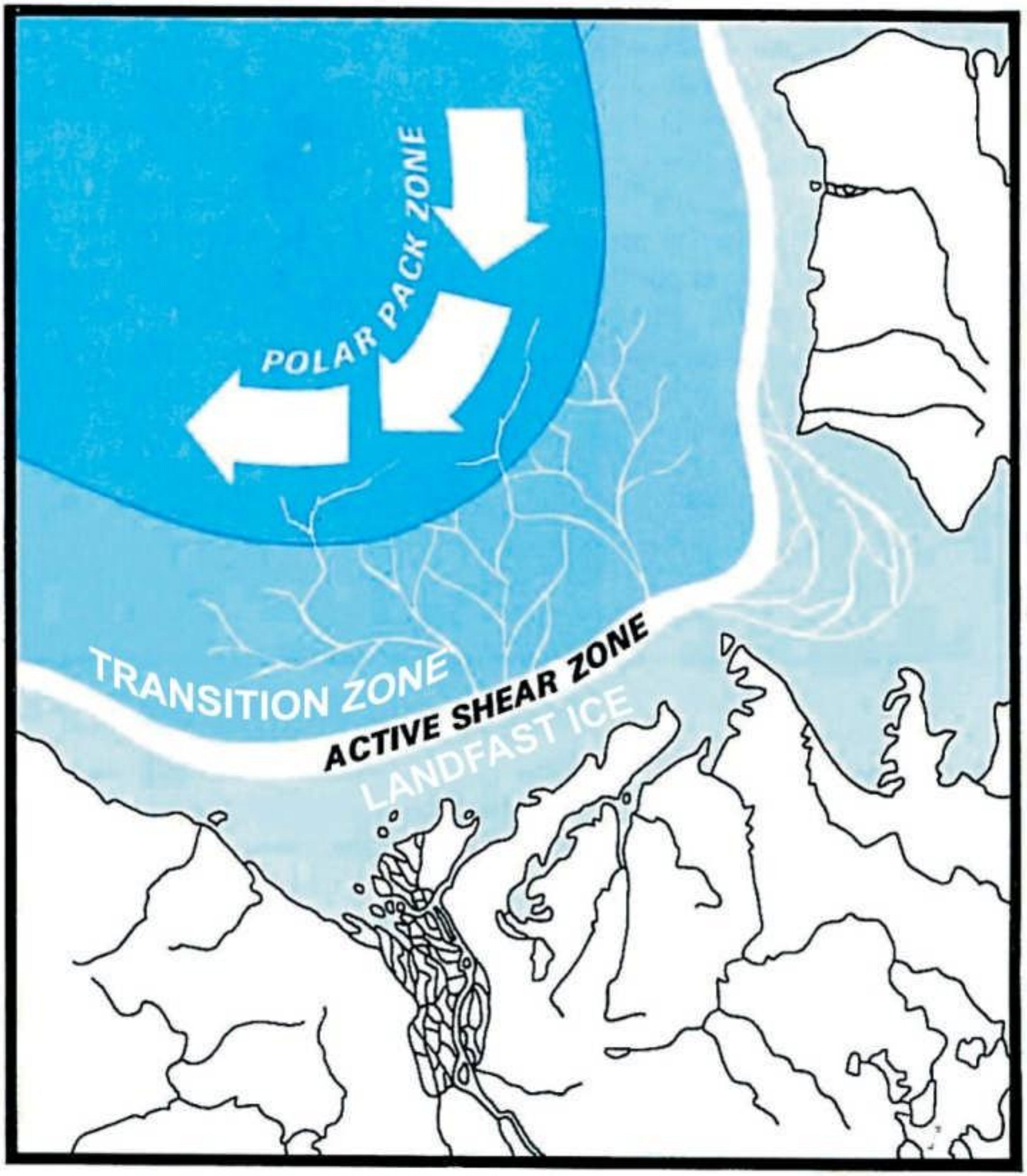


Figure 6 Breakdown of the ice cover of the southeastern Beaufort Sea into zones occupied by ice of similar origins and dynamic properties. Note that the timing and extent of the landfast ice zone is also variable annually and interannually.

The overall areas of interest for this study are primarily confined to Environment Canada's Mackenzie Region and the inner portion of the Canada Basin Region. Environments Canada's Canadian Ice Service historical ice chart sea ice concentration database for these areas spans the time period 1968 to the present. The yearly time series of sea ice areal coverage data, expressed as a percentage of total area, for the middle of the months of June, July, August, September and October are presented in Figure 7. A striking feature of the sea ice extent is the large amount of inter-annual variability, particularly in the Mackenzie Shelf region. The variability occurs over a wide range of periods, ranging from two years or less to eight years or longer.

Trend data extracted from this database for the latter region are presented in Figure 8 along with comparable statistics extracted for the indicated offshore and deeper waters of the Canada Basin. In both regions the decadal trends in overall ice extents and in the corresponding major ice age/thickness categories (old = multi-year; first year (FY) and young/ thin ice, thicknesses < 50 cm) are plotted for mid-month June through October. Tabulations of basic coverage statistics and decadal trends are provided in Table 1. As expected, the Canada Basin trends are similar to those noted above for the encompassing Arctic Region, with changes in total ice caused primarily from the old ice fraction which, in the late summer and fall months, was seen to decrease at rates ranging between 8% and 11% per decade over a period of 44 years. The only statistically significant changes in the Mackenzie region appeared to be limited to early season (June) data and correspond to somewhat lower, 6% to 8%, changes in both total and old ice coverage. Since old ice concentrations in this southerly region were usually low these results corresponded to early summer reductions in the content of both first- and multi-year ice components.

Data were also extracted from this same database on fine spatial scales corresponding to the four distinct sub-regions of the larger Mackenzie region. The changes for each sub-region (Figure 9) are generally largest in the slope region, as would be expected from the Arctic Ocean and Mackenzie Shelf results presented above. The largest change, of nearly a 10% reduction per decade, occurs in mid-October (Figure 9) with much of the sea ice reduction being due to the loss of old ice. Although less than that of the slope, the mid-outer shelf region also exhibits substantial reductions in mid-October with the loss of old ice and young ice being a large part of the total ice reduction. The long-term trends towards reduced sea ice concentration are much smaller in the inner shelf in mid-September because little ice is present in this area in mid- to late-summer. However, consistent reductions do occur in mid-July and mid-October. Old ice is rarely present in the inner shelf; therefore these trends are very small. In the inshore area of Kugmallit Bay, the long-term trends in sea ice concentrations are lower during the summer, but a reduction in total ice concentration does occur in mid-October. This is due to the later formation of sea ice resulting in a reduction of the thicker, first-year ice type, which is partially offset by an increase in the thinner young-ice categories.

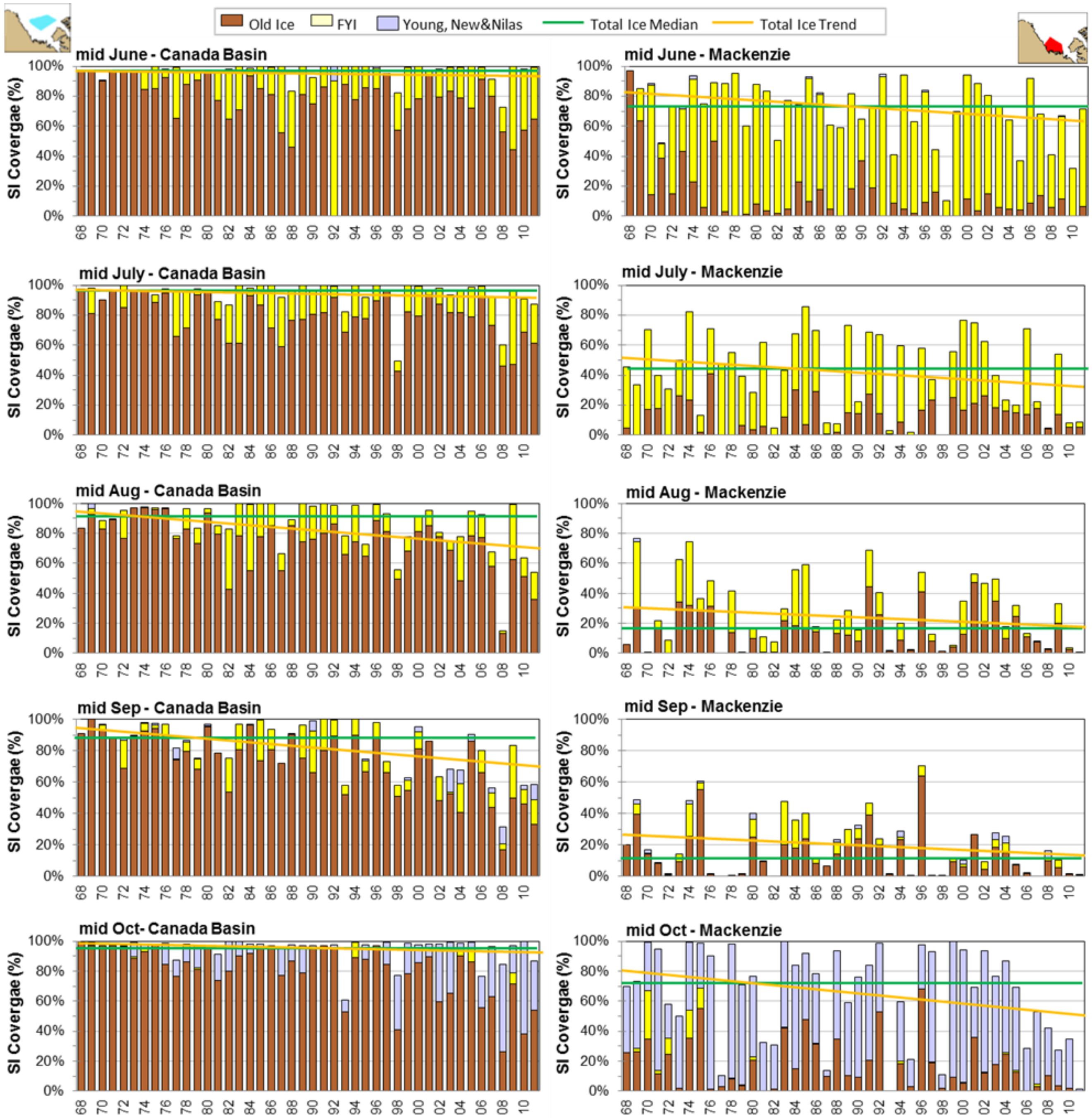


Figure 7 Mid-month historical sea ice (SI) percentage areal coverage from mid-June to mid-October, 1968–2011 for total ice and individual ice types

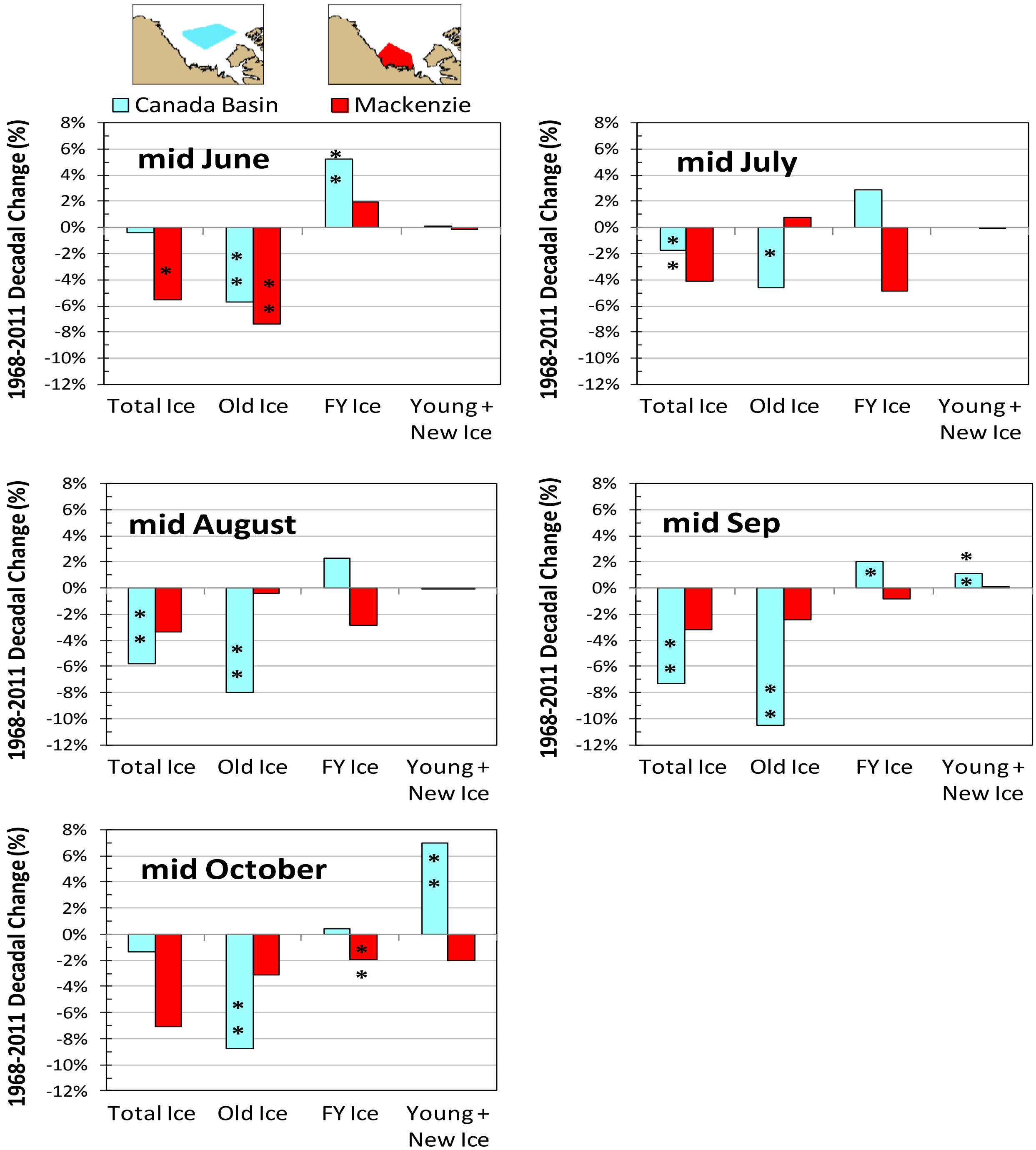
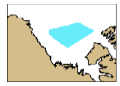
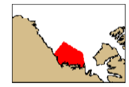


Figure 8 **Trends in sea ice coverage from mid-June to mid-October for the Canada Basin and Mackenzie regions in the Canadian Arctic, 1968–2011 (derived from Canadian Ice Service regional data). Statistical significance shown in the bars:* p<0.05: ** p<0.01.**

Table 1 Ice statistics from 1968–2011 CIS ice chart data

Ice Type	Canada Basin 				Mackenzie Shelf 			
	DC (%)	P	Med (%)	StDv (%)	DC (%)	P	Med (%)	StDv (%)
mid June								
Total	-0.4		98.4	5.6	-5.6	*	74.0	19.6
MYI	-5.7	**	82.5	18.6	-7.4	**	8.4	19.1
FYI	5.3	**	15.2	16.3	2.0		60.2	24.3
Y-N	0.0		0.0	1.5	-0.1	*	0.0	0.5
mid July								
Total	-1.7		97.0	9.9	-4.1		44.1	25.8
MYI	-4.6	**	81.1	14.4	0.7		13.9	10.4
FYI	2.9	*	14.1	10.1	-4.9		30.6	21.3
Y-N	n/a				-0.02		0.0	0.1
mid Aug								
Total	-5.8	**	92.7	16.1	-3.4		18.9	23.1
MYI	-8.0	**	77.8	17.7	-0.4		11.4	13.3
FYI	2.3		10.3	10.5	-2.9	*	7.5	12.8
Y-N	-0.1		0.0	0.6	-0.1		0.0	0.3
mid Sep								
Total	-7.4	**	88.9	16.0	-3.2		11.0	18.9
MYI	-10.5	**	76.7	19.6	-2.4		9.3	14.8
FYI	2.0	*	6.9	7.8	-0.9		1.5	6.4
Y-N	1.1	**	0.0	3.4	0.1		0.0	1.4
mid Oct								
Total	-1.3		97.4	7.7	-7.1		74.6	29.7
MYI	-8.8	**	86.6	18.0	-3.1		11.9	17.1
FYI	0.4		0.0	2.2	-1.9	**	0.0	6.2
Y-N	7.0	**	9.8	15.0	-2.1		45.4	24.6

NOTE:

Entries are included for decadal change rates (DC) (in % coverage change per decade); statistical significance; median ice concentration and standard deviation of median ice concentration. Separate statistics are provided for total ice, multi-year (MYI), first year (FYI) and young-new (Y-N) categories.

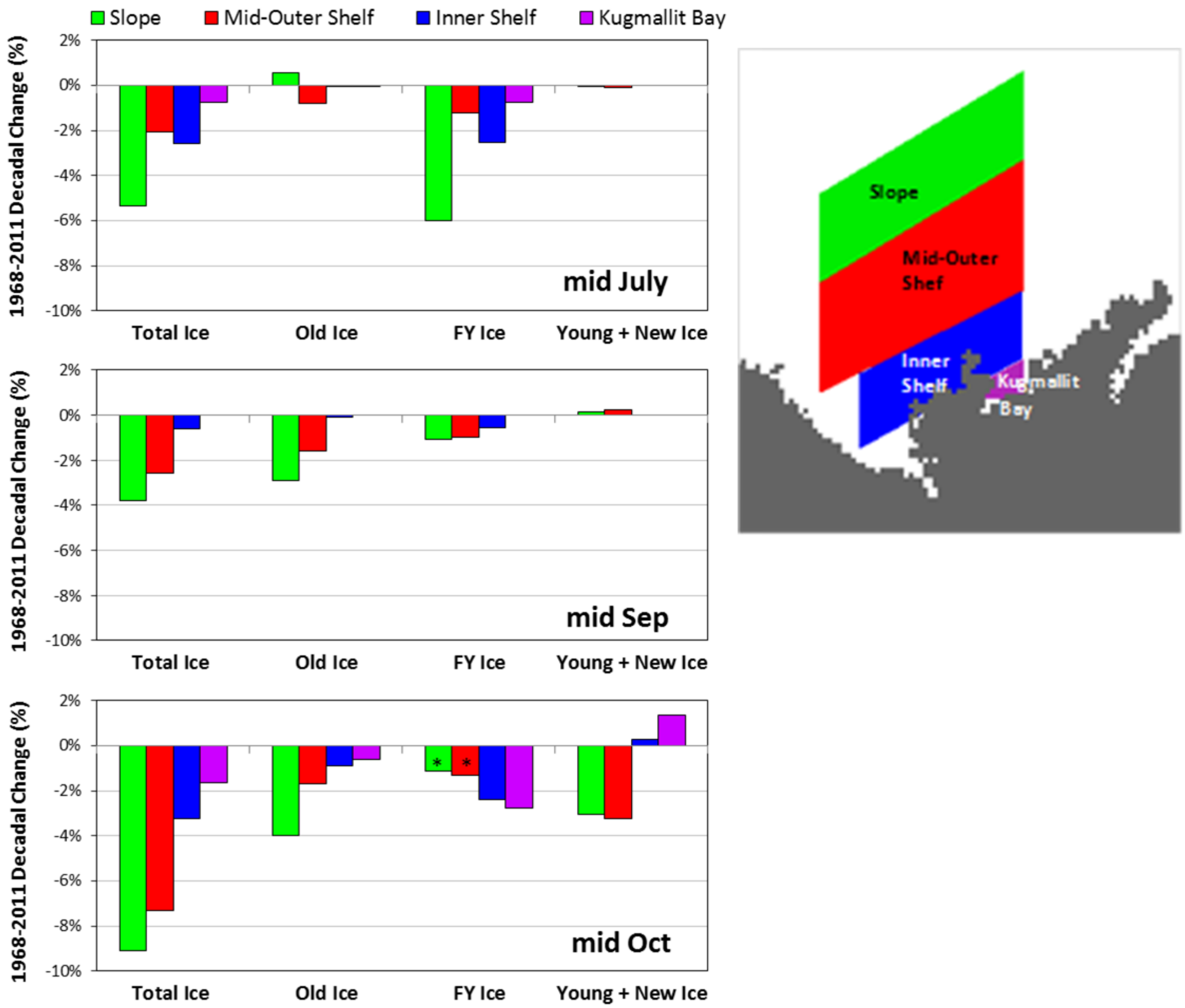


Figure 9 **The computed changes in sea ice concentration from 1968 to 2011 for the four subregions (shown on the right) in mid-July, mid-September and mid-October.**

A recent study by Galley et al. (2012) on landfast sea ice conditions in the Canada Arctic reveals that the formation of landfast ice in the coastal margins of the Mackenzie area of the Beaufort Sea (area shown in Figure 9) has undergone a delay of 2.8 weeks per decade from 1983 to 2009, which is statistically significant. Over this same 26 year period, the break-up dates of the landfast ice have advanced at 0.65 weeks per decade also at a statistically significant level. Reductions in the duration of the landfast ice season will reduce the duration for use of ice roads, which are used to support inshore oil and gas activities resulting in a curtailment of inshore drilling operations in fast ice during winter and spring. The timing of the onset of the melting of fast ice, which occurs prior to break-up is very important because after this time, transportation on the ice effectively ends.

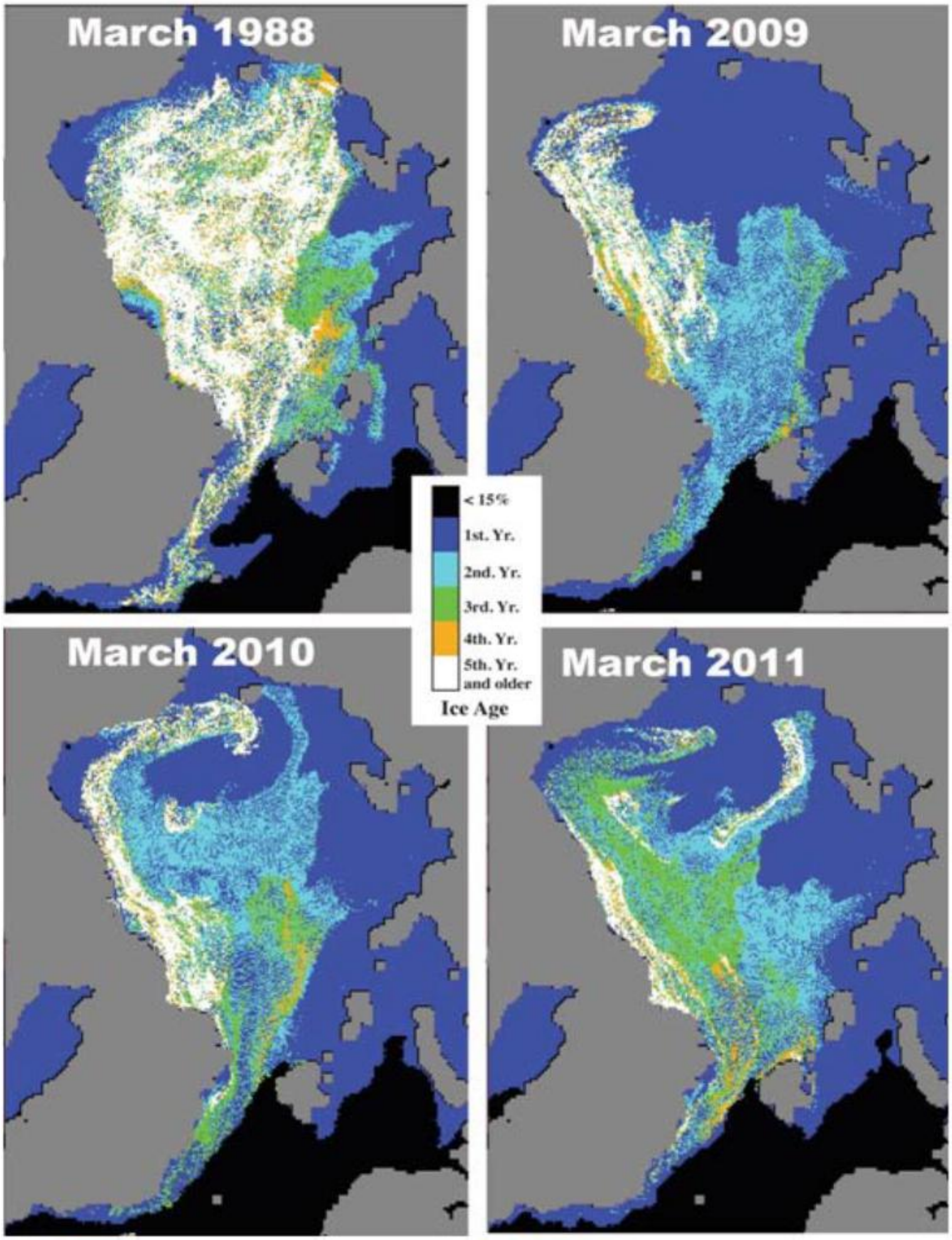
3.2 Sea Ice Thickness

Corresponding changes in sea ice thickness are harder to quantify than is areal extent. Reductions in sea ice thickness in the deep water basins of the Arctic Ocean have been inferred from comparisons of submarine upward looking sonar measurements from 1958 to1976 with those obtained in the 1990s (Rothrock et al. 1999; Wadhams and Davis 2000). Comparison of sea-ice draft data acquired on submarine cruises indicates that the mean ice draft at the end of the melt season has decreased by about 1.3 m in most of the deep water portion of the Arctic Ocean, from 3.1 m in 1958 to 1976 period to 1.8 m in the 1990s. The decrease is greater in the central and eastern Arctic than in the Beaufort and Chukchi seas (Rothrock et al. 1999). The mean ice draft in the Beaufort Sea, as measured by submarine cruises was reduced from 1.95 m (1958 to1976) to 1.0 m (1993 to1997). More recent measurements from the ICESAT satellite program 2003 to 2007 datasets indicate only a very small change in the average ice draft of less than 5% from those of the mid-1990s (Kwok and Rothrock 2009).

The reduction in multi-year sea ice can be quantified through the computation of ice age using satellite observations combined with modeling, as shown in Figure 10, and illustrates how the areal extent of multi-year ice in the Beaufort Sea deep water areas has declined dramatically in the years 2009–2011 as compared to 1988 especially in the four-year and older category. The overall sea ice concentrations in March are little changed, with first, second, and third-year ice being present in the area. Reduced amounts of old ice would lead to reduced ice thicknesses. However, deformation of first-year ice can also create drafts as large as older ice, and under larger ice drifts that have been reported in the Arctic Ocean, it is possible that first-year ice is becoming more deformed which may lead to larger maximum ice draft values for this sea ice category.

A modest level of recovery in the amount of old ice may have occurred in the overall Arctic Ocean (Maslanik et al. 2011) subsequent to the record low year of 2007 (Figure 10). However, the same study has shown that “the recovery has been weakest in the Beaufort Sea and Canada Basin, with multiyear ice coverage decreasing by 83% from 2002 to 2009 in the Canada Basin, and with more multiyear ice extent now lost in the Pacific sector than elsewhere in the Arctic Ocean.” (Maslanik et al. 2011).

The considerable changes in the late summer sea ice cover of the Arctic Ocean as a whole and in the deep water area of the Canada Basin adjoining our study area, may be related to a change in the atmospheric circulation patterns of the western Arctic Ocean. Sea ice and ocean observations from 2001-2011 suggest that the Arctic Ocean climate has different characteristics in recent years than those of the period 1979-2000 (Proshutinsky 2011). In particular, there is less sea ice and the upper part of the ocean is warmer and fresher. The changes appear to be related to “the anticyclonic (clockwise) wind-driven circulation regime (which) has dominated the Arctic Ocean for at least 14 years (1997–2011), in contrast to the typical 5-8 year pattern of anticyclonic/cyclonic circulation shifts observed from 1948–1996” (Proshutinsky 2011). The decline in sea ice extent and large reduction in multi-year ice, as described previously, in the form of melting ice as well as other mechanisms has increased the fresh water content of the upper ocean in the offshore Beaufort Gyre area. Over the shelf areas, the trend for increased freshwater has not occurred (Melling, pers. communication, 2012). Ocean heat content typically affects the melt flux to the sea ice either through upwelling of warmer water from depth or through solar insolation heating the ocean surface mixed layer which then adds heat to the base of the sea ice.



SOURCE: Perovich et al. 2011; figure courtesy of J. Maslanik and C. Fowler

Figure 10 Sea ice age in the first week of March derived from tracking the drift of ice floes in 1988, 2009, 2010 and 2011.

For the Mackenzie shelf region, more than two decades of ice draft data have been collected by Dr. H. Melling of DFO from upward-looking sonars moored in the southeastern and eastern ends of the Beaufort Sea since 1991. The longest duration record, collected at 70.3^0 N, 133.7^0 W, corresponding to the shoreward half of the mid-outer shelf region NNW of Kugmallit Bay, provides the best basis for detecting change in thickness or draft parameters. Figure 11 presents compilations of monthly means for this site based upon averaging carried out solely as a function of time and, as well, with restrictions to time intervals when ice was detectable at the monitoring site. Data are included only up to mid-2008. The trend lines, derived by Melling for both the corresponding overall and ice-only means, are not indicative of statistically significant trends. Nevertheless, it is of interest to explore the possibility that the apparent post-1998 downward trend in northern hemisphere ice extents and in trend plots of 1992–2011 Canada Basin for old and total ice has a counterpart in the draft records. Some insight in this respect could be gathered from the mean thickness data included in Figure 12 for the years 2005–2010. Although still inconclusive these results (Niemi et al. 2012, in press) suggest that recovery from the downward 2005–2008 trend appeared to occur in 2009–2010 leaving intact Melling's conclusion that no trend in thickness or topography has, as yet, been detected on the Mackenzie Shelf and, in any case, any trend present would currently be overshadowed by year to year and shorter term variability.

3.3 Meteorology: Air Temperature, Precipitation and Winds

Long-term coastal weather station data provides a means of examining changes over many decades. For this study, the Environment Canada weather station data collected at Tuktoyaktuk and Sachs Harbour were analyzed for long-term trends by individual months (Table 2 and Figure 13). The long-term trend results show an overall increase in monthly mean air temperatures for all months over the past 50 years. The largest amount of warming occurs in the fall and winter with a total warming of about 4°C in the past five decades or a decadal change of 0.8°C for both Tuktoyaktuk and Sachs Harbour. We note that the relationship between warming and sea ice extent can be complex. For example less ice can create warmer coastal temperatures due to advection of warmer air masses into the region from the south and may not affect sea ice extent at all.

In the spring and summer months, the warming is less and not statistically significant with increases over 50 years ranging from 0.7°C (August) to 2.6°C (June) at Tuktoyaktuk, with an overall increase of 0.4°C per decade. The warming is less in spring and summer at Sachs Harbour with an overall increase of 0.3°C per decade.

The trends in other meteorological parameters have been examined in this study and in the literature. In conjunction with warming air temperatures, precipitation in the Arctic has been increasing over the past century, although the trends are smaller than for air temperature, at about 1% per decade, and highly variable by subregions (McBean et al. 2005). It should be noted that the amount of total annual precipitation in Arctic regions, including the Beaufort Sea, is very small by comparison to temperate regions. However, long-term changes in accumulated snow and occurrences of blowing snow can be important to oil and gas activities.

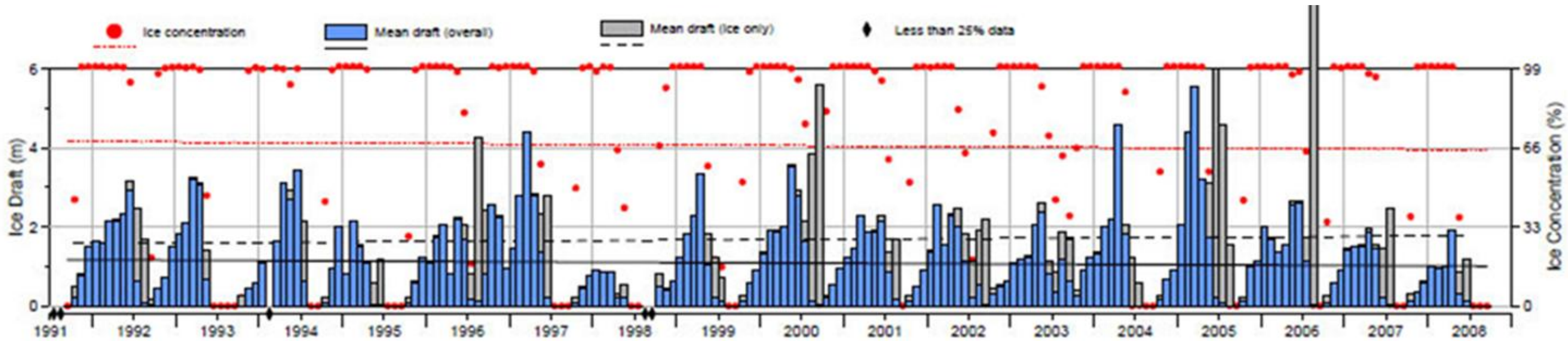


Figure 11 **Monthly mean draft of sea ice at a mid-shelf location on the Mackenzie shelf of the Beaufort Sea (70.3N, 133.7W). Trend lines are shown for the ice concentration (red), overall ice draft including open water as ice of zero draft (solid black) and ice draft excluding open water. None of the trends are statistically significant.**

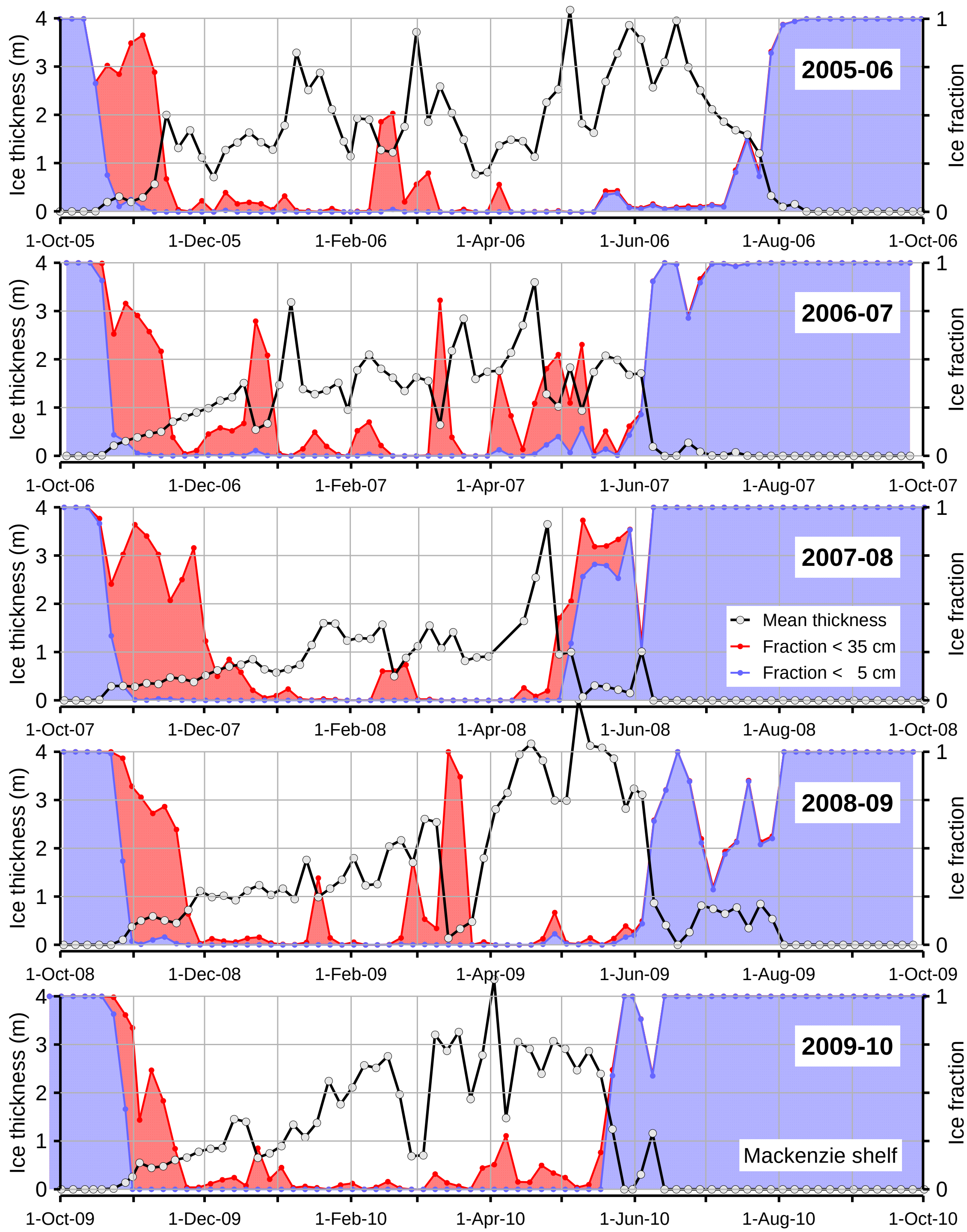


Figure 12 **The mean ice thickness, along with ice fractions of thinner ice (< 5 cm and < 35 cm) at 5 day intervals at the mid-shelf measurement site in the Canadian Beaufort Sea for five years: 2005–2006 to 2009–2010.**

Table 2 Monthly air temperature trends from 1960 to 2011 at Tuktoyaktuk and Sachs Harbour

(*) if p≤0.05 and two (**) if p≤0.01

	Tuktoyaktuk			Sachs H.		
Month	TC	p	DC	TC	p	DC
Jan	4.2	*	0.8	5.1	**	1.0
Feb	5.2	**	1.0	4.5	**	0.9
Mar	4.1	*	0.8	2.5		0.5
Apr	4.1	*	0.8	4.2	**	0.8
May	1.8		0.4	0.3		0.1
Jun	2.6	**	0.5	0.9		0.3
Jul	1.3		0.3	0.9		0.2
Aug	0.7		0.1	1.4		0.3
Sep	2.0	*	0.4	2.2		0.4
Oct	1.7		0.3	2.6		0.5
Nov	2.9		0.6	3.9	*	0.8
Dec	2.5		0.5	3.2		0.6
Med	***2.6***		**0.5**	***2.6***		**0.5**
Med FW	4.1		0.8	3.9		0.8
Med SS	1.8		0.4	0.9		0.3

NOTE:

The computed change in the long-term trend (TC, computed as 2001–2011 mean less the 1960–1970 mean), statistical significance (* $p<0.05$, ** $p<0.01$) and decadal change (DC in °C/10 years) are presented. Med=median, FW=fall-winter, SS=spring-summer).

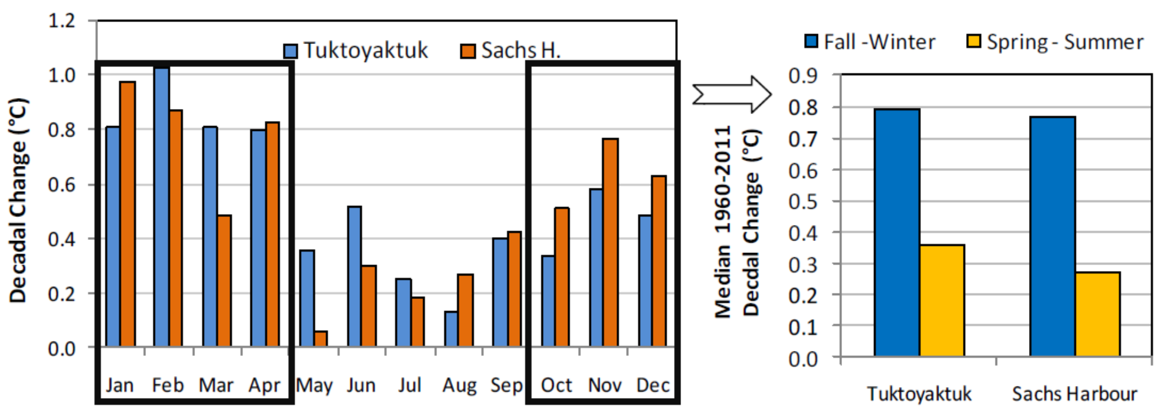


Figure 13 Monthly decadal change in air temperature for Tuktoyaktuk and Sachs Harbour 1960–2011 (left) and seasonal median decadal changes (right).

Surface wind data from coastal weather stations, available over the past 50 years or more, indicate little or no increase in wind speeds and storm frequencies along the coastline of the Beaufort Sea (Hudak and Young 2002; Atkinson 2005; Manson and Solomon 2007). A recent study of monthly Beaufort Sea winds (measured at Tuktoyaktuk NWT and the marine weather station at Pelly Island NWT) reveal only small trends for most months. The long term trends in the monthly average coastal wind speeds as computed for the March-April and October-November periods had a net change of approximately –20% over the years 1958 to 2007 (Fissel et al. 2009). The analysis of monthly wind stress from re-analyzed numerical model wind results over the years 1948 to 2006 (Hakkinen et al. 2008) are consistent with negative trends for the inshore shelf waters of the western Arctic Ocean. Overall, the monthly mean wind speeds in coastal areas appear to have decreased over the past five decades. However, wind speeds may be increasing in offshore areas (Hakkinen et al. 2008). There is an increase in the depth of offshore low pressure systems but not an increase in the frequency of cyclones (Lukovich and Barber 2006; Barber 2012, personal communication). More cyclones tend to follow the sea ice/ocean interface and as such these storms are moving further offshore as the ice edge retreats. The Beaufort Sea high pressure system has become stronger in the years 1996 – 2011 (Moore and Pickart 2012) leading to enhanced easterly winds in the Beaufort Sea with larger increases at more offshore locations.

Reduced visibility, along with increased cloudiness, are also potential consequences of the longer open water season associated with the reduced duration of sea ice described above. During the spring and fall shoulder seasons open water persists longer in the presence of very cold air temperatures. This may result in more fog and thus reduced visibility. Increased cloudiness has been linked as a coupled process to the earlier clearing and later formation of sea ice (AMAP 2011).

Changes in the atmospheric boundary layer of particular importance are the strength and height of the surface inversion and its downwind potential for adverse air quality conditions. Bintanja et al. (2012) determined that the autumn and winter surface inversion is weakening under warming air temperatures which has the potential to increase the amount of surface air temperature increases due to climate change. However, the surface inversion is not prevalent in the summer months.

3.4 Oceanography: Ocean Currents, Temperature and Salinity and Waves

The availability of long time series of oceanographic data in the study area is much more limited by comparison to atmospheric and sea ice data sets. Extended ocean current measurements were first made during the Beaufort Sea Project of 1974–1975 and resumed during the oil exploration boom from the late 1970s to the late 1980s. In the 1990s to the early 2000s, oceanographic studies were very limited with the exception of some measurements on the continental slope by DFO in the 1990s and the ongoing long-term upward looking sonar mooring measurement program (sea ice and ocean currents) at a mid- and outer shelf location north of Tuktoyaktuk (Melling et al. 2005). Starting in the mid-2000s to the present, multi-year measurement programs have resumed through university (ArcticNet CASES and CFL projects) and oil industry programs, especially on the outer shelf and slope areas (as discussed in more detail in Section 2.1: Literature Search and Review).

However, the available oceanographic data sets described above preclude a characterization of the long-term trends or changes in oceanographic properties over the past two to three decades. Continuous measurements of oceanographic properties spanning several years or longer at specific locations do not exist, other than the two mooring sites offshore of Tuktoyaktuk (Melling et al. 2005). The problem is compounded by the nature of ocean current variability, which has spatial scales of 10 km or less – much smaller than the spatial scales of weather and ice parameters. Addressing these limitations will require ongoing oceanographic measurement programs that are better coordinated to generate long time series data sets of decadal duration at agreed upon locations representative of key dynamical regimes including: the inshore area in water depths of less than 20 m both within and beyond the Mackenzie concentrated plume area of the inner shelf, middle and outer shelf locations, the continental slope area and special dynamic areas of the Mackenzie Trough and the Cape Bathurst region.

Direct year-round measurement of ocean waves have been underway in the Southern Beaufort Sea over the past decade with the advent of moored upward looking sonar instruments that can be programmed to obtain non-directional wave data as well as ice draft measurements. Analysis of these data sets (Fissel et al. 2012) reveal episodes of larger waves observed over the past 10 years that are considerably larger than would be expected on the basis of earlier summer buoy-based wave measurements in the 1980's and wave modeling studies (Swail et al. 2007) based on these earlier data sets and the prevailing sea ice conditions of this earlier period. Of particular importance is the finding that the largest episodes of ocean waves occur in October and early November with significant wave heights reaching peak values of 5 - 8 m over the 10 year period of observations (Fissel et al. 2012) which are larger than the estimated 25 year significant wave height based on the earlier measurement and modeling studies.

3.5 Contaminants

In the coastal zone, increased air and water temperature will lead to melting of permafrost and the release of gases such as methane. An increase in the frequency, duration and intensity of storms leading to increased coastal erosion may release polycyclic aromatic hydrocarbons (PAHs) through re-suspension of sediments in the shallow coastal areas where oil based drilling muds and cuttings containing PAH were discharged in the past. Another factor that may increase contaminant input (particularly hydrocarbons) and contaminant dispersal and distribution to the coastal zone of the Beaufort Sea is an increase in suspended load and flow volume of the Mackenzie River driven by a warming watershed.

In the deeper offshore areas, changes in sediment and water quality will be less pronounced as this area is farther from most contaminant sources than the coastal areas, is less susceptible to disruptions to the water column and seabed, and has lower biomass.

Superimposed on the whole region will be changing inputs of contaminants from stores in permafrost, glaciers and sea ice and from long range transport of airborne pollutants (LRTAP). The magnitude and net direction of this effect is difficult to predict on local scales. It may not necessarily be significant but has the potential to enhance pyrogenic PAH, organochlorines (OCs), and other environmental contaminants (including mercury) thereby increasing the pre-development baseline chemical environment.

3.6 Seabed

Ice scours are a common feature of the seabed on the inner Beaufort Sea shelf. Ice scours occur when ice pressure keels cut through sediments in the seafloor. At water depths of 10 m or less, approximately

25% of the seafloor surface has been reworked by ice scours. In water depths greater than 10 m there is a significant increase in the amount of seabed surface reworked. In areas with depths in excess of 12 m more than 75% of the seafloor is reworked by ice scouring (Héquette et al. 1995). A comparison of ice scour impact rates for 1990–2003 and pre-1990 for scours with a depth of 0.5 m or greater resulted in an observed reduction of ice scour impact rates by 40% since the pre 1990 period (Blasco et al. 2004). With the reduction in the duration of sea ice predicted to continue ice scouring rates, especially for extreme ice scours, may also be reduced. However more mobility of sea ice may lead to increases in the deformation of first year sea ice which could increase ice drafts. Although the potential for extreme ice scour events may be decreasing as a result of reduced multi-year ice it does not completely eliminate their potential from occurring. The occasional presence of glacial ice, which is relatively new in the Beaufort Sea, may lead to ice scouring at depths beyond the 70 m water depth.

3.7 Possible Future Changes: The Next 20 to 50 Years

The possible changes from the present into the future over time scales of 20 to 50 years can be estimated through extrapolation of recent trends and from the use of global and regional climate models used in the study of climate change.

As discussed above, the trend toward reduced sea ice has been occurring for more than 40 years throughout the study area, with the largest reductions occurring in the deep water areas of the continental slope and further offshore. The trend of sea ice reduction, especially for the old ice, has increased in the past 10 to 20 years. Based on these findings, it would seem reasonable to expect the reduction of sea ice to continue at least in the short term of the next decade or two. For the Arctic Ocean as a whole the 30 year trend from 1980 to 2009 has been a net reduction of approximately 1% per year in sea ice areal extent during late summer at the time of minimal sea ice extent. If this trend were to continue at the rate of the past 30 years, then a seasonally ice free Arctic Ocean would occur in approximately 70 years from now, i.e., in 2080. If the reduction of sea ice occurs at a faster rate, which has been the case over the past 15 years, at approximately twice the past 30 year trend rate, a seasonally ice free Arctic Ocean would be realized in 35 years from now, i.e., in approximately 2045. Due to the powerful feedbacks in the system (AMAP 2011) some sea ice experts, most notably Dr. Wieslaw Maslowski of the US Naval Post Graduate School and Dr. Peter Wadhams of Cambridge University, have suggested a seasonally ice free arctic could occur sometime within the next decade or two. It should be noted that total clearing of ice from the Arctic Ocean is limited to the period of late summer. Seasonal ice would continue to occur in the fall, winter, spring and early summer seasons for many decades following the first year of total ice clearing in the Arctic Ocean.

Global and regional climate models have been developed and widely used to compute changing Arctic Ocean sea ice conditions in the 21st century. These models are in universal agreement that Arctic sea ice extent will continue to decline through the present century (Stroeve et al. 2007) with sea ice remaining present through most of this century. On average, the models, as run in the mid-2000s, forecast a 45% reduction in late summer sea ice extent by the year 2050 with reduced levels of sea ice persisting in late summer throughout the 21st century. However, a reduction of nearly this much was realized in the summer of 2007 from the previous year, as discussed above, and again in the summer of 2012 from that of 2011 to a new record low value since observations began in 1979. The actual sea ice areal extent from

2007 to 2012 continue to be lower than the model forecasts leading to the possibility that the Arctic Ocean may be free of sea ice well within this century, as has been suggested by Stroeve et al. (2007), Barber et al. (2009) and others over the past decade . The most recent modeling studies, which are initiated with the actual 2007/2008 Arctic Ocean ice extents, indicate that a nearly ice free Arctic Ocean could be realized by approximately the year 2037, 30 years after the major reduction in summer sea extent experienced in the year 2007 (Wang and Overland 2009). Another recent climate modeling study (Zhang et al. 2010) indicates that it is not likely that the Arctic Ocean will pass a threshold to become ice free in summer permanently before 2050 even though some individual summers may be ice free prior to that year. However, if Arctic surface air temperature increases 4°C by 2050 and climate variability is similar to the past relatively warm two decades, a summer ice free Arctic Ocean is possible by the mid-2040s or even earlier, as described above. Even under these model predictions of no sea ice coverage during the late summer period in the Arctic Ocean, sea ice will still form in the fall and be present through the winter, spring and early summer period; however, only first year sea ice will be present through the year and the harder and thicker multi-year sea ice will no longer occur over much of the Arctic Ocean. It should also be noted that the thick ice around the Canadian Arctic Islands will likely persist well after the Arctic Ocean itself is largely ice free in late summer due to the fact that sea ice circulates around the Beaufort Gyre and piles up along the northwest flank of the Canadian Arctic Islands. The multiyear ice in the Canadian Arctic Islands, especially along its northwest flank which is upstream of the Canadian Beaufort Sea, is likely to persist long after most of the Arctic Ocean becomes ice free in late summer.

Because the coupled models forecast air temperatures will remain well below the freezing point from late fall through to spring for many decades to come, the Arctic Ocean winter ice extent will continue to be present throughout the 21st century and beyond. This could make the Beaufort Sea ice environment very similar to what is currently experienced in Hudson Bay.

The expected reduced sea ice conditions, and their relation to regional and global atmospheric and climate conditions, will coincide with changes in other parameters:

- continuing increase in air temperatures, especially in the fall and winter at rates similar to those experienced in the past 50 years
- increases in precipitation as air temperatures warm with more snow in winter and more rain in summer
- warming and freshening of the offshore ocean waters due to more open water and increased ice melt
- larger ocean waves occurring over longer periods of time in summer and fall, in association with the reduced sea ice coverage
- enhanced upwelling at the shelf edge under the combined effect of reduced ice extent and the increased prevalence of the anticyclonic atmospheric circulation of the western Arctic Ocean (Pickart et al. 2011)

4 TRADITIONAL KNOWLEDGE ON CLIMATE CHANGE

There is a limited but growing body of traditional knowledge literature pertaining to climate change in the Western Arctic. In some cases the Traditional Knowledge study had a climate change focus (e.g., Barber et al. 2012) while other studies were project specific (e.g., KAVK-AXYS 2011, 2012) but climate change was raised by those interviewed. The literature focused on harvested species, harvesting areas, travel routes and communities. Although the literature does not discuss Traditional Knowledge in relation to offshore related oil and gas activities, the knowledge gained through these studies is useful in understanding the effects of climate change on the environment which in turn can be used to assess how these effects will potentially affect oil and gas activities.

There were several common observations amongst reports reviewed for this study. These included:

- changing and unpredictable weather
- increased frequency and severity of storms
- later freeze-up of ice and earlier break-up
- more open water in winter and thinner ice
- increased permafrost melting and slumping
- increased coastal erosion

Common weather observations from all ISR communities include; weather being less predictable, more wind in summer, higher temperatures, less snow, and winter lows not being as extreme (Community of Aklavik et al. 2005; Reidlinger and Berkes 2001). In Aklavik, Inuvik and Tuktoyaktuk it was also reported that summers were becoming longer and winters shorter (Barber et al. 2012; ICC et al. 2006) Observations on changes to the landscape common to all communities in the ISR include more erosion of banks and shores, more sedimentary deposits into the ocean and rivers, diminishing thickness of sea ice, earlier spring break-ups and later fall freeze-ups (Barber et al. 2012; Community of Aklavik et al. 2005; Reidlinger and Berkes 2001).

Climate change related observations specific to the community of Sachs Harbour on Banks Island included freeze-up occurring 3-4 weeks later than normal, more severe storms and wind, and the absence of ice flows and multi-year ice during the summer period. Residents have reported during the fall and winter period more open water, later freeze-up, thinner and less stable ice (Nichols et al. 2004; Reidliner 1999; Reidlinger and Berkes 2001) and increased rain in the fall period (Nichols et al. 2004). Permafrost was observed melting at faster rates than in the past (ICC et al. 2006; Reidliner 1999; Reidlinger and Berkes 2001). Residents also reported catching the occasional Pacific salmon such as pink and sockeye salmon (species identity confirmed by DFO) which was said to be new for the area (Reidliner 1999; Reidlinger and Berkes 2001).

A Traditional Knowledge study (ICC et al. 2006) was conducted in support of the Mackenzie Gas Project (MGP) and focused on areas used mainly by the communities of Aklavik, Tuktoyaktuk and Inuvik. In addition to the common observations mentioned above, these communities noted that the air is now damper, less ice was present in the Beaufort Sea during the summer than there used to be, and during the winter the ice was thinner than in the past. Study participants noted increased levels of coastal erosion and melting of permafrost. Many mudslides have been observed between Shingle and Kay Points. Coastal erosion is also increasing along Tuktoyaktuk Peninsula. Warmer water temperatures and later freeze-up may be affecting fish distribution and the timing of migrations. Some reported the fish as not appearing as healthy as in the past. Stephenson (2004) suggested climate change resulting in changes in the timing of fish appearance and location as one possible explanation for reduced harvest levels of fish.

Traditional Knowledge collected from Sachs Harbour, Ulukhaktok and Paulatuk refer to the sea ice in Amundsen Gulf as being thinner than in the past. During winter, the area between Cape Parry and Nelson Head on Banks Island often froze over; now it rarely freezes over (KAVIK-AXYS 2011; Barber et al. 2012). Freeze-up is reported to be occurring 2-4 weeks later while break-up is occurring up to two weeks earlier (KAVIK-AXYS 2011; Barber et al 2012). Travelling on the ice along the coast of Darnley Bay cannot always be done safely now until December (KAVIK-AXYS 2011). Similarly travel along the north coast of Amundsen Gulf has become more restricted with hunters unable to travel as far off the coast as they used to due to unsafe ice conditions or open water. Up to the 1980s one could travel over 40 miles straight out onto the ice in Amundsen Gulf from Nelson Head. Now it is dangerous to go out 5 miles as the ice is not as thick or strong (Barber et al. 2012).

The land fast ice around communities is reported as changing in terms of stability and thickness. These changes have been observed since the 1970s but changes are occurring more dramatically since the 1990s (Barber et al. 2012).

Floe edge conditions are reported to be changing. Ice ridges are smaller and fewer in number while there is more rubble ice. Around Pearce Point there is now more jumbled (rubble) ice caused by the ice being younger and not as thick and it is turned into rubble by the currents and winds (Barber et al. 2012). The ice around Cape Parry was also said to be looser until January or February (Barber et al. 2012).

Community residents of Sachs Harbour, Ulukhaktok and Paulatuk report more areas of open water though out the winter where in the past these areas would remain frozen over. There is also more open water along the floe edge (Barber et al. 2012).

The community of Paulatuk developed a climate change adaptation plan which identifies several key concerns that are also pertinent to oil and gas activities, in particular to those activities occurring in coastal areas. The concerns were identified through a community workshop and included:

- Increased blowing snow creating hazards and obstructions to transportation.
- Rising sea levels coupled with increased storm activity and its potential impacts through shoreline erosion.
- Increased thawing of permafrost and its potential effects on infrastructure integrity and lifespan.
- Increased ponding due to permafrost thawing.

Climate change related Traditional Knowledge studies have been conducted in all six of the ISR communities. Unfortunately, there is no single compilation of the Traditional Knowledge contained in these studies, nor a complete mapping of all this information.

Traditional knowledge was collected and reported in Hartwig (2009) in support of the identification of Ecologically and Biologically Significant Areas (EBSAs) in the Beaufort Sea. Although this report does not include any discussion or comments related to climate change it may provide a good source of coastal baseline traditional knowledge and mapping to build future Traditional Knowledge studies on related to climate change.

5 CLIMATE AND SEA ICE VARIABLES

5.1 Climate Variables

The potential positive and negative effects of climate change on oil and gas activities were assessed for various exploration and development scenarios. For each potential effect, one or more climate or ice variables were identified. In many cases the effects of climate change for a particular activity remain the same regardless of the scenario; e.g., aircraft support may be required for all scenarios, and the potential effect of climate change restricting aircraft flights due to a possible increase in fog frequency remains the same throughout.

Climate change effects on oil and gas activities are primarily physical in nature, such as ice posing a threat to shipping or drilling activities, waves affecting ship based activities and coastal erosion affecting shore based support structures. Changes to chemical and/or biological oceanographic properties as a result of climate change generally will have an indirect effect on oil and gas activities. For example it is often difficult to separate cause and effect in many physical-biological coupled studies. Impacts may be due to development pressures or they may be due to climate change, or both. Similarly biogeochemical changes in the Southern Beaufort Sea (SBS) may have multiple sources, including effects from development and climate change, and attributing cause is often difficult.

Changes may occur in contaminant levels in the water column or biota due to climate change related changes in water temperature, wind direction or re-suspension of sediment due to wind action or flooding. Climate change may also affect species composition, distribution, migratory behavior, or sensitivity to perturbation by oil and gas activities. For example changes in water temperature and salinity could affect the migratory behavior of harvested species such as beluga or whitefish which in turn could affect harvesting opportunities and success rates. Higher contaminant levels (e.g. polycyclic aromatic hydrocarbons [PAHs], heavy metals and organic contaminants [OCs]) in the water column or biota, and other changes to the biota could lead to changes in necessary regulations or guidelines. Changes in guidelines or regulations could come about due to increased elevations of contaminants in the water column or sediment nearing or exceeding thresholds for aquatic biota resulting in restrictions of potential discharges by industry into the marine environment. Changes to guidelines or regulations could also affect oil and gas operations part way through the life cycle of an oil and gas project (e.g., production project).

WAVE HEIGHT (MAXIMUM AND MEAN):

Wave height has potential effects for both nearshore and offshore oil and gas operations. Temporary shut-down in seismic surveys or re-supply operations may result from increased wave height due to safety concerns for people and equipment. Wave height may also affect coastal areas through its contribution to accelerated rates of coastal erosion which may affect oil and gas industry infrastructure including pipelines where they come onto land. Increased or sustained increased wave heights can affect the construction and maintenance of artificial islands in nearshore areas through greater threats of erosion to the islands.

Advances in subsurface sonar and satellite technologies have enabled wave height data collection from late spring to late fall over the past decade. The occurrence of large wave events that could affect oil and gas operations is considered as occasional and would mainly occur during periods of high winds and in ice free conditions producing a larger fetch. Wave height issues may increase as summer ice levels continue to decline, thereby increasing fetch and the potential for larger wave development. The effects of wave height include the whole Beaufort Sea region and are expected to continue over the long-term.

WIND SPEEDS (MAXIMUM, MEAN AND PROJECTED EXTREME VALUES):

Increased and/or sustained wind speeds may affect both nearshore and offshore oil and gas activities in terms of the strength and frequency of storm winds. In the offshore, wind speeds and the fetch of the wind over open water affects wave height which in turn affects ship based activities such as drilling, re-supply or seismic surveys. Wind speed also can cause wind stress to offshore as well as nearshore or onshore infrastructure. Wind also affects the movement of sea ice; increased wind speeds may result in less response time available to conduct or react with ice management operations associated with offshore activities. Wind speed's contribution to wave height may lead to increased coastal erosion affecting oil and gas infrastructure, pipelines or construction and maintenance of artificial islands in nearshore areas.

The measurement of wind speed is practical to obtain and has a high degree of measured accuracy. Long-term records exist, at least for coastal areas. There are no permanent meteorological stations in the offshore and therefore site specific wind speed measurements in the offshore are restricted to when vessels are present to record this information. The effect of wind speed on oil and gas operations is not continuous but would occur during periods of high wind speed. Shore based stations are known to have different wind speed (and often direction) than winds offshore (Barber and Hanesiak 2004). Technologies have been developed (Komarov et al. 2012) to acquire both wind speed and direction in the Marginal Ice Zone (MIZ) and will be useful in offshore monitoring.

OCEAN TEMPERATURES AND HEAT CONTENT:

Increasing sea surface temperature can contribute to the increased rate of ice melt, and delays in freeze-up, resulting in both potential positive and negative effects on oil and gas operations. Earlier ice break-ups associated with reversals in the Beaufort Sea ice gyre results in decreased surface albedo which increases the heat in open water areas hastening ice melt. Increasing sea surface temperatures in coastal waters can also contribute to increased coastal erosion. With warmer sea surface temperatures there is the potential for invasive species accidentally transported to the Beaufort Sea via ships to survive and reproduce, where in the past colder water temperatures would prevent many species from establishing themselves. Native species may also be affected by increased sea surface temperatures, affecting their movements, distribution and behavioral traits. Resulting changes in biota from increasing sea surface temperature could lead to changes in operating conditions (e.g., timing of flaring, tanker operations) for oil and gas operators, with some of these changes occurring mid-stream through a project (e.g., during production phase).

While sea surface temperature is a practical measurement which can be recorded directly by in-situ instruments or indirectly through satellite imagery, the more important thermodynamic climate variable is the surface mixed layer heat content. The effect of sea surface temperatures and ocean heat content on oil and gas operations is not well understood but the potential for effects is long-term. The whole Beaufort Sea region would be affected by increasing sea surface temperatures.

SEA LEVEL RISE:

Sea levels are expected to increase in the Beaufort Sea. Many coastal areas in the western Arctic are low lying, especially along the outer Mackenzie delta and Tuktoyaktuk Peninsula. Rising sea levels could lead to flooding in low lying areas especially during periods of storm surge. The effects of rising sea level are further compounded by coastal subsidence which is occurring in some areas of the Western Arctic such as Tuktoyaktuk and Sachs Harbor. With projections of continuing sea level rise and subsidence for some areas of the Western Arctic there is a subsequent increased risk to oil and gas industry related infrastructure. Potential risks include damage to pipelines and other infrastructure such as camps, storage areas and docks due to erosion. There are also potential risks of coastal infrastructure being flooded with sea water especially during storm surges.

Sea level is already measured in some areas of the Beaufort Sea (e.g., Tuktoyaktuk) and is a practical measurement to obtain. Sea level rise can also be modelled for planning purposes in conjunction with isostatic rebound or subsidence.

COASTAL EROSION (RATE OF LOSS):

The effects of coastal erosion on oil and gas operations relate to onshore infrastructure and areas where offshore pipelines make landfall. Increased rates of erosion can lead to the de-stabilization or loss of infrastructure, or damage to pipelines. Adaptive engineering techniques may be required to protect coastal infrastructure and/or construction of more costly shore line protection may be necessary.

Rates of coastal erosion can be measured and modeled. Measurements can have a high degree of accuracy. Increased rates of coastal erosion are occurring and coastal erosion will likely continue and potentially accelerate over the long-term. Effects of coastal erosion are most pronounced along the Yukon North Slope, western coastline of Banks Island and at Tuktoyaktuk, although other areas of the Tuktoyaktuk Peninsula are likely also subject to increased erosion.

SEA ICE TYPE, DISTRIBUTION AND CONCENTRATION:

The elements of these sea ice variables can result in both positive and negative effects on oil and gas operations in the Beaufort Sea. Positive effects of reduced ice cover include improved seismic coverage, reduced requirement for ice breaking, and less obstacles to the movement of support vessels thereby improving efficiency of resupply. Reduced or no ice may also improve operating conditions during dredging or artificial island construction in nearshore areas. Offshore operation seasons may also be extended due to more favorable ice conditions over a longer period.

Multiyear ice occurs in the SBS and is expected to be present for some time to come. Due to the recirculation of sea ice in the Beaufort Gyre, it is expected that thick first-year ice, and even small areal extents of very thick multiyear ice could persist for several years. Sea ice affects wave height through the fetch relationships previously described, and increased winds increase the velocity of sea ice floes. This increase in velocity may create challenges for industry in ice management. Negative effects may include ice hazards to stationary drill ships and support vessels and reduction of the length of the drilling season. Because of the importance of sea ice to other climate variables, further discussion of sea ice is provided in Section 5.2

Information on sea ice type, distribution and concentration is routinely collected. Sea ice variables can be both measured directly and/or modeled, with direct measurements providing more accurate data. Long-term trend data is available. The effects of sea ice are continuous and long-term and affect the whole Beaufort Sea region.

MARINE GLACIAL ICE:

Recent studies have highlighted the fact that ice shelves along the NW flank of Ellesmere Island have lost significant mass. In the past century, a continuous ice shelf extended over 450 km of the Islands' NW coast, joining many discrete exit glaciers. While sporadic losses of ice have occurred from the ice shelves since their discovery in the late 19th century, this large continuous shelf began to break-up at much increased rates early in the last decade with complete loss of the Markham and Ayles Ice shelves and significant mass loss of the Ward Hunt, Milne, Petersen and Serson Ice Shelves (e.g., Copland et al. 2007). Pieces of these ice shelves are now a common feature in Beaufort Sea Ice due to the Beaufort Gyre. Recent work conducted onboard the CCGS Amundsen identified, and placed GPS position beacons on, seventeen of these marine glacial ice features. The features were all very thick (>40m) and varied in size from 100's of meters to kilometers in radius (D.G. Barber, Personal Communication). These marine glacial ice features pose a significant hazard to both stationary drill ships and service shipping required by the hydrocarbon industry. Their detection and management will be of concern.

Seventeen climate and ice variables (Table 3) were identified that relate to potential effects of climate change on oil and gas activities. Each of these were assessed to ordinate their importance (high, medium or low) (Table 4). Seven variables were scored high. These variables are:

- sea ice type, distribution and concentration
- sea temperature and heat content
- sea level rise
- air temperature
- wind speeds (maximum, mean and projected extreme values)
- wave height (maximum and mean)
- coastal erosion (rate of loss)

5.2 Sea Ice Variables

Sea ice variables are both important in their own right, and also have important effects on other climate variables such as ocean waves, currents, temperature and salinity. To understand the distribution of sea ice, coupled ice-ocean-atmospheric models are widely used to understand the distribution of sea ice on spatial scales from the full Arctic Ocean region to more localized subregions.

5.2.1 Coupled Global and Regional Climate Models with Application to the Arctic

Global climate models have been widely used to forecast the rapidly changing sea ice conditions in the Arctic as part of the Intergovernmental Panel on Climate Change, Fourth Assessment Report (IPCC AR4) and other scientific projects. As noted by Stroeve et al. (2007), global climate system models do not include all components of the Arctic climate system, and errors remain in their simulation of the current and past state of the Arctic. These errors arise from many sources including errors propagating into the Arctic from lower latitudes, inadequate representation of polar climate processes, and coarse model resolution (Cassano et al. 2011). A way to overcome these limitations is in the development of regional coupled atmosphere-ice-ocean-land models that can operate at much higher resolution grid sizes and which can provide improved representation of coupling processes due to the finer resolution and the use of more appropriate parameterizations for ocean-sea ice-atmosphere (OSA) coupled process linkages.

Regional coupled climate models for the full Arctic or for subregions are presently under development in Canada, the United States, Europe, East Asia and Australia. Collaborative research is being conducted by Canadian scientists in Environment Canada and Fisheries and Oceans Canada through the CONCEPTS initiative which is being used by the BREA program ("Forecasting Extreme Weather and Ocean Conditions in the Beaufort Sea", Lead: Fraser Davidson). The results from these models will be used to provide better forecasts for the changing Arctic ice including the Beaufort Sea, as well as atmospheric and oceanographic parameters.

Table 3 Climate/Ice Variable Summary

Climate Variable	Region	Present Trend	Estimated Future Changes	Comments; Level of Uncertainty
Sea Ice Area and Concentration (late summer and early fall)	• Canada Basin / Slope • Shelf	• Reduced by 7% / decade • Reduced by 2-3% / decade (but more in early summer)	• Increasing rate of reduction • Reductions will extend later into fall and earlier into late spring	• Trends indicate that nearly ice free conditions will prevail in late summer within 10-30 years; • Models projections are lagging observations.
Sea Ice Type: Old (Multi-Year) Ice	• Canada Basin / Slope • Shelf	• Reduced by 11% / decade • Reduced by 2-3% / decade	• Increasing rate of reduction	• Even with nearly ice free conditions in late summer, incursions of multi-year ice from the CAA will occur ; frequency and severity is uncertain
Sea Ice Thickness	• Far offshore incl. Canada Basin • Shelf and Slope	• Reductions far offshore from 1.95 to 1.0 m • No trends evident since 1991	• May continue to decrease in far offshore areas; • Changes in shelf waters are not known	• Ice thickness is more variable than ice extent regionally; models have difficulty with ice thickness over long time scales
Glacial Ice (Ice Islands)	• Slope and outer shelf areas	• Occurs only rarely but more observations of thick glacial made in recent years	• Occurrences may persist and even increase	• Source levels due to ice shelf ablation in CAA and N. Greenland have increased in the past decade; many uncertainties as to future trends
Ice Velocity	• Far offshore incl. Canada Basin	• Ice velocities have increased by 17% per decade (winter) and 8.5% per decade (summer) Rampal et al., 2009	• Likely to continue to increase	• Long-term trend analysis results are not available the S. Beaufort Sea and sub-regions
Ice Available Days	• Nearshore areas	• Formation delayed by 2.8 weeks / decade (1983-2009); • Break-up dates have advanced by 0.65 weeks / decade	• Trend likely to increase as air temperatures increase but snow cover could reduce or reverse this trend	• Landfast ice models could be improved to provide better understandings

Table 3 Climate/Ice Variable Summary (cont'd)

Climate Variable	Region	Present Trend	Estimated Future Changes	Comments; Level of Uncertainty
Sea Temperature and Heat Content	• Full region	• Long term trend analysis are not available; • solar heat inputs will increase as sea ice concentrations decrease	• Likely to increase given sea ice clearing	• Analysis of existing data sets is complicated by lack of long-term measurements at one location; • model based forecasts are needed
Salinity	• Full region	• Long term trend analysis are not available	• Not clear due to unknowns in trends for river runoff and advection rates out of the region	• Analysis of existing data sets is complicated by lack of long-term measurements at one location; • model based forecasts are needed
Sea Level	• Coastal Areas	• 0.2 mm/yr. sea level rise for Tuktoyaktuk per 1 mm global sea level rise due to Greenland. • Subsistence in Tuktoyaktuk are is 2.5 mm/yr.	• Likely to continue or increase	• Contributions of sea level rise from Greenland cannot be predicted accurately over time. More localized measurement of sea level in the coastal Beaufort Sea region would assist in understanding effects of sea level rise and planning purposes.
Ocean Currents	• Full region	• Present trends are not known due to limited long term data sets	• Not known	• Better coordination in research programs required to provide long-term data sets at same locations; also improved ocean circulation models
Air Temperature	• Coastal regions • Offshore areas	• 0.8 °C / decade warming in fall and winter • 0.3-0.4 °C / decade warming in spring and summer • No data available	• Present trend expected to continue and possible increase based on climate model studies	• More data required for offshore areas
Precipitation		• Smaller trends expected than for air temperature, from climate models	• Present trend expected to continue	• Increased precipitation is not likely to be important, given its present very low levels, but it could be important to increased snow cover

Table 3 Climate/Ice Variable Summary (cont'd)

Climate Variable	Region	Present Trend	Estimated Future Changes	Comments; Level of Uncertainty
Winds	• Coastal regions • Offshore areas	• Trend to reduced averaged wind speed of -20% over past 50 years; • Possible increase in wind speeds	• Long term wind trends are not well understood; • Enhanced easterly winds occurring relative to 1990's and earlier; • Deeper low pressures in offshore cyclonic systems	• Require better understanding of large-scale and regional atmospheric circulation processes from improved coupled atmospheric models and more offshore data collection
Fog / Snow Limited Visibility	• Coastal regions • Offshore areas	• Quantitative estimates not available due to limited data sets	• Occurrences of fog may increase during spring and fall shoulder season as open water persists longer	• Improved data sets and models required to make quantitative estimates
Wave Heights	• Coastal regions • Offshore areas	• Episodes of larger waves observed in fall in the 2000's vs. expected conditions	• The largest wave events are expected to continue to increase as ice areal extent decreases	• Need improved understanding of the future wind regime and sea ice extent as input to modeling studies
Storm Surges	• Coastal regions	• Trend results not available	• Large storm surge events likely to increase as ice extent decreases	• Need improved understanding of the future wind regime and sea ice extent as input to modeling studies
Coastal Erosion	• Coastal regions	• Large coastal erosion events observed in some regions; • No definitive study of coastal erosion rates available	• Coastal erosion likely to increase due to expected increases in sea temperatures, waves and currents and reduced duration of protective sea ice cover	• Understandings of future changes of this complex process required long-term coastal monitoring data and improved model based approaches

Table 4 Key Climate Variable Matrix: to determine key climate/ice variables

Climate/Ice Variable	Practical	Effect (positive and negative)	Frequency of Effect	Urgency	Relevance to Effect	Measured/ Modeled	Measurable/ Accuracy	Spatial Scope	Temporal Scale	Long-term trend data available	Rating
Sea ice areal extent	Yes	• Impediment to Drilling and marine support	Occasional	low	Medium to high	Measured and modeled	High	All	Long-term	High	M
Sea ice type distribution / concentration	Yes	• Reduced ice levels improve seismic coverage • Reduce icebreaking efforts • Increase wave height affecting seismic, and drilling • Less ice results in reduced obstacles for support vessels • Reduced ice may provide improved conditions for dredging and construction of artificial island but increase waves due to wave height may have negative effect • Less ice may improve or extend period for mobilization and demobilization activities	Continual	high	High	Measured and modeled	High	All	Long-term	High	H
Sea ice thickness	Yes	• Thicker ice as a hazard to marine operations such as support ships • Thicker ice may result in increased ice breaking effort • Thin landfast ice is a hazard for inshore winter roads	Continuous	Medium	Medium	Measure and modeled	High?	All	Long-term	Medium	M
Glacial ice (ice islands)	Yes	• Effect on drilling and production due to hazards posed by ice islands.	Rare	Medium	Low	Measure	High	Shelf and deep	Long-term	Low	M
Ice velocity	Yes	• Increased ice velocity poses threats to drill and production platforms	Continuous	Medium	High	Measured	High	All	Long-term	Low	M
Ice available days	Yes	• Ice islands may not be viable thereby having to use more costly options for drilling platforms	Continuous	Medium	High	Measured and modeled	High	Nearshore	Medium to long-term	Medium	M
Sea temperatures and heat content	Yes	• Melting permafrost affecting coastal infrastructure • Changes to regulations or guidelines due to changes in marine mammal migration and habitat use	Unknown	High	Low to Medium	measured	High	All	Long-term	High	H
Salinity	Yes	• Affect location of EBSAs or marine mammals affecting how oil and gas operations may be conducted mid-stream through a project	Continual	Low	Medium	Measure and model	High	All	Long-term	High	M
Sea level rise	Yes	• Sea level rise especially in conjunction with coastal subsistence can accelerate coastal erosion and increase the area affected and severity of storm surges in coastal areas which could affect oil and gas coastal infrastructure.	Continual	Medium	High	Measure	High	Coastal	Long-term	Medium	H
Ocean currents	Yes	• Changes or increases in bottom currents could affect seabed erosion especially at shelf break affecting drilling and production activities • Changes in currents could affect productivity and locations of EBSA's	Continual	Low	High	Measure	High	Shelf and deep	Long-term	Medium	M

Table 4 Key Climate Variable Matrix: to determine key climate/ice variables (cont'd)

Climate/Ice Variable	Practical	Effect (positive and negative)	Frequency of Effect	Urgency	Relevance to Effect	Measured/ Modeled	Measurable/ Accuracy	Spatial Scope	Temporal Scale	Long-term trend data available	Rating
Air Temperature	Yes	• Affects other variables both positive and negative • Reduced ice coverage • Increased coastal erosion affecting infrastructure	Continuous	High	Medium	Measured and modeled	High	All	Long-term	High	H
Precipitation	Yes	• Increased snow cover can lead to reduced strength of ice affecting coastal ice roads	Continuous	Low	Low	Measured	High	All	Long-term	Medium	M
Wind speeds (max, mean and extreme)	Yes	• Elevated winds may cause increased wave heights or wind stress causing effects on support vessel movements, seismic operations, island construction and operation, drilling, production and mobilization and demobilization activities.	Occasional	Medium	High	Measure and model	High	All	Long-term	Medium	H
Days with fog or snow and poor visibility (means and max)	Yes	• Increased incidence of fog related to climate change can restrict flying with effects on ice reconnaissance and aerial support. Safety issues and prohibits potential spill response capability.	Occasional	Low	High	Measured	Medium	All	Long-term	Low	L
Wave height (max and mean)	Yes	• Mobilization and demobilization to Beaufort Sea • Marine shipping support operations • Seismic operations • Drilling activities • Shoreline erosion effects on pipelines and causeways • Artificial island construction and maintenance	Occasional	Medium	High	Measured	High	All	Long-term	Medium	H
Storm surge	Yes	• Storm surge can cause erosion and flooding around coastal infrastructure	Occasional	Low	High	Measured	High	Coastal	Long-term	Low	M
Coastal erosion (rate of loss)	Yes	• Effects on pipelines, • Effects on coastal zone facilities and infrastructure	Continuous	High	High	Measured and modeled	High	Nearshore	Long-term	Medium	H

NOTES:

Practical: no or yes (practical in terms of cost and technical capability)

Frequency: rare; occasional; or continuous - What is the likely frequency that an effect related to a climate variable will occur?

Urgency: low, medium, high - based on when the effect will be of concern to the oil and gas industry or the length of time to develop good baseline or predictive models.

Relevance to effect: low, medium, high - how relevant is the variable to the resulting effect. Example "wave height" is directly relevant to ship related activities therefore relevance is "high".

Accuracy: low; medium; high - whether data collected or modeled for a climate variable can be done so with a high or lesser degree of accuracy.

Spatial Scope: limited to one area (e.g., nearshore); use in two areas (e.g., nearshore and shelf); all - useable throughout Beaufort Sea

Temporal scale needed for measuring the variable: short-term; medium-term; long-term

Long-term trend data available: low; medium; high - low refers to little or no long-term trend data, medium to some long-term trend data but may be incomplete or for intermediate period, while high refers to long-term trend data is satisfactory

Score: low, medium, high

If not practical then cannot be a key climate variable

5.2.2 Key Sea Ice Variables

The key sea ice variables identified for use in this study are derived from the following ice categories:

1. Sea Ice: Sea ice areal extent, type, concentration, thickness, and thermodynamic state are especially important to shipping operations, including drillship activities and supply vessels. The arrival, departure and operating season for drill ships is usually directly related to sea ice conditions. Sea ice consists of different ice types, some of which pose more challenges for vessel operations: old ice (second year and multi-year ice), thick and highly concentrated hummocky first year ice and very large ice keels (pressure ridges) created by high levels of deformation of medium to thick first year ice. Sea ice is also important in shoreline changes through direct interactions and also in reducing the magnitude of currents and waves and for pipeline design and construction due to the possibility of ice scour in inshore waters.
2. Landfast Ice: Landfast Ice is nearly stationary sea ice that forms from the coastline out to water depths of 10-20 m in the autumn and early winter. This nearly stationary characteristic, and an often less deformed ice surface, makes this ice type useful for winter vehicle transportation. The thickness and seasonal duration of landfast ice is strongly dependent on air temperature and snow cover, as discussed in detail below in Section 5.4.
3. Glacial Ice: Glacial ice is ice formed on land through long-term processes of freshwater ice accretion in cold climates. For glacial ice shelves in the form of tidewater glacier and ice sheets, very large ice pieces can break off to form icebergs or ice islands. Icebergs are generally very thick with ice drafts of tens of meters to 100 m or more. Ice islands are sheets of level glacial ice that can be several tens of meters thick with very large horizontal dimensions of 1 to 30 plus km. Once launched, these glacial ice features pose formidable hazards to marine operations until they break up and melt. Ice islands can form off northern Greenland and the northernmost Arctic Islands (Ellesmere and Axel Heiberg islands) and drift south-westward through offshore portions of the Canadian Beaufort Sea. Icebergs and islands now exist in both the SBS and Eastern Arctic.

Ice variables that are required to describe conditions necessary for characterizing hazards and opportunities for oil and gas activities have been selected as:

- Sea Ice Areal Extent (based on ice concentrations for all ice present) for specified areas of interest. This variable is readily measured from satellites as well as aircraft and ship-based observers.
- Sea Ice Type distribution / concentration (based on partial ice concentrations by types of sea ice). The ice type is an important variable for characterizing the degree of hazard that sea ice can pose to industry applications, with hard multi-year sea ice being much more hazardous than new or young sea ice.
- Ice thickness is measured in a variety of ways using mechanical ice augers, from below using upward looking sonars and from above by satellite and aircraft-mounted sensors (Fissel and Marko 2011). Ice thickness is of fundamental importance in determining the loading of sea ice on fixed platforms or vessels and is also important for near-shore ice roads in winter.
- Ice velocity is measured from above by comparison of sequential satellite images, using in situ GPS beacons, by ship observers and from below using specialized sonar instruments. Ice velocity is an

important variable in determining the viability of ice management operations and in determining the loading of ice on fixed platforms and vessels operating in the ice.

- Ice available days, is a measure of the duration of ice of specified type for use in nearshore industry operations.
- Landfast ice extent and thickness are essential parts of the ice environment in nearshore and inshore areas in terms of providing a platform for winter-based oil and gas industry operations and as an impediment to shipping in spring and early summer.
- Glacial ice (ice islands), including total mass and horizontal and vertical dimensions, represent a hazard to offshore operations such as drilling and shipping. Marine glacial ice sources include the ice shelves of the NW flank of the CAA. These get incorporated into the Beaufort Sea pack ice and now routinely drift down over the areas of proposed offshore oil and gas development. This is a new feature of this ice directly due to climate warming and increased mobility of these marine glacial ice features. The increase in the velocity of the Beaufort Sea pack ice encourages the movement of these ice hazards into the current area of exploration drilling.

6 CLIMATE CHANGE AND ITS POTENTIAL EFFECTS ON OIL AND GAS ACTIVITIES

The effects of climate change on oil and gas activities must be viewed in the context of what oil and gas exploration and development in the Beaufort Sea may look like in the foreseeable future. Oil and gas activities include seismic operations, exploration drilling, production, abandonment and all related support activities.

Exploration activities are not expected to be as concentrated as in the 1970s and 1980s when multiple wells were drilled each year in the inner and outer shelf. Exploration drilling ceased in 1989 with no further activity until the winter of 2005/2006 when a single well was drilled by Devon Canada. No wells have been drilled since then. Since 2006 there have been one to two seismic surveys conducted per year. Most of these seismic surveys have been 2D with only a few small 3D programs being carried out. It is expected that the number of 2D seismic programs will decrease after 15 years with 3D seismic surveys being on track with drilling programs (Callow 2012).

Earlier predictions for oil and gas scenarios in the Beaufort Sea (Morrell 2005, 2007) assumed the Mackenzie Gas Project (MGP) would proceed, creating a focus on the nearshore Beaufort Sea for further gas exploration and production tied to the pipeline. Since these predictions were made, doubt has arisen whether the MGP will proceed due to low North American gas prices which make it less attractive to build. It was suggested by Callow (2012) that drilling in the shallow waters of the Beaufort Sea could begin as early as 2016. However this time frame now seems unlikely.

Industry interest has shifted from shallow nearshore areas to the deep offshore waters of the Beaufort Sea with a number of exploration leases being acquired which are focused on potential oil discoveries. Drilling in the Beaufort Sea, is likely to occur first in the deep offshore waters using either an existing arctic class drill ship or a new vessel designed for the purpose. Due to the short season for drilling a well in the deep offshore waters, it is expected a single well will take 2-3 years to drill. If a deep water well is approved, drilling would likely not begin until 2020 or later. Drilling may also occur within the Amauligak Significant Discovery License (SDL) area, in shallower water approximately 30m water depth. The Amualigak is the largest oil and gas discovery in the Beaufort Sea at this time. Drilling at the Amauligak SDL could happen within the same time frame as a deep offshore drilling program and would be with the intention of developing a production project. The expectation is that only one or possibly two drilling programs would occur in any one year once or if drilling resumes.

Potential Climate Change Effects from Sea Ice

As described in Section 3.1, there is clear evidence that changes in sea ice areal extent and ice concentrations have been occurring in the summer to early fall period over the past 30-40 years in the offshore areas of the continental slope and outer shelf. It is logical to assume that changes are also underway over the winter period but scientifically there is much less information available to confirm this. The evidence for reduced summer ice areal extent for the inshore and mid-shelf areas is not as strong due to the large degree of inter-annual variability and the generally lower ice concentrations in these areas. However, there are clear trends for reduced ice concentrations in October for the shelf areas and inshore areas, which is consistent with later ice formation and reduced ice thickness including the landfast ice areas. The thickness and duration of the landfast ice are also likely to be reduced in the long term, with the warming of air temperatures in fall and winter. The consensus derived from climate model studies (atmosphere, sea ice and oceanographic) is that the reduction in summer and fall ice extent and concentrations will continue over the next several decades.

The effects of climate related changes to sea ice on oil and gas industry activities include:

1. Reduced ice concentrations and areal extent:

   All Phases of Oil and Gas Activities:

   - Lower ice concentrations and areal extents may improve or extend the period for mobilization and demobilization activities. This includes mobilization and demobilization into and from the Beaufort Sea as well as from vessel overwintering sites in coastal areas of the Beaufort Sea.
   - Extended operating seasons for all phases and areas of operation of oil and gas related activities.

   Seismic:

   - Reduced ice levels may improve seismic coverage by not having to avoid areas with ice on the Beaufort Sea shelf and slope.

   Drilling and Production - Shelf and Slope:

   - Reduced impediments to drilling and marine support activities through reduced icebreaking efforts and more efficient shipping operations including support vessels for activities on the Beaufort Sea shelf and slope.

   Drilling and Production - Nearshore:

   - Reduced ice cover may provide improved conditions for dredging and construction of artificial islands in nearshore areas. The construction of artificial islands is not expected to occur in the next 10 years or longer, unless the MGP proceeds.

   Harbours:

   - Impacts on Tuktoyaktuk harbour – the longer seasonal access to the harbour may increase the need for dredging to accommodate vessels of moderate and larger drafts and to accommodate a potential floating facility to load and unload vessels. This would not occur until a drilling program is approved. Also the possibility of losing the protection of Tuk Island via shoreline erosion will also have an impact on Tuktoyaktuk Harbour.

2. Changes in ice thickness

   Drilling, Production and Associated Support - Shelf and Slope:

   - Thicker ice is a hazard to marine operations such as support ships, potentially resulting in safety issues.
   - Thicker ice may result in increased ice breaking effort in support of supply vessels and to maintain safe drilling operations.

3. Increased ice velocities

   Drilling and Production - Shelf and Slope:

   - Increased ice velocity poses threats to drill and production platforms because of the shortened time between detection of an ice hazard and the response to the approaching ice. If the response to fast moving ice is too slow damage could occur to the drilling or production platform.

4. Landfast ice extent and thickness

   Drilling and Production - Nearshore:

   - Ice roads can be used to support inshore oil and gas activities during winter and spring. Reductions in the duration of the landfast ice season will limit the use of ice roads in comparison to past levels of use. With the exception of the Inuvik to Tuktoyaktuk winter ice road, ice roads are most commonly used to support nearshore drilling programs during the winter season.
   - Thin landfast ice is a hazard for inshore winter roads limiting the size of loads or duration of use of these roads. Some coastal areas may be more prone to having thin ice than other areas (e.g., Yukon North Slope).
   - Reductions in the duration of landfast ice may also eliminate the ability to use ice spray islands to conduct drilling in nearshore areas.
   - Weaker landfast ice will also create problems when icebreakers enter into solid fast ice, potentially increasing the probability it will break up early, thereby affecting other use for travel (particularly by Inuit).

The potential effects of changing sea ice conditions on oil and gas activities are expected to be generally positive although some adverse effects are also expected to occur. As is occurring now, the levels of interannual variability are expected to be very large so the effects may vary considerably from one year to another. Industry will be required to plan and manage operations to reflect this variability, most likely through flexibility in operational plans and in the engineering design of platforms and structures. These responses can build on past experience by industry dating back to the 1970s and 1980s. The changes will also be quite different according to the area of operation: inshore, shelf and deeper offshore waters. In the absence of improved seasonal forecasts, industry operations planning may be more difficult resulting in potential operating inefficiencies.

Potential Climate Change Effects From Ocean Waves and Storm Surge

Changes in ocean wave properties, along with the related increase in the frequency and severity of storm surges, have been occurring over the past decade as a consequence of reduced ice concentrations and areal extents resulting in a longer duration of ocean wave activity (Fissel et al. 2012). In recent years there is evidence of moderate to large wave events starting earlier than June and extending into November in comparison to the previous “normal” season of mid-June to late October (Fissel et al. 2012). These trends are expected to continue and increase in the future due to the anticipated future reduction in sea ice cover. Long period swell waves originating from distant storms have only rarely occurred in past decades but may become more frequent in the future (Barber et al. 2010). Large waves and storm surges can affect the marine operations of offshore and nearshore oil and gas industry activities as well as coastal infrastructure required to conduct offshore activities.

The effects of potentially large ocean waves include:

All Phases:

- Delays in vessel mobilization and demobilization to and from the Beaufort Sea as vessels may be required to anchor in safe harbour or sail at slower than normal speeds until seas recover to a safer state for travel.
- Search and rescue (SAR) operations could be hampered, especially in situations of a man overboard or rescue of those in a life raft.

Seismic All Areas:

- Periods of high waves can affect seismic data quality and lead to damage of seismic cables and other equipment. While the ocean waves are not as large as in other oceans where seismic operations occur, delays in seismic operations may increase from that experienced in the past due to more frequent periods of increased wave height. Increased wave height may also create safety issues aboard vessels due to increased ship motion.

Vessel Support Activities:

- Increased wave height can hamper regular marine shipping support operations as supplies and personnel cannot be safely transferred to nearshore or offshore drilling or production platforms during these periods.

Drilling and Production - Nearshore:

- Increases to shoreline erosion effects on pipelines and causeways in nearshore areas due to increased wave action.
- Adverse effects on artificial island construction and maintenance in nearshore areas due to erosion issues or the disruption of dredging operations during artificial island construction.

POTENTIAL CLIMATE CHANGE EFFECTS FROM WINDS, AIR TEMPERATURE, PRECIPITATION AND VISIBILITY

There is a clear trend towards warmer air temperatures, particularly in the fall and winter months, and climate models clearly indicate that the warming trend will continue over the decades ahead.

The main effect of increased air temperature on oil and gas activities will be a reduction in the extreme cold operating conditions in the fall, winter and early spring seasons. In addition, there will be moderately warmer conditions from mid-spring through the summer. Increasing air temperatures effect other environmental parameters, most notably sea ice conditions.

The warming air temperatures also affect precipitation, with more snowfall likely in winter and more snow and rain in summer. Fog may be more frequent, with subsequent effects on visibility, as increased air temperatures will allow the air to hold more water vapor.

As discussed in Section 3.3, the long term trend for wind speeds, derived from extended inshore and coastal data sets, is a modest decrease in wind speeds. The affect of wind speeds on oil and gas operations would be dependent on the location and type of operation, and size and type of vessels or platforms used.

Drilling and Production - Shelf and Slope:

- Increased precipitation and fog can negatively affect air services to and from drilling or production platforms and shore bases as aircraft may be grounded due to low visibility.
- Low visibility due to fog or snow can also affect SAR activities by delaying response activities.

Drilling and Production - Nearshore:

- Increased snow fall levels on ice can lead to thinner ice conditions, thereby affecting ice road capabilities and safety.

POTENTIAL CLIMATE CHANGE EFFECTS FROM OCEAN CURRENTS AND WATER TEMPERATURES

The determination of climate change effects on ocean currents is hampered by the lack of knowledge of trends in ocean currents and water temperatures in the recent past. Obtaining this knowledge is difficult due to the high variability of the ocean currents in the Beaufort Sea combined with the comparatively short data sets of a few years or less available at particular measurement sites. Wave orbital velocities associated with ocean waves will increase and also penetrate to greater depths due to larger swell waves. The effects of the wave orbital velocities, which are generally confined to 20 m depth for regionally generated waves and to perhaps 100 m for swell waves, could result in disturbances to the seabed including enhanced erosion of sediments, scouring around seabed structures and the loss of bearing strength associated with the increased potential for bottom liquefaction.

Drilling and Production:

- Changes or increases in bottom currents could affect seabed erosion, especially at shelf break, affecting drilling and production activities due to changing stability of the seabed.

Production:

- Changes in ocean currents and water temperatures can lead to changes in distribution, abundance and composition of marine fauna. These effects for short term projects such as seismic or exploration drilling projects can be managed and mitigated through the environmental assessment and/or regulatory processes. The effects may be more significant for longer term projects such as production projects which may operate for 30 years or longer. Changes in marine fauna or the ecological importance of an area where production activities are occurring may result in costly changes having to be made in operating conditions midstream through a project's life.

POTENTIAL CLIMATE CHANGE EFFECTS FROM SEA LEVEL RISE, STORM SURGE AND COASTAL EROSION

Sea level changes in the Beaufort Sea are influenced by a number of factors, including; glacial ice melt, ocean warming, large storm surges, compaction of deltaic sediments, post ice age isostatic rebound and gravitation effects. Based on evidence over the past decades, it appears that sea level rises due to oceanic conditions are outpacing the geological factors. Coastal zone erosion in Arctic regions is a complex process affected by factors common to all parts of the world; exposure, relative sea-level change, and climate and soil properties: and by factors specific to the high latitudes; low temperatures, ground ice and sea ice (Anisimov et al. 2007). The most severe erosion problems arise in areas of rising sea level, where warming coincides with areas that are seasonally free of sea ice or where there is widespread ice-rich permafrost (Forbes 2005). Areas with bedrock near the surface, which includes much of the Canadian Arctic Islands, or areas where glacioisostatic rebound is occurring, are less vulnerable to erosion.

Despite common concerns expressed by community residents of increased erosion rates in the western Arctic, including the Yukon and Alaska coast, a regional analysis for the southern Beaufort Sea detected no significant increase in the trend in areas of rapid erosion for the 1972–2000 time interval. Erosion rates of 1.0 to 2.0 m/year have been reasonably consistent over the past 30 years (Manson and Solomon 2007). However, further warming, combined with sea-level rise, coastal subsidence (especially west of Paulatuk) and reduced sea ice, can be expected to maintain or increase this already relatively high rate of coastal retreat along the Beaufort Sea coast (Prowse et al. 2009) and result in increased areas potentially affected by storm surge.

The potential effects on oil and gas activities from climate change related sea level rise, storm surge and coastal erosion include:

Shore Based Activities and Harbours:

- Coastal zone erosion could potentially affect oil and gas industry infrastructure such as camps and docking facilities. No new infrastructure is anticipated for the next 10 plus years however the location and construction of any new or refurbishing of existing infrastructure will require consideration of the effects of coastal erosion and permafrost degradation.
- Increased coastal erosion could lead to increased frequency of dredging required to maintain entrances and anchorages in harbours such as McKinley Bay and Tuktoyaktuk Harbour.
- Many coastal areas around the Beaufort Sea are low lying and not far above normal sea level. Increased sea levels could accelerate coastal erosion and cause flooding affecting coastal infrastructure, including pipelines, used by the oil and gas industry.
- Sea level rise in conjunction with coastal areas undergoing subsistence can lead to larger areas being affected by storm surge and the flooding with seawater of coastal infrastructure.

POTENTIAL CLIMATE CHANGE EFFECTS FROM SEDIMENT AND WATER QUALITY

Any influence driven by global climate change that the chemical environment could have on oil and gas development activities in the Beaufort Sea would be a direct consequence of the effects of climate change on the physical environment. Through changes in characteristics of the physical environment (air and water temperature, reduction in sea ice coverage, waves, currents, storms etc.), the net transport of water and sediment, the spatial and temporal distribution of contaminants and other chemical species, and chemical equilibria could be affected. Such changes to contaminant cycling and pathways have implications for the uptake of contaminants by biota, changes to the environmental fate of contaminants, and mobility of contaminants in the arctic food chain.

For the oil and gas industry, there are two main implications related to changes in contaminant cycling that could be affected by climate change.

Drilling and Production Activities:

1. Need to make predictions on environmental effects of contaminants in drilling wastes from a cumulative loading (climate change induced effects and drilling wastes effects) perspective. This information will be useful for dispersion modeling and the design of effects monitoring studies.
2. Need for more detailed baseline measurements with an emphasis on spatial and temporal patterns. With a potentially changing chemical landscape of the receiving environment, the historical chemical contaminant database may not be adequate to assist in identifying the most appropriate strategies and practices for the disposal of drilling wastes in some local areas, particularly those in the vicinity of previous drilling sites.

Overall, the influence of chemical oceanographic variables altered by climate change will be less profound and damaging to oil and gas activities than the potential consequences of climate driven changes to the physical environment of the Beaufort Sea.

7 SYNTHESIS AND REVIEW OF EXISTING REGULATIONS, GUIDELINES, BEST PRACTICES AND ENVIRONMENTAL ASSESSMENTS

7.1 Regulations, Guidelines and Best Practices

Regulations and guidelines that pertain to oil & gas activities can be grouped into two main categories:

1. Project Approvals: the Acts, regulations and guidelines that apply to projects before construction.
2. Project Operations: the Acts, regulations and guidelines that apply during the construction and operation of a project.

These Acts, regulations and guidelines were reviewed to identify specific requirements that are potentially influenced by a changing climate. These potential influences may be obvious, for example thresholds or exceedance of limits with regard to parameters directly affected by climate change, or they may be inferred.

The National Energy Board (NEB), an independent federal agency, is the primary regulator for oil and gas activities in the Beaufort Sea. The NEB regulates these activities under the Canadian Oil and Gas Operations Act (COGOA) and its regulations. These activities include oil and gas exploration, development and production activities. For frontier areas such as the Beaufort Sea the NEB responsibilities also include the calculation of discovered and undiscovered hydrocarbon resources and the development of emergency environmental contingency plans.

A number of Acts and associated regulations were not reviewed, including the *Fisheries Act, Migratory Birds Convention Act and Regulations, and Arctic Waters Pollution Prevention Act*, as these acts do not contain provisions for climate change although they are applied in environmental assessments related to offshore oil and gas activities.

PROJECT APPROVAL REQUIREMENTS RELATED TO CLIMATE CHANGE:

ENVIRONMENTAL IMPACT SCREENING COMMITTEE (EISC): ENVIRONMENTAL IMPACT SCREENING GUIDELINES (2011)

Most oil and gas activities proposed in the Beaufort Sea first go through the Inuvialuit environmental impact screening process. The EISC guidelines do not specifically address climate change effects on the environment or climate change effects on project activities.

ENVIRONMENTAL IMPACT REVIEW BOARD (EIRB): ENVIRONMENTAL IMPACT REVIEW GUIDELINES (2011)

One of the goal statements of the EIRB is to “Minimize contributions to climate change throughout all phases of the proposed development”.

Specific requirements regarding climate change which are to be included are:

- Describe how the proposed development may contribute or not contribute to climate change.
- Identify other elements which could be impacted by climate change.

The guidelines do not provide specific guidance on how to meet these requirements.

National Energy Board Filing Requirements for Offshore Drilling in the Canadian Arctic 2011 (NEB)

The NEB's filing requirements are based on input obtained by the NEB through a review of offshore drilling in the Canadian Arctic (NEB 2011). The filing requirements do not explicitly refer to climate change. However, there is a requirement to identify any environmental factor which may potentially affect a project and describe how this effect will be addressed.

Safety Plan Guidelines (NEB, CNSOPB and CNLOPB 2011)

The Safety Plan Guidelines are intended to assist operators in meeting the requirements of sections 6 and 8 of the Drilling and Production Regulations (SOR/2009-315) under the Canada Oil and Gas Operations Act, which pertain to the submission of a Safety Plan. In particular, the guidelines require:

a. a summary of studies undertaken to identify hazards and to evaluate safety risks related to the proposed work or activity
b. a description of the hazards that were identified and the results of the risk evaluation
c. a summary of the measures to avoid, prevent, reduce and manage safety risks
d. if the possibility of pack sea ice, drifting icebergs or land-fast sea ice exists at the drill or production site, the measures to address the protection of the installation, including systems for ice detection, surveillance, data collection, reporting, forecasting and, if appropriate, ice avoidance or deflection

Offshore Physical Environment Guidelines (NEB, CNSOPB and CNLOPB, 2008)

Section 3 of the guidelines provides recommendations for meteorological, oceanographic and ice observations and reporting to be included as part of an Environmental Monitoring Program plan submitted along with applications for regulatory approvals for drilling and production activities in offshore waters. The guidelines also identify training requirements for specific tasks such as meteorological and ice observations and reporting. In waters where sea ice or icebergs are expected to occur an ice management plan is also required. The ice management plan is recommended to contain information on the following elements:

- detection
- surveillance
- data collection

- reporting
- forecasting
- avoidance or deflection

Incorporating Climate Change Considerations in Environmental Assessment: General Guidance for Practitioners (CEAA 2003)

To our knowledge, this is the only guide applicable in the Arctic which addresses how climate change should be taken into consideration in environmental assessment. The guide outlines the steps in the process to address climate change considerations as they pertain to greenhouse gas emissions. The Government of Nova Scotia (2011) has a similar guide. Neither guide pertains to other considerations related to climate change such as the effects of climate change on operations of a project. CEAA however does include the provision for a Section on the effects of the environment on the Project which has the potential, although there is no guidance to this effect, to be used to describe effects from climate change on project activities.

Nunavut Impact Review Board Guide to the Preparation of Environmental Impact Statements – Guide 7, 2006 (Nunavut)

The Nunavut Impact Review Board (NIRB) was established under the Nunavut Land Claims Agreement and has the responsibility for environmental assessments of project proposals in the Nunavut Settlement Area. The guide does not reference climate change. However, it does identify that the environmental impact statement (EIS) requires an assessment of the anticipated effects of the environment on the project. No guidance is provided in completing this portion of the EIS. The NIRB will consult with interested parties and members of the public in development of the scoping guidelines for an EIS. Climate change could be added to the scope of a project through this consultation process.

Arctic Offshore Oil and Gas Guidelines 2009 (Arctic Council)

These nonbinding guidelines are primarily aimed at regulators of Arctic nations to assist in their development of regulations and guidelines for Arctic offshore oil and gas activities. Activities include the full range of potential oil and gas operations from planning through to decommissioning. The guidelines recommend that in association with dealing with direct environmental effects, the effects of climate change should be taken into account.

Offshore Petroleum Production and Pipe-lines (Assessment of Environmental Effects) Regulations 1999 (United Kingdom)

These regulations were amended in 2007. The regulations identify when an environmental assessment is required and the types of information and analysis required in that assessment. Climate change is not identified in these regulations nor is there a requirement to assess the potential effects of the environment on the project.

Offshore Petroleum Activities (Conservation of Habitats) Regulations 2001 (United Kingdom)

These regulations were also amended in 2007. The regulations provide the authority to the Secretary of State to stop oil and gas operations which are affecting special protected areas or listed species under the EEC Council Directive 92/43/EEC. It also outlines a process for appeal or modification of the operations to allow operations to resume. Climate change is not identified in these regulations nor is there a requirement to assess the potential effects of the environment on the project.

Guidance Notes for Oil and Gas surveys and shallow Drilling: Petroleum Operations Notice No. 14A and 14B, 2005 (United Kingdom)

The guidance notes identify when an environmental assessment is required and the types of information to be contained in that assessment. There is no reference to assessing effects from the environment on the project or on the potential effects from climate change.

Greenland Bureau of Minerals and Petroleum Drilling Guidelines 2011 (Greenland)

These guidelines are for operators planning to drill in Greenland's offshore waters. The guidelines provide information and explanations on the requirements under the Greenland Mineral Resources Act, the Danish Marine Environment Act and subordinate legislation. Offshore drilling defined under these guidelines includes all ancillary operations associated with a drilling program such as support vessel requirements and movements. The guidelines identify specific management plans required such as an Ice Management Plan and the type of record keeping required to meet regulatory requirements. The guidelines do not refer to climate change but do state that the Arctic Council Offshore Oil and Gas Guidelines are binding in Greenland. The Arctic Council guidelines recommend the consideration of climate change when assessing project effects.

Summary

Most of the guidelines reviewed do not take climate change into consideration, and when they do, it is generally in reference to greenhouse gas emissions. However, where guidelines refer to the need to identify the effects of the environment on the project, this may be interpreted to include the effects of climate change. This may be particularly appropriate for longer term projects such as oil or gas production.

Additionally, guidelines and regulations for developing environmental assessments generally include provisions for consultations with interested parties and the public when developing the scope for an environmental impact statement. Results of these consultations may lead to the inclusion of climate change considerations in an environmental assessment of a proposed project.

7.2 Environmental Assessments

Several forms of environmental assessments were reviewed: Regional Strategic Environmental Assessments (RSEA), Pre-lease issuance assessments (Alaska), and Project specific Environmental Assessments.

In Canada, the offshore waters of Newfoundland and Labrador as well as Nova Scotia have been the most active areas for oil and gas activities and the only areas where offshore production is occurring. In Newfoundland and Labrador, the Canada Newfoundland-Labrador Offshore Petroleum Board (CNLOPB) oversees offshore oil and gas activities while in Nova Scotia it is the Canada Nova Scotia Offshore Petroleum Board (CNSOPB). The CNLOPB has developed four regional strategic assessments (Golder 2003; Jacques Whitford 2003 and 2006; LGL et al. 2010) for different regions of their offshore waters. None of these assessments discuss climate change but rather focus on current environmental conditions. The Canada Nova Scotia Offshore Petroleum Board draft RSEA for the Scotian Shelf including Middle and Sable Island Banks (Stantec 2012a, b) identifies climate change as a process which could affect offshore activities due to increased storm severity and wave height. The environmental assessment stated that these potential effects would be addressed through engineering design.

Project specific environmental assessments completed for the CNLOPB and CNSOPB include assessments for seismic acquisition, exploratory drilling and production projects. Climate change is not discussed for assessments pertaining to seismic acquisition or exploratory drilling projects. This can be expected as these two types of projects are short term in nature, usually 1-2 years in length, and therefore span too short a period for climate change factors to likely have an effect. Production projects typically occur over longer time periods (e.g., 30+ years) and therefore a potential exists for climate change to affect oil and gas operational activities. The Hebron project produces heavy oil off the coast of Newfoundland and Labrador. The project is located 350 km southeast of St. John’s at a water depth of 92 m. The Hebron Comprehensive Study Report (Stantec et al. 2010) identified several potential effects related to climate change on oil and gas activities; increased sea levels, increased storm intensity and frequency, increased wave height related to storm events, and ice and icebergs. The proponent addressed these potential effects through engineering design to mitigate the effects. Many of these same effects are likely to occur for potential future production facilities along the Beaufort Sea shelf.

The EA prepared for the CNSOPB for the Deep Panuke offshore gas production project (EnCana 2006) briefly discusses climate change both in terms of the project effects on climate change and climate change effects on the project. Climate effects on the Project were stated to be related to increased intensity and frequency of storms and associated waves. The assessment states that engineering design would mitigate these potential effects.

Currently in the Canadian Arctic offshore, only oil and gas exploration activities are occurring and all within the Beaufort Sea. These activities mainly relate to seismic operations. Some screening submissions to the EISC have referred to climate change in terms of its potential effects on biota as part of the environmental overview for a project area (e.g., KAVIK-AXYS 2008; Upun LGL 2010). Others do not identify climate change in any context (e.g., GX Technology et al. 2011). These screening documents do not assess the potential effects of climate change on project activities. Only one exploratory drilling program by Devon Canada has been conducted in the last 10 years In the Beaufort Sea. A Comprehensive Study (Devon 2004) was completed for this exploratory drilling program. The Study discussed how climate change may have affected physical conditions (e.g., ice and coastal erosion) at that time as compared to conditions in the 1970s and 1980s. The assessment included a section on how the environment would affect the Project which contained a brief discussion on climate change. It was concluded that no effects would occur as a result of climate change due to the short life span (1-2 years) of the project.

In Alaskan offshore waters an environmental assessment is prepared before an area can be offered for lease. Climate change and its current and anticipated effects on the physical, biological and social conditions in the project area are discussed (U.S. Dept. of the Interior 2008, 2011). Environmental assessments for seismic surveys in the offshore waters of Alaska occasionally discuss climate change but generally in regard to very specific topics such as beluga distribution patterns (U.S. Dept .of the Interior 2005). In other instances climate change is not discussed at all (U.S. Dept .of the Interior 2010). EAs for exploratory drilling have included climate change effects in the assessments both in the direct assessment of particular animals (e.g., polar bear) (U.S. Dept. of Interior 2011) or water quality and with regard to greenhouse gases ((U.S. Dept. of Interior 2009). A cumulative effects assessment for Shell's proposed Camden Bay drilling program included consideration of the effects of climate change on fish and marine mammals (U.S. Dept. of Interior 2011).

A preliminary assessment of hydrocarbon activities in the KANUMSA East Area of the West Greenland Sea (NERI 2009) was conducted based on current conditions. However, it discussed climate change in the context of potential changes to the physical, chemical and biological components of the environment in the future. The assessment noted that current conditions may be altered due to climate change resulting in assumptions made in the assessment that may not apply in the future.

A Strategic Environmental Assessment was conducted for the Irish and Celtic Seas (Xodus Group 2011). This assessment focused only on the exploratory oil and gas phases (e.g., seismic and exploratory drilling). This assessment discussed climate change only in the context of greenhouse gas emissions.

An environmental statement (Metoc plc 2004) prepared for the construction of buried marine gas pipeline on the UK side of the North Sea focused its assessment on the potential impacts to benthic communities, coastal processes and fisheries. There was no consideration to the potential effects of climate change or the effects of the environment on the Project.

In general for the assessments reviewed, climate change was not considered or was considered in terms of either greenhouse gas emissions or in the context of changes to the current environment. The exceptions for this were for production projects which more often assessed the effects of climate change on project activities. In these cases the effects of climate change were said to be mitigated through engineering design of infrastructure.

8 IDENTIFICATION AND ANALYSIS OF KEY DATA GAPS AND RECOMMENDATIONS

8.1 Data Gaps

The following data gaps are categorized by type, including: sea ice, weather, waves, ocean currents and water temperature, coastal erosion and storm surges, contaminants, and ecological/biological conditions.

A. Sea Ice:

The adequacy/limitations of the baseline data, as presented in Section 3 were assessed and judged to be largely adequate. The data sets available over the past 30 years clearly indicate the large changes in sea ice and related environmental variables which have occurred. The early baseline data dating back to the 1970's provide comprehensive understandings of the Beaufort Sea environment in relation to oil and gas exploration. These data were produced through the Beaufort Sea Project of DFO (Milne 1976, Milne and Herlinveaux 1976; Ross et al.1977; as well as 41 Technical Reports) and other government oceanographic studies conducted during and shortly after the active period of oil and gas exploration (early 1970's to late 1980's). These studies were continued, by government agencies (DFO, Natural Resources Canada and Environment Canada) albeit in a less intense manner through the 1990's and 2000's. Satellite-based sea ice data products became operational in the 1970's and these data sets, along with derived and synthesized data products (especially the Canadian Ice Service ice charts and U.S. NSDIC daily ice maps of the entire Arctic Ocean) provided invaluable baseline data. In the early 2000's, university research programs began and developed in the Beaufort Sea, providing major oceanographic and sea ice data sets. Of particular note are the NSERC funded Canadian Arctic Shelf Exchange Study (CASES; Fortier et al. 2008) and the International Polar Year (IPY) Circumpolar Flaw Lead (CFL; Barber et al. 2012) projects. Both of these studies are unique in that they over wintered (CASES in fast ice and CFL in mobile ice). These projects provide valuable insights into many aspects of both the physical and biological system and in particular provide rare winter observations. Starting in the latter half of the first decade of the 2000's, oil and gas industry funded environmental studies resumed with the acquisition of exploration licenses by oil and gas companies, especially in the more distant offshore areas of the Canadian Beaufort Sea.

Key findings to date related to sea ice and climate change include:

- A large portion of sea ice loss in the northern hemisphere is associated with the Pacific sector of the Arctic and is where the trend of the largest proportion of multi-year sea ice is expected to continue.
- Fast ice periodicity is getting smaller seasonally with later dates of formation and earlier dates for break-up.
- The thickness of fast ice has remained the same but the strength of the fast ice may be decreasing as increased snow cover insulates the ice (keeps it warmer) over the winter period.

- There are more glacial ice hazards in the SBS due to the behavior of the Beaufort Sea gyre and the break-up of ice shelves on the NW flank of the Canadian Arctic archipelago.
- Ice management of both thick multi-year ice and glacial ice is difficult due to problems of detection (i.e., Radarsat data cannot detect these features) and their predicted motion is poorly understood.

Although baseline data is largely considered adequate it is not complete. Our present understanding of the changes in sea ice conditions, in particular sea ice thickness, and landfast ice baseline data needs to be improved through measurement and modeling studies. In particular the nature of ice circulation appears to be changing (increase in speed) yet the BG operates as it has historically done. This leads to several questions about the recirculation of sea ice within and over the hydrocarbon exploration areas.

Glacial Ice:

The presence and movement of glacial ice within the Beaufort Sea ice affects environmental and human risk levels for deep offshore oil and gas activities. Risks can range from stoppage of operational activities such as seismic or drilling and production to damage to ships or drilling platforms. Specific questions include:

1. Will the quantities of glacial ice in the form of ice islands and icebergs in the Beaufort Sea continue to increase due to increased ice production in the northern Canadian Arctic Islands or will the land based ice sheets be depleted and quantities decrease?

   This question can be addressed through ongoing and perhaps more focused research on the present and projected amount of calving of ice islands from tidewater glaciers and ice sheets from the Queen Elizabeth Islands to the east. In addition some planned BREA studies could be useful in assessing the changing conditions from the past to the present and into the future ("Understanding Extreme Ice Features in the Beaufort Sea: Lead: Christian Haas; Radarsat Mapping of Extreme Ice Features in the Southern Beaufort Sea"; Lead: David Barber; "Beaufort Sea Environmental Database", Lead: Ivana Kubat).

2. How will the transport mechanisms of glacial ice in the Beaufort Sea change due to climate change and what is our ability to predict these changes? How fast does this ice melt, especially under the warmer water temperatures of the Beaufort Gyre, and how long does the glacial ice stay in the Beaufort Gyre? Do the winds and ocean currents transfer glacial ice from the Beaufort Gyre to the Transpolar Gyre, leading to removal from the Beaufort Sea region, or do these ice hazards remain within the Beaufort Gyre?

   In addition to the BREA studies mentioned above, oceanographic data collection and modeling of currents and temperatures will be required to address these questions. The BREA atmosphere-ocean-ice modeling studies presently underway (Lead Investigators: Fraser Davidson and Gregory Flato) could also be very useful for understanding the transport of floating glacial ice through the Beaufort Sea region. These and other models need to incorporate deterioration mechanisms (melt, wave effects) to be fully effective for this application.

First and Multi-Year Sea Ice:

The presence, thickness and movement patterns of first and multi-year sea ice affects environmental and human risk levels for offshore oil and gas activities. Risks are the same as for glacial ice. Specific questions include:

1. Will the trend towards more open water and reduced sea ice seasons continue over the next decade and beyond? Will multi-year ice concentrations continue to decrease? Will the Beaufort Sea become seasonally ice free during late summer in the decades ahead?
2. Will the thickness of sea ice floes, both first year and multi-year, exhibit changes and over what time scale will these occur?
3. Sea Ice appears to be moving at higher velocities as concentrations decline; will this continue and at what rate.
4. Will circulation of the BG increase the thickness of first-year and remnant multiyear ice along the NW flank of the Canadian Arctic Archipelago (CAA) due to the predominant anti-cyclonic rotation of the BG?

Ongoing and future modeling studies are required to address these questions. The BREA modeling study ("Forecasting Extreme Weather and Ocean Conditions in the Beaufort Sea", Lead: Fraser Davidson) will contribute to this as will the ArcticNet modeling initiative and larger scale Arctic Ocean modeling research that is funded in Canada (Canadian Climate Centre Modeling Analysis group), the U.S. and in Europe. Ongoing oceanographic and sea ice data collection is required to calibrate and validate the models, especially in the more remote and deeper offshore areas. Past and present DFO Beaufort Sea and ArcticNet oceanographic research programs have contributed to this requirement and recent BREA research studies (Leads: David Barber, Christian Hass, Michelle Johnson and Martin Fortier) are also providing additional new data sets. However, a commitment to sustained and long-term time series oceanographic and sea ice data sets at the same locations, spanning 10 years or longer is essential to address the needs of climate change modeling and analysis.

Landfast Ice:

Landfast ice along the shorelines is important to oil and gas industry activities as a means of building roads to support inshore drilling operations in the winter and spring. Ship traverses through the landfast ice can have destabilizing effects on the landfast ice itself, with potential adverse consequences for access by Inuvialuit hunters. This may restrict areas and the timing when shipping can occur to avoid conflicts with harvesters.

1. How will the thickness and ice season duration change as winter air temperatures increase and precipitation in the form of snow changes? How will this affect the structure and stability of fast ice? Will it become less stable or more fragile?
2. If an icebreaker cuts a pass through the ice, ice would normally freeze relatively quickly behind. Would there be the potential that the refreezing will take longer and/or the icebreaker traffic could break off large sections of landfast due to increased instability?

3. The timing of fast ice formation is very important to the oil and gas industry (and subsistence use). There is evidence that the dates of onset of fast ice formation and the onset of fast ice decay are beginning to change (Galley et al. 2012). What is the prediction for these dates in the decades ahead?
4. The development of improved numerical models on how landfast ice responds to increasing air temperatures and amounts of snow cover could address these issues.

   Modeling studies of landfast ice which use projections for future air temperatures and precipitation (especially snow) are required, as well as more under-ice and remote sensing data collection in the landfast ice zones (e.g. Galley et al. 2012). Improved access for climate model studies to existing Environment Canada ice data sets would also be useful, such as the BREA Research Study "CanICE – A Sea Ice Information Database and Web-Based Portal", Lead: Leah Braithwaite).

B. WEATHER:

Improved regional atmospheric models, including realistic coupling to sea ice and the ocean, are the key to understanding the changing atmospheric conditions in the future. Such models are under development by Environment Canada through the CONCEPTS program (Ritchie et al., 2012). ArcticNet is also conducting modeling scenarios for their four Integrated Regional Impact Studies (IRISs). The SBS IRIS will make use of a coupled ocean-ice model (NEMO) forced with scenarios from the Canadian Regional Climate model, thereby providing future ocean and sea ice climate state variables. When the models are sufficiently robust to be used in a forecast mode, these models can provide projections of the changing atmospheric conditions for the Canadian Beaufort Sea region. The BREA research program, "Forecasting Extreme Weather and Ocean Conditions (Lead: Fraser Davidson, DFO) is such an application relevant to climate change and oil and gas activities. Model development requires accurate and representative atmospheric data sets for providing suitable inputs to the models and for verification studies. Atmospheric data sets are rather sparse in the Canadian Beaufort Sea, especially long term measurement records. A promising development in this regard is the recent announcement by Environment Canada of the METAREA initiative, in particular the newly defined Arctic METAREA XVII for the Western Arctic (Gauthier et al. 2012).

Specific questions include:

1. What is our knowledge on whether there would likely be increased or decreased levels of fog?
2. Will wind speed and directions change on average as a result of climate change?
3. Can improved coupled weather and ocean/ice models improve our understanding of the frequency, severity and seasonal timing of storms?
4. How will the changing ice edge locations affect weather patterns? (e.g., cyclones/low pressure systems often track ice edges).
5. How will reductions in timing of sea ice clearing and formation affect the development of low pressure systems and what sort of feedback can we expect these systems to have on the sea ice and oil and gas activities?

Addressing these questions requires ongoing atmospheric-ice-ocean coupled modeling research studies that are funded in Canada (e.g., Canadian Climate Centre Modeling Analysis group). International research for the Arctic Ocean including those in the U.S. and in Europe are also relevant since these address the Canadian portions of the Beaufort Sea. A key factor in obtaining reliable and pertinent results will be the use of higher resolution regional models. Higher resolution models will require extended and representative data sets in the region which are not likely to exist at present in many regions.

C. WAVES:

The levels of inter-annual variability in wave activity will be very large so the potential effects on oil and gas activity will vary considerably from one year to another. Because of this large variability and the lack of accurate and high resolution atmospheric and ice data inputs for regional wave models, especially for forecast models that span years into the future, the rate of increase in ocean wave activity is uncertain in the short to medium time frame. In the longer term, the clearing sea ice conditions are likely to result in increased wave action (e.g., larger waves). Our present understandings of the potential changes in regional wave conditions need to be improved through modeling studies supported by long term measurement programs to provide verification data sets.

1. How will wave and storm surge be affected by climate change over the years and decades ahead?
2. Can improved regional wave and storm surge models determine if the wave and storm surge activity is presently changing and where the changes in wave and storm surge activity will be the largest in the future?
3. Are swell waves increasing in height and extending to longer periods as open water fetch increases due to the reduced sea ice concentrations in summer and fall?

Answers to these questions will require the application of the results of research, atmospheric-ice-ocean models (which require development as discussed above), along with additional data collection. Wind, sea ice extent and wave data sets are required to provide data inputs and verification data sets for wave and storm surge models for the Canadian Beaufort Sea slope and shelf regions.

D. OCEAN CURRENTS AND WATER TEMPERATURE:

The development of robust and accurate Arctic Ocean and regional ocean circulation models would provide a means of addressing the very limited data availability and potentially a means to estimate the magnitude of the changing ocean currents and temperatures over the short to longer term time periods. Regional ocean current modeling with sufficiently high resolution to provide useful results will require accurate forcing on the large open boundaries of the Beaufort Sea with the remainder of the Arctic Ocean through coupling with Arctic Ocean basin scale models. Other requirements are coupling the sea surface to the atmosphere and to sea ice modeling. In particular, representing the effects of the sea ice distribution and concentrations is very important to represent accurately and with suitable resolution in the ocean circulation models. The hydrological effects of freshwater outflows from the Mackenzie and other rivers are also important for ocean modeling. Scientific projects of this nature are underway in DFO research laboratories including the Institute of Ocean Sciences, the Bedford Institute of Oceanography and the Northwest Atlantic Fisheries Centre. Oceanographic data sets are essential for model development, both in terms of providing required data inputs and as data sets to be used for model verification studies. The regional scale ocean circulation modeling being developed through the DFO-Environment Canada CONCEPTS is being incorporated into BREA projects:

- Forecasting Extreme Weather and Ocean Conditions in the Beaufort Sea (Lead: Fraser Davidson, DFO)
- Southern and Northeastern Beaufort Sea Marine Observatories (Lead: Martin Fortier)

E. COASTAL EROSION AND STORM SURGES:

Coastal erosion resulting from climate change can occur through warming air temperature and its effects on permafrost, increased wave activity, higher sea levels and increased frequency and severity of storm surges. It is known that land surface temperatures are warming, subsidence is occurring in some areas such as Tuktoyaktuk, and that sea levels are rising and are projected to continue to rise. These factors can all increase levels of coastal erosion. Increased storm activity in conjunction with coastal subsidence and rising sea levels can cause flooding and increase the area and severity of effects from storm surges.

1. How well can we predict the frequency and severity of storms and the effects these storms have on coastal erosion and infrastructure?
2. How will coastal erosion affect water quality parameters and use by aquatic organisms, and would such changes affect oil and gas activities?
3. Can the predictability of erosion rates and processes be improved as inputs to coastal planning and development of mitigation measures related to oil and gas activities?
4. How will rising sea levels affect coastal erosion and infrastructure?

Development of improved regional wind-wave models, as described above, and the related data collection for waves and storm surges to support this model development are required. In addition, high resolution circulation and sediment transport/geomorphological models for the Canadian Beaufort Sea shoreline regions must be developed. These models can best quantify expected coastal erosion levels associated under future conditions of atmospheric forcing and sea ice distributions that will differ from present conditions.

F. CONTAMINANTS:

Climate change effects such as increased wave action and increased frequency or severity of storms may lead to re-suspension of sediments and subsequent contaminant release from sediment in coastal areas, thereby increasing the potential for some contaminants to become available to marine organisms. To assess this issue in more depth, it is necessary to gain an understanding of the links between climate change and contaminant mobility and distribution.

1. Do we know what increased levels of contaminants may occur? Will climate change affect our ability to predict the flow of contaminants in the food web? Will it be safe to eat fish, marine mammals, etc.?
2. If there is increased snow LRTAP, the total contamination burden in the biota may increase. Could this increase contaminant levels to the threshold for human consumption?

3. How will increased contaminant burdens in the biota compounded by climate change effects, affect regulations on allowable discharge?
4. How will weather patterns change (e.g., winds, temperature, particulates in air and water) and how will this affect the input of contaminants into the food chain?
5. How will climate change effects on Shelf basin exchanges change contaminant flow in the Beaufort Sea?
6. If water temperatures increase in temperate or southern waters the amount of contaminant transport into the Beaufort Sea might decrease. What is our understanding of this potential?
7. What are the error bars in our models and predictions? How can these error bars be reduced?

G. ECOLOGICAL/BIOLOGICAL:

Changes to ecological systems due to climate change are difficult to predict due to their complexity and the lack of complete understanding of these systems. Climate change effects may lead to changes in productivity, species composition and abundance. Although these changes are unlikely to directly affect most oil and gas activities they can lead to changes in regulations and guidelines which can affect how oil and gas operations proceed. Changes in ecosystem properties due to climate change may also lead to false perceptions of the cause of change and be incorrectly blamed on oil and gas activities. As communities and community organizations in the Beaufort Sea region can influence the decisions on environmental screenings or assessments, false perceptions on changes to the ecosystem could negatively affect the outcomes of environmental assessment and screening processes.

1. Restrictions or added mitigation may be required for Ecological and Biological Significant Areas (EBSAs). If the size or position of EBSAs change during the life of a project what are the implications to the oil and gas industry? What processes are involved which cause areas to be defined as ecologically and biologically significant?
2. How will climate change affect the migration patterns of fish, marine mammals and seabirds?
3. How will climate change affect the introduction of new species and how will this impact regulations (e.g., ballast regulations)
4. How will changes in physical parameters such as salinity, water temperature and irradiance affect productivity within the Beaufort Sea?
5. How to create guidelines or adaptation strategies to plan for oil and gas operations which span 30 years or more, or to plan coastal infrastructure in light of increased erosion and sea levels?

8.2 Recommendations

As described in the previous sections there is a growing body of knowledge on the Beaufort Sea and the effects of climate change on a variety of its biophysical parameters. Over the past decades some key understandings of the effects of climate change on the Beaufort Sea environment have been developed. These include, but are not limited to;

- A large portion of sea ice loss in the northern hemisphere is associated with the pacific sector of the Arctic. The largest proportion of multiyear sea ice is attributed to this sector and is projected to continue.
- The Beaufort Sea ice gyre still operates in a dominant anticyclonic mode but reverses to a cyclonic mode more often now and through a larger proportion of the annual cycle (particularly April through December). This causes more divergence in the ice and thus affects the ice albedo feedback.
- Land surface temperatures have been increasing.
- There has been an increase in the depth of low pressure systems; but not an increase in the number of cyclones.
- Cyclones tend to follow the sea ice / ocean interface and as such these storms are moving further north as the ice retreats.
- Fast ice periodicity is getting smaller seasonally, with later formation and earlier melt.
- The thickness of fast ice has remained the same but not its strength.
- There are more glacial ice hazards in the south Beaufort Sea due to the behavior of the Beaufort Sea gyre and the break-up of ice shelves on the NW flank of the CAA.
- There is evidence of thick and hazardous multi-year ice still existing along the NW flank of the CAA, just upstream of oil and gas industry exploration licences.

Despite this growing body of knowledge more research is required. The following recommendations (Table 5) provide guidance and suggestions on the research required to improve the understanding of the potential effects of climate change on oil and gas activities in the Beaufort Sea. The recommendations are based on considerations of applicability to understanding climate change effects on oil and gas activities and practicality or feasibility of implementation.

In some cases research to address these recommendations may be underway or planned but unknown to the authors of this report. Research in other parts of the polar world may also provide guidance on the best approach for acting on these recommendations.

Table 5 Recommendations; Their Importance to Offshore Oil and Gas Activities; and, Current or Required Research

Recommendations	Importance to Oil & Gas Activities	Current or Required Research
Priority Recommendations		
Traditional Knowledge		
Continue interaction and knowledge exchange between Inuvialuit and western scientists.	Important for utilizing both sets of knowledge for decision making.	ArcticNet has established a Traditional Knowledge database. This database can assist with knowledge exchange.
Utilize or establish community based monitoring programs for the monitoring of climate change (integrate western science); integrate western science and TK programs through community based monitoring.	Important for utilizing both sets of knowledge for designing and interpreting monitoring programs, and decision making.	Currently being done for some harvest monitoring programs and ArcticNet Programs. Need to expand further.
TK Coordinator – involve from start of programs and continue with Community Consultations.	Important for utilizing both sets of knowledge for decision making.	There is an Inuvialuit Cultural Resource Centre.
Research Requirements		
Processes required for developing atmospheric regional model • Response – cyclones • Upper air data, not just surface	Atmos. Circulation of great importance to sea ice, currents, water levels and waves.	Need more upper air data (LIDAR); JC Gascard program may help; Amundsen ship-based. Marine atmospheric boundary layer data required, limited to Amundsen.
Marine Glacial Ice; source, pathways and duration.	Ice hazards have potentially very large effect on many O&G activities very occasionally.	Need process understandings to support better models for source amounts and pathways/duration.
Research on Ice Deformation, response to atmospheric water forcing – ridges/leads, degradation of large ice features; Role of frazil ice – relation to sediment processes and atmospheric forcing.	Very important to CC understandings; ice hazards.	Key processes on multi-year ice formation on the north coasts of CAA and N. Greenland; some observations in Nares Strait, Fram Strait; NRC; more data and research required.
Ecosystem Functioning.	Improve knowledge for environmental assessments and for the development of mitigation and monitoring programs.	Many process gaps in ecosystem components; at rudimentary level; focus on climate change effects on migratory routes, hot spots in terms of O&G that underpin ecosystem function.
Modeling		
Landfast ice.	Link to Ice hazards; high priority.	Insufficient capabilities.
Contaminant Transport – pathways – sediment, water, atmosphere.	Link to erosion.	Insufficient knowledge on pathways.

Table 5 Recommendations; Their Importance to Offshore Oil and Gas Activities; and, Current or Required Research (cont'd)

Recommendations	Importance to Oil & Gas Activities	Current or Required Research
Priority Recommendations (cont'd)		
Modeling (cont'd)		
Contaminant Transport – pathways - biota.		Insufficient knowledge on pathways.
Inshore wave and surge modeling.	Importance for coastal erosion for O&G infrastructure of shore facilities and pipeline crossings.	inshore waves and surges to build on GSC gauge programs.
Monitoring		
inventory of monitoring ; embed into national and intl. monitoring programs.	Long term measurements important to climate change understandings; Monitoring of variables important to ocean/ice/atmosphere coupled models.	Assist in making monitoring efforts more efficient and prevent duplication.
Guidelines		
Climate Change EA Guidelines.		Very generic CEAA guidelines for climate change in EA's; need for improved and more specific guidelines for EA practitioners.
Government Related		
Long Term Science Programs required • More monitoring – requires long-term sustained programs • Maintain expertise (esp. govt)	Very important to improve knowledge base for environmental assessments and for improved understanding of potential effects. This information could be utilized in developing or improving climate change related guidelines.	Need to focus on key indicators; key variables at key locations. Multiple sensor measurements at key sites. Need to ensure quality control and archival.
Adaptation		
Investigate climate adaptation options.		
Important and Ongoing Activities that Should Continue		
Research		
Beaufort Sea Gyre.	Changing regime for Offshore O&G operations.	WHOI/IOS programs active since 2003; Amundsen and international research programs; good coverage for average parameters.
Coastal Erosion.		Need thermodynamic/mechanical data; thermal and seabed data; acceleration to be determined (BREA/underway); repetitive mapping at 5 years (LIDAR).

Table 5 Recommendations; Their Importance to Offshore Oil and Gas Activities; and, Current or Required Research (cont'd)

Recommendations	Importance to Oil & Gas Activities	Current or Required Research
Important and Ongoing Activities that Should Continue (cont'd)		
Research (cont'd)		
Wind driven Wave for shelf and offshore.	Important changes in wave regime for O&G operations.	BREA program (W. Perrie) Waves in ice: ONR funded work; industry and ArcticNet activities; D. Dumont/UQAR; IOGP JIP application to oil in ice.
Modeling		
Climate coupling – Regional.	200 km	Ongoing – EC, CIS, UM, UA, BIO (CONCEPTS/EC/DFO).
Climate coupling – Local.	30 km	UM/UAF – just starting; very high res. for ice.
Regional Atmospheric.		Industry high res. forecast model; contact John Fyfe/EC.
Local Atmospheric.		Mesoscale meteorlogical models – under development and ongoing.
Ice (1st year/multiple year).	Albedo feedbacks required.	Average responses; CIS model improvements underway; ice features require new approaches.
Ecosystem function.		ArcticNet – IRIS underway.

9 SUMMARY

An assessment of the potential impacts on oil and gas activities due to climate change was conducted. This assessment began with a literature search and review. Of the large number of climate change reports published, only a few relate specifically to the potential impacts of climate change on oil and gas activities. Reports reviewed spanned numerous disciplines including physical oceanography, sea ice, climatology, contaminants, geology, ecology and traditional knowledge, as well as guidelines, best practices and environmental assessments.

CHANGES IN THE ENVIRONMENT PAST TO PRESENT:

Ice conditions in the Beaufort Sea are strongly influenced by oceanic and sea ice exchanges with neighboring regions. Changes in sea ice areal extent and concentration for the Canada Basin are similar to those of the full Arctic Ocean with changes in total ice coming primarily from the old ice component, which in late summer and fall months was seen to be decreasing between 8 and 11% per decade over the 44 years of available data.

For the four sub-regions of the Mackenzie Region (slope, mid-outer shelf, inner shelf and Kugmallit Bay) the largest changes in sea ice concentration occur in the slope sub-region. The largest changes per decade for all sub-regions were recorded in mid-October with the slope results indicating an almost 10% reduction in sea ice concentration per decade. The least amount of change per decade occurred in Kugmallit Bay, with mid-October results showing < 2% reduction in sea-ice concentration.

In the deep offshore areas of the Alaskan Beaufort Sea and Chukchi Sea the reduction in the average ice thickness was 1-2 m between the late 1950s and 1990s. Data collected between 2003 and 2007 indicates only a small change from the 1990s, with average ice thickness decreasing by less than 5% during this period. There has been no significant trend detected for changes in ice thickness on the Mackenzie Shelf although any such trend would likely be overshadowed by year to year and shorter term variability.

Models and satellite data show a dramatic decline in 4 year and older ice. Second and third year ice still remain but the reduction of older ice leads to reduced ice thickness. Recirculation of sea ice in the BG can create very thick ice along the NW flank of the CAA and this ice can occur as perennial or annual forms. Deformation of first year ice can create ice drafts as large as old ice. It is possible that under conditions of divergence, first-year ice thickness may be increasing. Reversals of the Beaufort Sea ice gyre suggests that we have more divergence in the Beaufort pack than occurred >30 years ago and this will also increase the rate of reduction in thickness and aerial extent of sea ice.

Environment Canada weather data for Tuktoyaktuk and Sachs Harbour show that mean air temperatures have increased in each month over the last 50 years with the largest warming occurring during the fall and winter. In the fall/winter for both Tuktoyaktuk and Sachs Harbour there has been an increase of 0.8ºC every 10 years for a total increase of 4ºC over the last 50 years. Precipitation levels have also been increasing over the last 50 years but at a much reduced rate compared to air temperature with a 1% increase in precipitation every decade. The observation systems at climate stations have a relatively low precision and as such this small change in precipitation should be interpreted with caution. Of perhaps greater importance than precipitation in general is accumulated snow which may increase, especially in spring and fall, in coastal areas. Accumulation amounts are more complicated over the ocean due to the amount of sea ice present and the losses of snow into the ocean. Surface winds have shown only small positive or negative trends over the last 50 years. Cyclones or low pressure systems do not appear to be increasing in frequency but they do appear to be becoming stronger (i.e., deeper low pressures). Also, easterly winds are becoming more prevalent in the last 15 years due to strengthening of the Beaufort Sea high pressure system. These changes in atmospheric circulation have significant effects on dynamic (wind) and thermodynamic (snow) forcing of the sea ice.

Models suggest continued 'episodic' (and significant) decreases in the areal extent of ice such as those that occurred at the summer minimums of 1998, 2007 and 2012. These will be interspersed with periods of increased ice cover, with the overall decline continuing to be curvilinear. Depending on the continued rate of ice loss used in modeling, a seasonally ice free Arctic is expected sometime around 2030, plus or minus 10 years. Regardless of the timeframe for a seasonally ice-free Arctic Ocean, models are almost universally in agreement that Arctic sea ice extent will decline through the present century.

Once the ocean surface mixed layer loses its heat to the atmospheric boundary layer sea ice will form. This process is expected to continue well into this century and the maximum extent of sea ice will not decrease nearly as much as the seasonal minimum. That said, the ice will largely be perennial in nature and thus will be much more susceptible to dynamic forcing through atmospheric and oceanic forcing.

The expected reduced sea ice conditions, and their relation to regional and global atmospheric and climate conditions, will coincide with changes in other parameters, including:

- Continuing increase in air temperatures, especially in the fall and winter, at rates similar to those experienced in the past 50 years
- Increases in precipitation as air temperatures warm with more snow in winter and more rain in summer. There is also potential for increases of liquid precipitation in winter. This feature has significant potential impacts on the physical, biological and human systems in the SBS (Barber et al. 2012).
- Warming and freshening of the offshore ocean waters due to more open water and increased ice melt which appears to be occurring in the Beaufort Sea. Freshening will stratify the water column limiting upwelling of nutrients to the euphotic zone. Warming will increase the heat flux to the lower atmosphere creating a higher probability for more intense storms, particularly in the fall and early winter period (Raddatz et al. 2011).
- Larger ocean waves occurring over longer periods of time in summer and fall, in association with the reduced sea ice coverage. These waves are a challenge to development but also increase the loss of sea ice by breaking up flows into smaller sizes which are more mobile and melt more easily (Asplin et al. 2012).
- Enhanced upwelling at the shelf edge has been observed since 2003 under the combined effect of reduced ice extent and the increased prevalence of the anticyclonic atmospheric circulation of the western Arctic Ocean (Pickart et al. 2011; Moore and Pickart 2012). The underlying atmospheric

circulation processes are not well understood but appear to be a combination of overall strengthening of the Beaufort Sea high (anticyclonic) pressure system and more intense cyclones penetrating the Arctic from the Pacific and Atlantic (Lukovich and Barber 2006).

TRADITIONAL KNOWLEDGE

The number of traditional knowledge studies that were specifically designed to obtain information regarding climate change is limited. However, a larger body of traditional knowledge has been collected in support of preparing environmental assessments which often contain information on climate change. Both types of traditional knowledge information shared a number of common observations on climate change effects. These included;

- changing and unpredictable weather
- increased frequency and severity of storms
- later freeze-up of ice and earlier break-up
- more open water in winter and thinner ice
- increased permafrost melting and slumping
- increased coastal erosion

Traditional knowledge provides an important perspective on climate change for the Beaufort Sea region as observers collect knowledge over long periods of time and for all seasons, which is not always the case for western based science. Traditional knowledge provides a complimentary knowledge base to western science for use in planning, environmental assessments and the development of regulations and guidelines.

REGULATIONS GUIDELINES AND BEST PRACTICES

Regulations and guidelines pertinent to oil and gas offshore operations and climate change were reviewed for Canada, Alaska and northern European countries. No best practices were identified pertaining to potential climate change effects on oil and gas activities. Most regulations and guidelines reviewed make reference to the effects of the project on producing greenhouse gases or on how climate change may affect the environment. However few deal with climate change effects on projects. All projects proposed in the Canadian Beaufort Sea are first submitted to the Environmental Impact Screening Committee (EISC). The EISC does not reference climate change in their guidelines to proponents. Projects submitted to the EISC may be forwarded to the Environmental Impact Review Board (EIRB) for further review. The EIRB requires a project to describe how a proposed development may contribute or not contribute to climate change and also to identify other elements which could be impacted by climate change. Canadian Environmental Assessment Agency (CEAA) requires that climate change effects on a project be assessed and has guidelines to guide environmental assessment practitioners in carrying out these assessments. Other guidelines or regulations which require the assessment of the effects of climate change on a project do not provide guidance on how to conduct this assessment but refer to the CEAA guidelines.

ENVIRONMENTAL ASSESSMENTS

Environmental assessments were reviewed for Canadian, Alaskan and northern European marine waters. In a majority of cases where climate change was discussed it was in the context of the potential of the project to produce greenhouse gases and not on the effects of climate change on oil and gas activities. The assessment of potential climate change effects on oil and gas activities generally was conducted for longer term production projects, which may operate for 30 or more years. Changes to the environment due to climate change would be expected to occur over a longer time period. Short term exploration projects were primarily assessed based on current conditions. Addressing potential climate change effects on a project was typically dealt with through engineering design. For example a production platform would be designed to meet the changing conditions which may occur over its life span.

CLIMATE AND ICE VARIABLES

Climate and ice variables were identified for a wide range of oil and gas activities and an array of plausible oil and gas exploration and development scenarios. In all, 18 variables were identified, with seven of these variables considered high in importance and nine of medium importance. The seven high climate and ice variables are:

- wave height (maximum and mean)
- wind speeds (maximum, mean and extreme)
- sea temperature and heat content
- air temperature
- coastal erosion (rate of loss)
- sea level rise
- sea ice type, distribution and concentration

Sea ice and coastal erosion are the two most apparent elements which may affect oil and gas activities due to climate change. The effects of ice and related variables are divided into three categories glacial ice, landfast ice, and first and multi-year ice.

CLIMATE CHANGE EFFECTS ON OIL AND GAS ACTIVITIES

Exploration drilling for oil and gas in the Beaufort Sea began in the early 1970s and extended to the late 1980s. This activity occurred in shallow nearshore areas and on the shelf. The last exploratory well drilled during this period was in 1989 and no wells were drilled again until the winter of 2005-2006. Since 2006, oil and gas activities in the Beaufort Sea have been limited to seismic operations. Exploration drilling is not expected to occur again until 2020 or later.

Previous predictions on future oil and gas scenarios (Morrell 2005, 2007) assumed a Mackenzie Valley gas pipeline would be constructed. Scenarios included activity occurring in the Beaufort Sea nearshore and focused on gas exploration and future production. There is now a great deal of uncertainty whether construction of the Mackenzie Valley gas pipeline will proceed. Over the last 5 years a number of exploration licenses have been issued for the deep offshore, which is a shift in focus from earlier periods. It is anticipated that the next exploration well to be drilled be in deep offshore waters. However, a feasibility study is also being conducted to assess the potential for oil production at the Amauligak site in the inner shelf in approximately 30 m water depth. Amauligak is the largest oil and gas discovery to date in the Beaufort Sea. Drilling at the Amauligak SDL could proceed in the same general time frame as the offshore deep water drilling, or a few years later. It is expected that once drilling resumes in the Beaufort Sea, activity would likely be limited to one or two wells per year (Callow 2012).

The effects of climate change on oil and gas activities is mainly related to physical changes to the environment such as to ice, wind, waves and coastal erosion. These various climate variables can have effects on all phases of oil and gas operations from seismic exploration to production.

Effects on seismic operations are generally positive with reduced ice coverage and potentially longer operating seasons. Seismic operations can be negatively affected by high wave heights which may cause stoppages in seismic operations to prevent damage to seismic equipment, safety and potential for acquiring poor data.

Exploration or production drilling projects are generally short-term, 1-3 years in length, but they can be extended. Beneficial effects for drilling projects from climate change may be expanded drilling seasons and reduced requirements for ice breaking. Negative effects include the threats to drilling platforms from glacial ice islands and ice velocity increases. Other negative effects are mainly related to support activities related to transfer of supplies and personnel during periods of poor weather conditions such as low visibility.

The effects on production activities are similar to those for drilling operations. However, due to the longer timespan of production operations (25-30+ years), additional effects on these activities may occur due to a changing chemical and biological environment. These effects are difficult to predict but could include costly changes to operating procedures midstream through a project. Where the production activity is occurring (e.g., nearshore versus offshore) will also have a role in the types of effects on this activity. For example, offshore production platforms may have a longer operating period over time, while nearshore operations may be more concerned about erosional effects on artificial islands and winter ice roads.

All phases of oil and gas projects require some level of support. Support can be in the form of supply vessels, icebreakers, aircraft support and land base support. Some operations will require all of these. Positive effects on support activities include reduced ice cover and longer operating seasons. Negative effects include delays in supply vessel mobilization due to high wave events, delays to aircraft support due to poor visibility conditions and erosion of land base support infrastructure.

Climate change has brought a high degree of inter-annual variability to weather and ice conditions in the Beaufort Sea. This high level of variability means that the oil and gas industry must prepare and plan for extreme events. This means that although ice coverage may improve in general, they still have to be prepared to address ice issues if they arise.

A summary of potential climate change effects on oil and gas industry offshore activities by climate variable is provided in Table 6.

Table 6 Summary of climate change effects and their impact on oil and gas activities

Climate Variable	Climate Change Effect	Impact on Oil and Gas Activities
Sea ice	Reduced sea ice concentrations and areal extent	• Reduced impediments to drilling and support activities • Improved seismic coverage • Increased wave height negatively affecting drilling and seismic operations • Improved conditions for dredging and construction • Extended operating period for all offshore oil and gas activities
	Changes in ice thickness	• Thicker ice a hazard to marine operations • Thicker ice may increase ice breaking effort • Thin landfast ice hazard for inshore winter roads
	Increased ice velocities	• Threats to drilling and production platforms
	Landfast ice extent	• Reduced availability for ice roads
Ocean waves	Increased wave size	• Delays in vessel mobilization and demobilization • Hampering of shipping support operations • Delays in seismic operations due to shut downs to prevent damage to equipment • Increased shoreline erosion related to pipelines and causeways • Adverse effects on artificial island construction and maintenance
Air temperature	Warmer temperatures especially in winter	• Reduction in extreme cold operating conditions
	Reduced sea ice conditions especially in form of landfast ice	• Negative effects on nearshore ice roads
	Increased precipitation in form of snow in winter and rain and snow in summer	• Restrict aircraft support activities
	Increased periods of fog	• Restrict aircraft support activities
Ocean currents and temperatures	Changes or increases in bottom currents could affect seabed erosion.	• Effects on drilling and production activities (e.g., pipelines)
Coastal erosion	Increased coastal erosion due to increased sea levels, increased wave action and warming temperatures melting permafrost.	• Effects on coastal infrastructure required for offshore oil and gas activities • Effects on landfall tie in with pipelines
Sea level rise	Increased coastal erosion and increased severity of storm surges due to higher water levels	• Coastal erosion can threaten coastal oil and gas related infrastructure • Flooding of coastal oil and gas infrastructure

Table 6 Summary of climate change effects and their impact on oil and gas activities (cont'd)

Climate Variable	Climate Change Effect	Impact on Oil and Gas Activities
Sediment and water quality	Increases in input of hydrocarbons and PAHs in the water column and biota due to increased re-suspension of sediments; methane release in coastal areas	• Changes in regulations or guidelines mid-way through project (e.g., during production) • Increased negative perception of oil and gas activities affecting community support
	Changes in regional contaminants from LRTAP	• Changes in regulations or guidelines mid-way through project (e.g., during production) • Increased negative perception of oil and gas activities affecting community support

INFORMATION GAPS

This assessment identified a number of information gaps. A majority of these gaps pertain to ice and climate. A limited number of gaps were identified for ecological/biological considerations but these are broad in nature due to their high level of complexity.

Information gaps for ice are divided into three categories: glacial ice, first and multi-year ice, and landfast ice. Glacial ice information gaps include the quantification of glacial ice in the form of ice islands, tabular ice bergs and ice sheets, and an improved understanding of the transport mechanisms of glacial ice. First-year and multi-year ice information gaps are in understanding the trends in concentration, thickness and speed of movement of these ice types. There is also a need to understand sea ice recirculation in the Beaufort Sea Ice Gyre under a changing climate regime. This includes how long sea ice will grow through convergence along the NW flank of the CAA and how long it takes to melt these features as they drift south in the summer over the SBS. For landfast ice, information gaps include: a better understanding of changes in ice thickness, structure and stability; the future timing of freeze-up and break-up; and, improved numerical models for landfast ice. There is also need to develop a better understanding of the role of precipitation (both liquid and solid) and landfast and mobile ice thermodynamic processes.

Information gaps for weather include: whether periods of fog will increase or decrease in frequency due to climate change; changes in wind speed and direction; the effects of changing ice edge locations on weather patterns; and, an improved overall understanding of the interaction between weather patterns and ice.

Wave and storm surge information gaps include how changes in weather patterns will affect wave height, storm surge frequency and intensity. A component of this is the requirement for better wave and storm surge models.

Coastal erosion is related to weather and ice conditions but some specific information gaps for coastal erosion include:

- improved understanding of erosion processes
- improved prediction capabilities of erosion rates

- improved predictive capabilities of the effects of changing weather, ice conditions and wave action on coastal erosion,
- improved prediction capabilities of sea level rise and its effects on coastal erosion and infrastructure
- coastline mapping of erosion vulnerability

There is a requirement for a better understanding of whether contaminant concentrations are likely to increase in the water column and biota due to potential increases in sediment re-suspension and LRTAP or potential changes in shelf basin exchanges. Modeling of contaminants requires improvements to reduce the size of error bars associated with many of the models.

Information gaps for potential ecological and biological changes are difficult to address due to the complexities of ecosystems. However, information gaps include: how EBSAs will be affected; changes in marine mammal and fish migrations; and, how climate change may affect the introduction of new species into the Beaufort Sea.

Twenty-four recommendations were identified through the Preliminary Assessment Report, comments received from climate change experts who reviewed the report and results of the November 19-21, 2012, workshop. Recommendations are related to traditional knowledge, research and modeling requirements, guidelines, monitoring, adaptation and other related requirements. Of the 24 recommendations, 15 were considered a priority, whereas the remaining 9 referred to the continuation of existing programs.

A key recommendation was for continued interaction and information exchange between traditional knowledge holders and western scientists in order to utilize both forms of knowledge. This is considered necessary to improve our understanding of the Beaufort Sea and particularly for decision making with respect to new research and management of oil and gas activities in the region.

Priority research recommendations focused on: improving models and data for these models; an inventory of monitoring conducted in the Beaufort Sea which can be used to improve our understanding of climate change and its effects on the environment; and, establishing monitoring that may be able to be embedded in national and international monitoring programs.

A need was identified for improved guidelines for use in assessing climate change effects in environmental assessments of oil and gas activities. Current guidelines are very broad and provide little practical guidance to an environmental assessment practitioner.

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11 GLOSSARY

Anticyclonic Circulation: The circulation associated with high pressure atmospheric systems in which the winds turn to the right of the downward atmospheric pressure gradient, in the Northern Hemisphere, to describe a clockwise circulation pattern.

Beaufort Gyre: A wind-driven ocean current located in the Arctic Ocean polar region between the North Pole and the Beaufort Sea. The gyre's current moves in a clockwise or anti-cyclonic pattern.

Beaufort Ice Gyre: The movement of the Arctic Ocean sea ice in the Beaufort Gyre region as forced by the prevailing atmospheric and ocean circulation.

Biogeochemical: Of or relating to the dividing into parts and cycling of chemical elements and compounds between the living and nonliving parts of an ecosystem.

Biota: The plant and animal life of a region.

Circumpolar Flaw Lead Study: A study conducted as part of the International Polar Year to obtain a better understanding of the physical mechanisms the life cycle of sea ice, as well as the biological, biogeochemical and ecosystem processes in the open flaw lead of the Cape Bathurst polyna during the winter period.

Continental Slope: The region of the sloping sea bed between the outer edge of the continental shelf and the deep ocean floor.

Coupled Models: Numerical circulation models for the atmosphere and ocean which interact through surface exchange processes including momentum and heat fluxes. Arctic coupled models include coupling of atmosphere, ocean and sea ice models.

Cyclonic Circulation: The circulation associated with low pressure atmospheric systems in which the winds turn to the right of the downward atmospheric pressure gradient, in the Northern Hemisphere, to describe a counter-clockwise circulation pattern.

Cryospheric Circulation: The circulation of sea ice in the polar oceans.

Ecologically and Biologically Significant Areas: Areas which have significant importance to the function of the ecosystem or to the plants and animals in that ecosystem.

Exploration Licence: This licence gives the company the exclusive right to explore, drill, and test for oil and gas, develop land for production and obtain a production licence on Crown land. It is issued by the Minister of Indian Affairs and Northern Development and may be granted for up to nine years.

Fetch: The fetch is the distance over which a wind of reasonable constant direction blows over the open water area of the ocean.

First Year Ice: Sea ice which has formed since the previous summer.

Flaring: A process where excess gas from oil or gas wells is burnt off.

Gas Hydrates: An ice-like crystalline solid formed from a mixture of water and natural gas, usually methane. Gas hydrates occur in the pore spaces of sediments.

Glacial Ice: Ice of glacial origin, i.e. from glaciers and ice sheets.

Heavy Metals: Metals with a specific gravity greater than 5. The ‘toxic’ heavy metals are a subset of heavy metals which are environmentally significant. In the Arctic, the most important toxic heavy metals are lead, mercury and cadmium.

Ice Deformation: The process by which blocks of sea ice of uniform thickness, that has grown in place, is broken and combined into massive ice floes with large vertical scales.

Ice lead: Stretches of open water within fields of sea ice which often occurs in long linear features.

Ice Pressure Keel: A sea ice floe feature with large vertical scales that has been formed through ice deformation processes due to differential movement of sea ice.

Ice Scour: The interaction of sea ice keels on the seabed which results in removal of sea bed bottom materials causing a scour or trough in the seabed.

International Polar Year (IPY):	Is an international collaborative program of scientific research focusing on the polar regions (Arctic and Antarctica). This past 2007-2008 IPY was the third IPY to occur and actually continued into 2009. The first IPY was occurred in 1882-83 and the second IPY was fifty years later between 1932-33.
Landfast Ice:	Non-moving sea ice along coasts due to contact with the sea floor combined with internal forces within the sea ice.
Long Range Transport of Airborne Pollutants (LRTAP):	Compounds such as OC's, PAH's and mercury which, due to their chemical properties, can be transported in the atmosphere to locations far from their point of origin.
Marginal Ice Zone:	The area between the highly concentrated sea ice pack and open water areas.
Models:	Models use mathematical equations for various parameters to describe or represent a system. Often used for predictive purposes.
Multi-year Ice:	Sea ice which has survived two or more summers.
Organchlorines (OC):	Organic compounds containing at least one covalently bonded chlorine atom. Examples include herbicides, insecticides, fungicides and a wide range of industrial chemicals including PCB's. These compounds are of concern because of their effects on the environment and on human and animal health even at trace concentrations.
Pack Ice:	An expanse of large pieces of floating ice driven together into a nearly continuous mass, as occurs in polar seas.
Passive Microwave:	Electromagnetic radiation with a wavelength of 1 mm to 1 m which is emitted by all objects.
Permafrost:	Permanently frozen subsoil.
Polycyclic Aromatic Hydrocarbon (PAH):	PAH's are potent atmospheric pollutants that consist of fused aromatic rings and do not contain heteroatoms or carry substituents. Examples include benzo(a)pyrene and naphthalene. They are of concern because some PAH's are carcinogenic.

Seismic: Techniques used in oil and gas exploration where sound waves are produced and passed through the earth's crust. The resulting reflected and refracted sound waves are picked up by sensors and the data is used to map geologic features in the earth's crust.

Shelf: The area of seabed around a large landmass where the sea is relatively shallow compared with the open ocean.

Significant Discovery Licence (SDL): When oil and/or gas is discovered in an area under an exploration licence, a company can apply to the National Energy Board (NEB) for a significant discovery declaration and to INAC for a significant discovery licence (SDL). The significant discovery licence will not be issued until the significant discovery has been declared. This licence covers the area of the discovery and provides indefinite ownership to the discovery. The SDL allows the holder to continue exploration, drilling and testing within the SDL and to apply for a production licence.

Slope: See Continental Slope.

Storm surge: A rising of the sea as a result of atmospheric pressure changes and wind associated with a storm.

Traditional Knowledge: Refers to knowledge about the environment and use of the land that is held by local Aboriginal peoples.

Transition Zone: The large area between the Arctic Ocean pack ice and the sea ice covering the inner portions of the continental shelf.

Upwelling: The process by which warm, less-dense surface water is drawn away from the shore by offshore currents and replaced by cold, denser water brought up from below the surface.

Wind Stress: The drag or tangential force per unit area exerted on the surface of the earth by the adjacent layer of moving air.

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APPENDIX B

Effects on Oil and Gas Activities and Climate Variables

Table B-1 Effects and their Severity to Oil and Gas Activities

Activity	Area	Effects: Positive	Effects: Negative	Severity of Effect	Confidence in Prediction of Effect	Time Scale	Climate Variables	Supplementary Variables
All Scenarios								
Ice breaker support	All* *except when drilling (shallow) on ice island in winter	Reduced ice reduces support requirements	Reduced lead time to react to changes in ice flows Larger waves impede operations	Nil	Medium to High	Short/medium/long	• Ice concentration and ice thickness • Ice Velocity • Wind speeds (means and maximum) (maximum and extremes) • Wave height (means and maximum) (maximum and extremes) • Days with fog/poor visibility (means and maximum)	
Ice reconnaissance - aircraft and ship	All Nearshore, Shelf, Deep	Reduced ice - reduces requirements	Fog restricting flying	Low	Medium	Short/medium/long	• Ice Concentration • Days with fog/poor visibility (means and maximum)	
Aviation support	All Nearshore, fast ice zone Shelf, Deep	n/a	Fog restricting flying due to reduced visibility	Low	Medium	Short/medium/long	• Days with fog/poor visibility (means and maximum)	
Demobilization* (equipment, drill or production unit, consumables) *Does not apply to 'all year' production activities	All Nearshore, fast ice zone Shelf, Deep	Reduced ice – extends season	Increased wave heights during storm events Delayed start (winter)	Low Nil (summer) Medium (winter)	Medium to High	Short/medium/long	• Ice concentration and ice thickness • Land fast ice extent • Wind speeds (means and maximum) (maximum and extremes) • Wave height (means and maximum) (maximum and extremes)	
Exploration - Seismic								
Seismic ship operations	All	Reduced ice	Increased wave height during storm events	Low	Medium to High	Short/medium/long	• Ice concentration and ice thickness • Wind speeds (maximum and extremes) • Wave height (maximum and extremes)	
Seismic ship operations	All	Neutral/unknown- marine mammal distribution and habitat usage may change and influence exploration activities (mitigations, timing, etc.)		Low	Medium	Short/medium/long	• Ice concentration and ice thickness • Water temperature and salinity,	Marine mammal distribution/ migration surveys
Seismic ship operations	All		Ecologically and Biologically Sensitive Areas (EBSAs) may change creating regulatory uncertainty	Low	Low	Long-term	• Ocean currents, ice distribution	
Other support vessels	All	Reduced ice	Increased wave height during storm events	Low	Medium to High	Short/medium/long	• Ice concentration and ice thickness • Wind speeds (maximum and extremes) • Wave height (maximum and extremes)	

Table B-1 Effects and their Severity to Oil and Gas Activities (cont'd)

Activity	Area	Effects		Severity of Effect	Confidence in Prediction of Effect	Time Scale	Climate Variables	Supplementary Variables
		Positive	Negative					
Exploration – Seismic (cont'd)								
Other support vessels	All	Neutral/unknown- marine mammal distribution and habitat usage may change and influence exploration activities (mitigations, timing, etc.)		Low	Medium	Short/medium/long	• Ice concentration and ice thickness • Water temperature and salinity, marine mammal surveys	
Resupply and crew change		Reduced ice	Increased wave heights during storm events	Low	Medium	Short/medium/long	• Ice concentration • Wind speeds (means and maximum) • Wave height (means and maximum)	
Exploration – Drilling – Shallow – Ice Island – winter only								
Ice road construction	Nearshore fast ice zone	n/a	Delayed start; reduced load limits	Medium	Medium to High	Short/medium/long	• Land fast ice extent and thickness	
Mobilization of island building equipment	Nearshore fast ice zone	n/a	Delayed start; reduced load limits	Medium	Medium to High	Short/medium/long	• Land fast ice extent and thickness	
Build island	Nearshore fast ice zone	Warmer air temperatures	Reduced duration	Low	Medium to High	Short/medium/long	• Land fast ice extent and thickness • Air temperature (minimum and mean)	
Mobilization of drilling equipment and drilling consumables	Nearshore fast ice zone	n/a	Delayed start; reduced load limits	Medium	Medium to High	Short/medium/long	• Land fast ice extent and thickness	
Drilling operations, resupply on going	Nearshore fast ice zone	Warmer air temperatures	Reduced duration	Medium to High (in long term)	Medium to High	Short/medium/long	• Land fast ice extent and thickness • Air temperature (maximum and mean)	
site restoration	Nearshore fast ice zone		Delayed start	Medium	Medium to High	Short/medium/long	• Land fast ice extent and thickness	
Exploration – Drilling – Shallow – Bottom founding Drilling Unit – Summer and Winter								
Mobilization – tow drilling unit to drilling site and set down	Nearshore and shelf	Reduced ice allows earlier start	Larger waves impede operations	Nil	Medium to High	Short/medium/long	• Ice concentration, • Wind speeds (means and maximum • Wave height (means and maximum)	
drilling site and set down	Nearshore, shelf	Neutral/unknown- marine mammal distribution and habitat usage may change and influence timing of drilling site set down (mitigations, timing, etc.)		Low	Medium	Short/medium/long	• Ice concentration, ice thickness, water temperature and salinity,	marine mammal surveys
drilling site and set down	Nearshore, shelf		Ecologically and Biologically Sensitive Areas (EBSAs) may change creating regulatory uncertainty	Low	Low	Long-term	• Ocean currents, ice distribution	Biological productivity studies

Table B-1 Effects and their Severity to Oil and Gas Activities (cont'd)

Activity	Area	Effects		Severity of Effect	Confidence in Prediction of Effect	Time Scale	Climate Variables	Supplementary Variables
		Positive	Negative					
Exploration – Drilling – Shallow – Bottom founding Drilling Unit – Summer and Winter (cont'd)								
Supply vessel or tug and barge support	Nearshore and shelf	Reduced ice	Larger waves impede operations	Nil	Medium to High	Short/medium/long	• Ice concentration • Wind speeds (means and maximum • Wave height (means and maximum)	
Supply vessel or tug and barge support	Nearshore and shelf	Neutral/unknown- marine mammal distribution and habitat usage may change and influence timing of supply vessel movements (mitigations, timing, etc.)		Low	Medium	Short/medium/long	• Ice concentration and ice thickness • Water temperature and salinity	
Drilling operations – summer	Nearshore and shelf	Less ice; longer drilling season	Fog restricting flying	Nil	Medium to High	Short/medium/long	• Ice concentration and ice thickness • Days with fog/poor visibility (means and maximum)	
Drilling operations - summer	Nearshore and shelf	Neutral/unknown- marine mammal distribution and habitat usage may change and influence exploration drilling activities (mitigations, timing, etc.)		Low	Medium	Short/medium/long	• Ice concentration and ice thickness • Water temperature and salinity; marine mammals surveys	Marine mammal distribution/migration surveys
Drilling operations – summer	Nearshore and shelf		Ecologically and Biologically Sensitive Areas (EBSAs) may change creating regulatory uncertainty	Low	Low	Long-term	• Ocean currents, ice distribution	
Drilling operations – summer	Nearshore and shelf	n/a	Reduced stability of mud volcanoes due to warming of bottom water temperatures	medium	Low	Long + 50 years	• Bottom sea temperatures	Side scan or other visual monitoring
Drilling operations - winter	Nearshore and shelf	Less ice; shorter drilling season	Fog restricting flying	Medium	Medium to High	Short/medium/long	• Ice concentration and ice thickness • Days with fog/poor visibility (means and maximum)	
Exploration – Drilling – Open Water– Floater Drilling Unit – Early Summer to Early Winter								
Mobilization of drilling unit and support fleet to Beaufort Sea	Shelf and Deep	Reduced ice allows earlier start	Increased wave height during storm events	Nil	Medium to High	Short/medium/long	• Ice concentration and ice thickness • Wind speeds (maximum and extremes) • Wave height (maximum and extremes)	
Mobilization of drilling unit and support fleet to Beaufort Sea	Shelf and Deep	Neutral/unknown- marine mammal distribution and habitat usage may change and influence exploration drilling activities (mitigations, timing, etc.)		Low	Medium	Short/medium/long	• Ice concentration and ice thickness • water temperature and salinity; marine mammals surveys	Marine mammal distribution/migration surveys

Table B-1 Effects and their Severity to Oil and Gas Activities (cont'd)

Activity	Area	Effects		Severity of Effect	Confidence in Prediction of Effect	Time Scale	Climate Variables	Supplementary Variables
		Positive	Negative					
Exploration – Drilling – Open Water– Floater Drilling Unit – Early Summer to Early Winter (cont'd)								
Positioning and anchor mooring operations	Shelf and Deep	Reduced ice allows earlier start	Increased wave height during storm events	Nil	Medium to High	Short/medium/long	• Ice concentration and ice thickness • Wind speeds (maximum and extremes) • Wave height (maximum and extremes)	
Drilling operations	Shelf and Deep	Reduced ice allows longer drilling season	Increased wave height during storm events; larger surface currents	Nil	Medium to High	Short/medium/long	• Ice concentration and ice thickness • Wind speeds (maximum and extremes) • Wave height (maximum and extremes) • ocean current (means and maximum)	
Drilling operations	All	Neutral/unknown- marine mammal distribution and habitat usage may change and influence exploration activities (mitigations, timing, etc.)		Low	Medium	Short/medium/long	• Ice concentration and ice thickness • Water temperature and salinity	
Drilling operations	Shelf and deep		Ecologically and Biologically Sensitive Areas (EBSAs) may change creating regulatory uncertainty	Low	Low	Long-term	• Ocean currents, ice distribution	Biological productivity studies
Drilling operations	shelf break	n/a	Changes to bottom could accelerate erosion of seabed at shelf break	Low	Low	Long + 50 years	• Bottom currents, • Bottom sea temperatures	
Resupply operations – Ware ship or bases in McKinley or Tuktoyaktuk	All	Reduced ice – longer operating season; higher water levels	Fog restricting flying; larger waves and storm surges (positive and negative	Nil	Medium to High	Short/medium/long	• Ice concentration and ice thickness • Ice Velocity • Days with fog/poor visibility (means and maximum) • Water levels and wave height (means and maximum)	
Resupply operations – Ware ship or bases in McKinley or Tuktoyaktuk	All	Neutral/unknown- marine mammal distribution and habitat usage may change and influence exploration activities (mitigations, timing, etc.)		Low	Medium	Short/medium/long	• Ice concentration and ice thickness • Water temperature and salinity,	
Production –artificial islands nearshore – all year								
Additional 3D seismic if required (see seismic exploration)	Nearshore	Reduced ice; extended operating season	Increased wave height during storm events	Low	Medium to High	Short/medium/long	• Ice concentration and ice thickness • Wind speeds (maximum and extremes) • Wave height (maximum and extremes)	
Construction of gravel or sand for production island	Nearshore	Reduced ice; extended operating season	Increased wave height during storm events	Nil	Medium to High	Short/medium/long	• Ice concentration and ice thickness • Wind speeds (maximum and extremes) • Wave height (maximum and extremes)	

Table B-1 Effects and their Severity to Oil and Gas Activities (cont'd)

Activity	Area	Effects: Positive	Effects: Negative	Severity of Effect	Confidence in Prediction of Effect	Time Scale	Climate Variables	Supplementary Variables
Production –artificial islands nearshore – all year (cont'd)								
Dredging for island	Nearshore	Reduced ice; extended operating season	Increased wave height during storm events	Nil	Medium to High	Short/medium/long	• Ice concentration and ice thickness • Wind speeds (maximum and extremes) • Wave height (maximum and extremes)	
Support vessels and resupply	Nearshore	Reduced ice; extended operating season	Increased wave height during storm events	Nil	Medium to High	Short/medium/long	• Ice concentration and ice thickness • Wind speeds (maximum and extremes) • Wave height (maximum and extremes)	
Support vessels and resupply	Nearshore	Neutral/unknown- marine mammal distribution and habitat usage may change and influence support vessel movements (mitigations, timing, etc.)		Low	Medium	Short/medium/long	• Ice concentration and ice thickness • Water temperature and salinity	marine mammal distribution/migration surveys
Construction of causeway or subsea pipeline to shore	Nearshore	Reduced ice; extended operating season	Increased coastal zone erosion due to permafrost degradation, higher water levels and larger waves	Medium	Medium	Short/medium term	• Shoreline retreat, permafrost degradation • Air temperatures (mean and maximum) • Water levels (means and maximum) • Wave height (means and maximum)	
Subsea pipeline to shore	Nearshore, shelf	Reduced risk of significant ice scour events due to reductions in multi-year ice	Although rare could still occur	Low	High	Short to long-term	• Ice distribution and thickness	
Marine maintenance facilities	Nearshore	Reduced ice; extended operating season, larger mean water levels	Increased coastal zone erosion due to permafrost degradation, higher water levels and larger waves, Fog restricting flying	Low	Medium	Short/medium term	• Shoreline retreat, permafrost degradation • Air Temperatures (mean and maximum) • Water levels (means and maximum) • Wave height (means and maximum) • Days with fog/poor visibility (means and maximum)	
Drilling and production	Nearshore	n/a	Increased wave height during storm events, increased erosion due to larger waves, reduced ice, fog restricting visibility for flying	Low	Medium to High	Short/medium/long	• Ice concentration and ice thickness • Wind speeds (maximum and extremes) • Wave height (maximum and extremes) • Days with fog/poor visibility (means and maximum)	
Drilling and production	All	Neutral/unknown- marine mammal distribution and habitat usage may change and influence drilling and production activities (mitigations, timing, etc.)		Low	Medium	Short/medium/long	• Ice concentration and ice thickness • Water temperature and salinity, marine mammals surveys	

Table B-1 Effects and their Severity to Oil and Gas Activities (cont'd)

Activity	Area	Effects		Severity of Effect	Confidence in Prediction of Effect	Time Scale	Climate Variables	Supplementary Variables
		Positive	Negative					
Production –artificial islands nearshore – all year (cont'd)								
Drilling and production	All		Ecologically and Biologically Sensitive Areas (EBSAs) may change creating regulatory uncertainty	Low	Low	Long-term	• Ocean currents, ice distribution	Biological productivity studies
Drilling and production	shelf break	n/a	Changes to bottom currents could accelerate erosion of seabed at shelf break	Low	Low	Long + 50 years	• Bottom currents, • Bottom sea temperatures	
Inspection operations (pipeline etc.)	Nearshore	Reduced ice; extended operating season	Increased wave height during storm events, increased erosion due to larger waves, fog restricting visibility for flying	Low	Medium to High	Short/medium/long	• Ice concentration and ice thickness • Wind speeds (maximum and extremes) • Wave height (maximum and extremes) • Days with fog/poor visibility (means and maximum)	
Production – nearshore and shelf using Gravity Based Structure (GBS) –all year								
Additional 3D seismic if required (see seismic exploration)	Nearshore, Shelf	Reduced ice; extended operating season	Increased wave height during storm events	Low	Medium to High	Short/medium/long	• Ice concentration and ice thickness • Wind speeds (maximum and extremes) • Wave height (maximum and extremes)	
Mobilization of GBS and set down	Nearshore, Shelf	Reduced ice; extended operating season	Increased wave height during storm events	Nil	Medium to High	Short/medium/long	• Ice concentration and ice thickness • Wind speeds (maximum and extremes) • Wave height (maximum and extremes)	
Dredging for seabed base	Nearshore, Shelf	Reduced ice; extended operating season	Increased wave height during storm events	Nil	Medium to High	Short/medium/long	• Ice concentration and ice thickness • Wind speeds (maximum and extremes) • Wave height (maximum and extremes)	
Support vessels and resupply	Nearshore, Shelf	Reduced ice; extended operating season	Increased wave height during storm events	Nil	Medium to High	Short/medium/long	• Ice concentration and ice thickness • Wind speeds (maximum and extremes) • Wave height (maximum and extremes)	
Support vessels and resupply	Nearshore, Shelf	Neutral/unknown- marine mammal distribution and habitat usage may change and influence support vessel movements (mitigations, timing, etc.)		Low	Medium	Short/medium/long	• Ice concentration and ice thickness • Water temperature and salinity,	marine mammals distribution and migration surveys
Drilling and production	Nearshore, Shelf	n/a	Increased wave height during storm events, increased erosion due to larger waves, reduced ice, fog restricting visibility for flying	Low	Medium to High	Short/medium/long	• Ice concentration and ice thickness • Wind speeds (maximum and extremes) • Wave height (maximum and extremes) • Days with fog/poor visibility (means and maximum)	

Table B-1 Effects and their Severity to Oil and Gas Activities (cont'd)

Activity	Area	Effects		Severity of Effect	Confidence in Prediction of Effect	Time Scale	Climate Variables	Supplementary Variables
		Positive	Negative					
Production – nearshore and shelf using Gravity Based Structure (GBS) –all year (cont'd)								
Drilling and production	All	Neutral/unknown- marine mammal distribution and habitat usage may change and influence drilling and production activities (mitigations, timing, etc.)		Low	Medium	Short/medium/long	• Ice concentration and ice thickness • Water temperature and salinity;	marine mammals distribution and migration surveys
Drilling and production	Shelf and deep		Ecologically and Biologically Sensitive Areas (EBSAs) may change creating regulatory uncertainty	Low	Low	Long-term	• Ocean currents, ice distribution	Biological productivity studies
Drilling and production	shelf break		Changes to bottom currents could accelerate erosion of seabed at shelf break	Low	Low	Long + 50 years	• Bottom currents, • Bottom sea temperatures	
Subsea pipeline to shore	Nearshore, Shelf	Reduced ice; extended operating season for construction of pipeline	Increased wave height during storm events, increased seabed erosion due to larger waves, fog restricting visibility for flying, Increased coastal zone erosion due to permafrost degradation, higher water levels and larger waves, Fog restricting flying	Low	Medium to High	Short/medium/long	• Ice concentration and ice thickness • Wind speeds (maximum and extremes) • Wave height (maximum and extremes) • Days with fog/poor visibility (means and maximum) • Shoreline retreat, permafrost degradation • Air temperatures (mean and maximum) • Water levels (means and maximum)	
Subsea pipeline to shore	Nearshore, shelf	Reduced risk of significant ice scour events due to reductions in multi-year ice	Although rare could still occur	Low	High	Short to long	• Ice distribution and thickness	
Tanker operations	Nearshore, Shelf	Reduced ice; extended operating season	Increased wave height during storm events	Nil	Medium to High	Short/medium/long	• Ice concentration and ice thickness • Wind speeds (maximum and extremes) • Wave height (maximum and extremes)	
Inspection operations (pipeline etc.)	Nearshore, Shelf	Reduced ice; extended operating season	Increased wave height during storm events, increased erosion due to larger waves, fog restricting visibility for flying	Low	Medium to High	Short/medium/long	• Ice concentration and ice thickness • Wind speeds (maximum and extremes) • Wave height (maximum and extremes) • Days with fog/poor visibility (means and maximum)	
Production –outer shelf and deep water using floating production unit –seasonal								
Additional 3D seismic if required (see seismic exploration)	Shelf, deep	Reduced ice; extended operating season	Increased wave height during storm events	Low	Medium to High	Short/medium/long	• Ice concentration and ice thickness • Wind speeds (maximum and extremes) • Wave height (maximum and extremes)	

Table B-1 Effects and their Severity to Oil and Gas Activities (cont'd)

Activity	Area	Effects: Positive	Effects: Negative	Severity of Effect	Confidence in Prediction of Effect	Time Scale	Climate Variables	Supplementary Variables
Production –outer shelf and deep water using floating production unit –seasonal (cont'd)								
Mobilization of drilling unit and support fleet to Beaufort Sea including ice-breaker support	Shelf, deep	Reduced ice from Pt. Barrow to Canadian Beaufort Sea; extended operating season	Increased wave height during storm events	Nil	Medium to High	Short/medium/long	• Ice concentration and ice thickness • Wind speeds (maximum and extremes) • Wave height (maximum and extremes)	
Positioning and anchor mooring operations	Shelf, deep	Reduced ice; extended operating season	Increased wave height during storm events	Nil	Medium to High	Short/medium/long	• Ice concentration and ice thickness • Wind speeds (maximum and extremes) • Wave height (maximum and extremes)	
Support vessels and resupply	Shelf, deep	Reduced ice; extended operating season	Increased wave height during storm events	Nil	Medium to High	Short/medium/long	• Ice concentration and ice thickness • Wind speeds (maximum and extremes) • Wave height (maximum and extremes)	
Drilling and production	Shelf, deep	Reduced ice; extended operating season	Increased wave height during storm events, fog restricting visibility for flying	Low	Medium to High	Short/medium/long	• Ice concentration and ice thickness • Wind speeds (maximum and extremes) • Wave height (maximum and extremes) • Days with fog/poor visibility (means and maximum)	
Drilling and production	All	Neutral/unknown- marine mammal distribution and habitat usage may change and influence drilling and production activities (mitigations, timing, etc.)		Low	Medium	Short/medium/long	• Ice concentration and ice thickness • Water temperature and salinity	
Drilling and production	All		Ecologically and Biologically Sensitive Areas (EBSAs) may change creating regulatory uncertainty	Low	Low	Long-term	• Ocean currents, ice distribution	Biological productivity studies
Drilling and production	shelf break	n/a	Changes to bottom currents could accelerate erosion of seabed at shelf break	Low	Low	Long + 50 years	• Bottom currents, • Bottom sea temperatures	
Subsea pipeline to shore	Shelf, deep	Reduced ice; extended operating season for construction of pipeline	Increased wave height during storm events, increased seabed erosion due to larger waves, fog restricting visibility for flying, Increased coastal zone erosion due to permafrost degradation, higher water levels and larger waves, Fog restricting flying	Low	Medium to High	Short/medium/long	• Ice concentration and ice thickness • Wind speeds (maximum and extremes) • Wave height (maximum and extremes) • Days with fog/poor visibility (means and maximum) • Shoreline retreat • Permafrost degradation • Air temperatures (mean and maximum) • Water levels (means and maximum)	

Table B-1 Effects and their Severity to Oil and Gas Activities (cont'd)

Activity	Area	Effects		Severity of Effect	Confidence in Prediction of Effect	Time Scale	Climate Variables	Supplementary Variables
		Positive	Negative					
Production –outer shelf and deep water using floating production unit –seasonal (cont'd)								
Subsea pipeline to shore	Nearshore, shelf	Reduced risk of significant ice scour events due to reductions in multi-year ice	Although rare could still occur	Low	High	Short to long-term	• Ice distribution and thickness	
Tanker operations	Shelf, deep	Reduced ice; extended operating season	Increased wave height during storm events	Nil	Medium to High	Short/medium/long	• Ice concentration and ice thickness • Wind speeds (maximum and extremes) • Wave height (maximum. and extremes)	
Inspection operations (pipeline etc.)	Shelf, deep	Reduced ice; extended operating season	Increased wave height during storm events, increased erosion due to larger waves, fog restricting visibility for flying	Low	Medium to High	Short/medium/long	• Ice concentration and ice thickness • Wind speeds (maximum and extremes) • Wave height (maximum and extremes) • Days with fog/poor visibility (means and maximum)	
Decommissioning – Islands - Nearshore								
Restoration operations	nearshore	Reduced ice – more time	Increased wave height during storm events	Nil	Medium to High	long	• Ice concentration and ice thickness • Wind speeds (maximum and extremes) • Wave height (maximum and extremes)	
Decommissioning - nearshore and shelf with GBS								
Movement of GBS out of Beaufort Sea or new location	Nearshore, shelf	Reduced ice from Pt. Barrow to Canadian Beaufort Sea; extended operating season	Increased wave height during storm events	Nil	Medium to High	long	• Ice concentration and ice thickness • Wind speeds (maximum and extremes) • Wave height (maximum and extremes)	
Reclamation	Nearshore, shelf	Reduced ice – more time	Increased wave height during storm events	Nil	Medium to High	long	• Ice concentration and ice thickness • Wind speeds (maximum and extremes) • Wave height (maximum and extremes)	
Decommissioning - outer shelf and deep water using floating production unit								
Movement of unit out of Beaufort Sea or new location	Shelf, deep	Reduced ice from Pt. Barrow to Canadian Beaufort Sea; extended operating season	Increased wave height during storm events	Nil	Medium to High	long	• Ice concentration and ice thickness • Wind speeds (maximum and extremes) • Wave height (maximum and extremes)	

NOTES:

Area: nearshore 0-20 m, shelf 20-100m, deep >100m, all fast ice zone? shelf break?

Severity of Effect: Nil, Low, Medium, High - Nil = no effect

Time Scale: Short (0-5 years), Medium (5-15 years), Long-term (15-30 years), all + 50 years

APPENDIX C List of Experts

Table C-1 List of Experts

Name	Affiliation	Phone number	E-mail	Area of Expertise
Gary Stern	Fisheries and Oceans Canada	(204) 984-6761	Gary.Stern@dfo-mpo-gc.ca	Contaminants, IRIS
Robie Macdonald	Fisheries and Oceans Canada	(250) 363-6409	Robie.macdonald@dfo-mpo.gc.ca	Contaminants
Fred Wrona	Environment Canada	(250) 363-8901	Fred.wrona@ec.gc.ca	Aquatic hydro-ecology
Terry Prowse	Environment Canada		Terry.Prowse@ec.gc.ca	Hydrology
David Barber	University of Manitoba	(204) 474-6981	dbarber@cc.umanitoba.ca	Marine
John Fyfe	Environment Canada	(250) 363-8236	John.yfe@ec.gc.ca	Climate modeling
Jesper Madsen	Aarhus University	4538142794	jm@dmu.dk	Arctic biodiversity
Heikke Lihavainen	Finnish Met Institute	358503623773	Heikki.lihavainen@fmi.fi	Atmosphere
Terry Callaghan	Swedish Academy Sciences	447770542123	Terry_callaghan@btinternet.com	Atmosphere
Richard Bellerby	Bjerknes Centre for Climate Research, University of Bergen	475558236	Richard.bellerby@uni.no	Climate modeling/oceanography
Jim Overland	NOAA	(206) 526-6795	James.e.overland@noaa.gov	Marine
Dr. Andrew Derocher	University of Alberta	(780) 492-5570	derocher@ualberta.ca	Ecology, conservation, and management of large Arctic mammals focusing on polar bears
Steve Ferguson	University of Manitoba/Fisheries and Oceans Canada	(204) 983-5057	steve.ferguson@dfo-mpo.gc.ca	Population health of marine mammals in the Canadian Arctic. / Global warming and human economic development in the Arctic affects the ecology of marine mammals and ways to mitigate potential problems.
Jim Reist	Fisheries and Oceans Canada	(204) 983-5032	Jim.Reist@dfo-mpo.gc.ca	Arctic fish
Louis Fortier	University of Laval/ArcticNet	(418) 656-5646	Louis.Fortier@bio.ulaval.ca	Arctic fish, zooplankton

Table C-1 List of Experts (cont'd)

Name	Affiliation	Phone number	E-mail	Area of Expertise
Steve Blasco	Natural Resources Canada	(902) 426-3932	Steve.Blasco@nrcan-rncan@gc.ca	Resource engineering geophysicist (seabed features e.g., mud volcanoes, ice scours)
Scott Dalimore	Natural Resources Canada	(250) 363-6423	Scott.Dalimore@nrcan-rncan@gc.ca	Gas hydrates
Julienne C. Stroeve	National Snow and Ice Data Center,	(303) 492-6199	stroeve@kyros.colorado.edu	Sea ice climate change – analysis and modeling
Jinlun Zhang	Polar Science Center, Applied Physics Laboratory	(206) 543-5569	zhang@apl.washington.edu	Modeling sea ice and climate change
Gregory M Flato	Canadian Centre for Climate Modelling and Analysis, Environment Canada	(250) 363-8233	greg.flato@ec.gc.ca	Modeling sea ice and climate change
Andy Mahoney	Geophysical Institute, University of Fairbanks	(907) 474-5382	mahoney@gi.alaska.edu	Sea ice, especially landfast ice
David E. Atkinson	Department of Geography, University of Victoria	(250) 721-7332	datkinso@uvic.ca	Wind and waves in nearshore areas – Western Arctic
Don Forbes	Geological Survey of Canada, Natural Resources Canada	(902) 426-7737	dforbes@nrcan.gc.ca	Large-scale coastal evolution; impacts of climate change
Humphrey Melling	Fisheries and Oceans Canada	(250) 363-6552	Humfrey.Melling@dfo-mpo.gc.ca	Sea ice, oceanography

APPENDIX D Workshop Proceedings

Proceedings of the BREA Climate Change Workshop
Midnight Sun complex, Inuvik, NT
November 19 to 21, 2012

MONDAY 19 NOVEMBER

Project and Workshop Objectives – Doug Chiperzak

This Project was conducted through the Beaufort Regional Environmental Assessment (BREA), Climate Change Working Group and funded by Aboriginal Affairs and Northern Development Canada (AANDC). The BREA is a multi-year, multi-stakeholder initiative to sponsor regional research and other activities that will make available historical and new information vital to the future management of oil and gas activity in the Beaufort Sea.

Objectives of this Project were to provide an assessment of the potential impacts of climate change related to all oil and gas activities and phases in the short, medium and long-term, for the;

- Nearshore
- Shelf and
- Deep waters

The purpose was to support efficient and effective environmental assessment and regulatory decision-making by managers, regulators and policy makers pertinent to the potential impacts of climate change on oil and gas activities in the Beaufort Sea.

The objectives of this workshop were to;

- Validate the Draft Assessment and Report
- Review information gaps relating to current knowledge of the Beaufort biogeophysical environment, regional climate change, and effects on oil and gas activities
- Propose research initiatives to improve the state of knowledge
- Identify current climate change information and its value to inform near-future (next 12-30 years) activities
- Make this information available for regulatory decision making and environmental assessments

Presentation: Climate Change and the Southern Beaufort Sea; Baseline conditions to the present, changes and trends – Prof. David Barber, University of Manitoba.

The presentation provided an overview of baseline conditions and identified trends and changes into the near future. The effects of climate change are amplified in the Arctic. Some key changes from baseline have been observed for the types, distribution and thickness of ice, timing of freeze-up and break-up, changes in circulation patterns such as with the Beaufort gyre, and the increasing presence of glacial ice. Storms are also increasing in strength and frequency. Coupled ice/ocean/atmosphere models on the regional and local scale require further development and verification. Significant challenges for the oil and gas industry are:

- Multi-year ice hazards

- Glacial ice hazards
- Cyclones and their effects on waves in ice and snow on ice
- Ice motion and direction
- Predicting motions
- Wind
- Warming of the Arctic
    - Glacial retreat
    - Permafrost
    - Winter ice roads

Questions/Comments:

1. From all the information collected, is the Federal government using it to do something about climate change?

    (Ans): The BREA project is funded by Aboriginal Affairs.

2. The weather patterns are becoming unpredictable e.g. there was about 7 weeks of above average temperatures in Banks islands – this caused problems for Muskox, there was no rain.

    (Ans): The models are poor at predicting precipitation; this is a more complex process. There is more persistence in wet and dry periods – this is related to climate change.

3. Is there currently research on water levels rising?

    (Ans): There is modeling on wave and storm surges, but not on sea level rising. Glacial ice is the problem in sea level rising, not sea ice. Water is coming from the land and going into the sea – this causes the sea level rising.

4. There is a need for better monitoring for both surface and deep water currents for the oil and gas industry and more real time measurements.

Presentation: Potential Oil and Gas Activity Scenarios – Doug Chiperzak

A presentation on potential oil and gas activity scenarios for the period 2012-2027 was presented. Predicting oil and gas activity into the future is challenging and can be affected by a number of factors, such as price of oil or gas, other potential areas in the world where a company may want to explore and regulatory regimes and timing or chances of approval. The presentation provided a brief history of oil and gas activities in the Beaufort Sea starting with seismic activities which led to the first well being drilled in 1972. Since then approximately 93 wells have been drilled in the Beaufort Sea with the last being in the winter of 2005-2006 in relatively shallow water. Types of oil and gas activities associated with exploration and production were also discussed such as seismic, support vessels, icebreakers, camps etc. The types of potential drilling platforms which can be used at various depths were also identified. One to two seismic surveys have been conducted in the Beaufort Sea since 2006 and this will likely continue at least for the next several years. The first deep offshore well, if approved was predicted earlier to occur possibly in 2018, however this now looks like it may be 2 -4 years later. There is also the potential that a well could be drilled in the inner shelf of the Beaufort Sea in the same general time period.

Questions/Comments:

1. There is limited infrastructure for offshore oil and gas e.g. ice breakers, drill ships; maybe onshore activities would be cheaper.
2. There is a lot of planning that takes place before drilling. Research timelines are long, if oil and gas activities are not happening soon, then there may not be an urgency for monitoring to get started.
3. The assessment should be focused on activities that may happen, not just the timelines for the activities.

   (Ans): There may be a bit of lead time to get required information; the models can be used for this before offshore oil and gas activities get started to help in planning.

4. Research depends on technology that currently exists; there is a big gap in the ability to highlight climate change since the full picture is not known e.g. would there be pipelines to get the oil and gas back to shore?

   (Ans): Pipelines are addressed in the report. Tankers are treated under shipping and ice conditions.

5. What about shore support? For the leases that are far away are port facilities going to be needed?

   (Ans): This is a possibility. There are several options, one is to use wareships or a combination of wareships and port facilities.

TUESDAY 20 NOVEMBER

Presentation: Potential Effects on Oil and Gas Activities due to Climate Change – Dave Fissel and Doug Chiperzak

The presentation discussed both positive and negative potential effects on oil and gas activities in the Canadian Beaufort Sea due to climate change for the next 25 years. The effects related to climate change were assessed for all phases of oil and gas operations, including seismic, exploratory drilling, production including ancillary activities such as pipelines, shipping traffic, harbor and port facilities. Potential positive effects included longer operating seasons for most activities, and reduced ice coverage providing fewer hazards to seismic operations. Potential negative effects on oil and gas activities due to climate change included but not limited to the presence of glacial ice posing a hazard to drilling platforms and shipping, reduced ice cover leading to larger waves affecting offshore re-supply and increasing coastal erosions and its potential effects on support infrastructure. Increasing severity and frequency of storms affecting seismic operations, offshore re-supply, and other activities.

Questions/Comments:

1. Comment on climate/ice variable from the presentation – this should be changed to ‘could there be an effect.

   (Ans): Presently there are not many oil and gas activities in the Beaufort Sea, so the effects are not certain, they are just a possibility.

2. Air temperature is not included as one of the six climate variables, why? Air temperature is a big variable for ice islands.

   (Ans): Air temperature is included in the effects, but it may not be a key variable; the direct effect would be the sea temperature on other variables.

3. What are the drivers for the six climate variables?

   (Ans): It is important to know these e.g. extreme events, variability, frequency of events etc.

4. What about air temperature and the interaction with precipitation e.g. wet vs. wet and freezing?

   (Ans): Extreme events are driving things, not the constant air temperatures; oil and gas activities need to plan for the extreme events.

5. What influences wave height?

   (Ans): Wind, but also ice cover; larger waves can form over larger areas of open water. The main issue is being able to measure the variables; most weather stations are located onshore, not offshore.

6. Over the last six years, there have been lower wave heights around Banks Islands. There used to be a lot more ice before and had high waves.

   (Ans): This could also depend on the wind direction as well. There is variability in the factors that are hard to predict.

7. Why are sea level and coastal flooding not included on the list?

   (Ans): These are captured in some other variables e.g. wind speeds, wave height. We will re-consider these events.

8. Atmospheric variables related to air pollutants (sources of pollutants) are not included; climate change will influence the pollutants.

   (Ans): Contaminant pathways were looked at. This may be an issue on its own, there is a need to understand the pathways, whether it is natural or industry related.

9. Winds and patterns in the area – this may relate to variability in circulation; storm patterns; the Arctic oscillation system can change.
10. Wind is still a problem; it needs to be part of a system. There is a need for monitoring offshore locations. Direct wind measurements would be needed to validate satellite and radar data. There has been some good advancement with improving mesoscale wind models.
11. Sea surface temperature – this is related to the heat content of the water; this impacts the ice content. Recommend this is re-named to 'Ocean Heat Content' as opposed to Sea Surface Temperature.
12. Recommend that ice velocity is included under sea ice; it is important to know how fast the ice is moving.
13. Freshwater inputs e.g. from the Mackenzie River – how does this affect all the variables, should this be considered?

   (Ans): The land plays a role e.g. pollutants transport, however it was not considered in this study. IRIS is funding another study to look at the effects of freshwater.

14. The volume and temperature of the freshwater may be important; what happens when this enters the southern Beaufort Sea?

    (Ans): The main issue will be the timing of the freshwater input; it is difficult to tie this to climate change effects on the oil and gas industry.

15. Recommend – the variables should be ranked. It may be a novel problem or not, it could have been considered in oil and gas activities in other regions or areas.
16. Dredging does affect fishing and whaling and is considered during assessments when dredging is conducted as part of oil and gas activities, but it may not be related to climate change.
17. The strength of ice is important, not just the thickness of fast ice. Ice strength should be considered.
18. There are no good models for land fast ice, they are geographically specific.
19. Data has been showing a trend of reduced air temperatures in winter; this may have a positive effect on oil and gas activities.
20. The effects of drilling and production activities should be defined; clarify if it is on shallow waters.
21. Coastal erosion changes and flooding – flooding should be included.
22. Contaminants – both long and short range should be looked at.

Presentation: Overview of the status of climate change knowledge as it relates to understanding climate change effects on oil and gas activities and knowledge gaps - Dave Fissel

Questions/Comments:

1. This is a regional assessment, is local scale information needed as well?

   (Ans): Yes this is regional, but local information is also used where needed.

2. Is there a good understanding of ice islands?

   (Ans): There needs to be work on source ice; how long the ice would exist in the gyre; there is a knowledge gap in appropriate sea ice models.

3. How is the migration of whales or fish going to be affected?

   (Ans): This is not directly related to the project.

   The document should acknowledge the wildlife may also be affected; perhaps identify where it is being addressed. Migratory patterns of wildlife changing could also affect oil and gas activities; this should be flagged for follow up.

4. The Mackenzie River inflow is important for the formation and breakup of land fast ice.
5. There is no mention of bottom fast ice; there will also be impacts to this.

   (Ans): This may not cause a big impact to oil and gas activities.

6. The trend to warming is clear, but there is a data gap in the changing wind regime, atmospheric circulation and how it affects the ice.

7. The report should make the distinction between weather and climate. Weather is what you see out the window while climate refers to long-term trends that is what you expect to see. Recommend the heading changed to Weather/Climate: Knowledge and Data Gaps.
8. The occurrence of more storm events should be considered e.g. increase in frequency of lightning strikes. Arctic oil and gas activities onshore are currently not grounded for lightning strikes.
9. Ongoing monitoring and the need for continued monitoring should be mentioned.
10. The models are good from an engineering standpoint, but there is a need to consider the uncertainty/unpredictability factor.
11. Coastal erosion – it is hard to detect the trends, but the regional variability needs to be considered.
12. Contaminants can be an issue for oil and gas activities; increased contaminants may be wrongfully attributed to oil and gas activities.
13. Would the Mackenzie River have inputs for contaminants?

    (Ans): Yes, that is a possibility, but it was not considered as part of this scope; the coastline was the boundary for the project.

Presentation: Preliminary Research Requirements – Doug Chiperzak

The presentation identified 13 preliminary recommendations that were presented in the Draft Assessment Report prepared for the workshop.

1. The preliminary research requirements do not include traditional knowledge. This is a key component and should be included.
2. There is a need for continuous long term monitoring programs e.g. community based monitoring programs, to validate the models and to update the model predictions with realistic occurrences.
3. The limitations of the models and input data should be highlighted; the models should be used for appropriate things; effective scales for the models are needed.
4. There is a difference between sea ice and marine glacial ice – the report should make a distinction with these.
5. Terminology should be defined in the report; recommend including a glossary.

Research priorities were discussed in an open forum at the workshop using the preliminary recommendations as a starting point. A table was constructed during this forum and is included below.

Traditional Knowledge	Importance to Oil & Gas Activities	Current or Required Research
Priorities		
Continue interaction and knowledge exchange between Inuvialuit and western scientists.	Important in obtaining both sets of knowledge for decision making	
Utilize or establish community based monitoring programs for the monitoring of climate change (integrate western science); integrate western science and TK programs through community based monitoring	Community monitoring provides for year round monitoring opportunities, provide advice on monitoring design and monitoring locations and assists with the dissemination of information into the communities	
TK Coordinator – involve from start of programs and continue with Community Consultations	Facilitate the collection, access and dissemination of Traditional Knowledge	
Research Requirements		
Processes required for developing atmospheric regional model • Response – cyclones • Upper air data, not just surface	Atmos. Circulation of great importance to sea ice, currents, water levels and waves	Need much upper air data (LIDAR); JC Gascard program may help; Amundsen ship-based Marine atmospheric boundary layer data required, limited to Amundsen
Marine Glacial Ice; source, pathways and duration	Ice hazards have potentially very large effect on many O&G activities very occasionally	Need process understandings to support better models for source amounts and pathways/duration
Research on Ice Deformation, response to atmospheric water forcing – ridges/leads, degradation of large ice features; Role of frazil ice – relation to sediment processes and atmospheric forcing	Very important to CC understandings; ice hazards	Key processes on multi-year ice formation on the north coasts of CAA and N. Greenland; some observations in Nares Strait, Fram Strait; NRC; more data and research required
Ecosystem Functioning		Many process gaps in ecosystem components; at rudimentary level; focus on climate change effects on migratory routes, hot spots in terms of O&G that underpin ecosystem function
Modeling		
Landfast ice	Link to Ice hazards; high priority	Insufficient present capabilities
Contaminant Transport – pathways	Link to erosion	Insufficient
Contaminant Transport – pathways - biota		Insufficient

Traditional Knowledge	Importance to Oil & Gas Activities	Current or Required Research
Priorities (cont'd)		
Inshore wave and surge modeling	Importance for coastal erosion for O&G infrastructure of shore facilities and pipeline crossings	Inshore waves and surges to build on GSC gauge programs
Monitoring		**Current Research Activities - Adequacy**
Inventory of monitoring ; embed into national and intl. monitoring programs	Long term measurements important to climate change understandings; Monitoring of variables important to ocean/ice/atmosphere coupled models	Assist in making monitoring efforts more efficient and prevent duplication
Guidelines		
Climate Change EA Guidelines	Provide clarity and guidance on how to best assess climate change in EAs.	Very generic CEAA guidelines for climate change in EA's; need for improved and more specific guidelines for EA practitioners
Government Related		
Long Term Science Programs required • More monitoring – requires long-term sustained programs • Maintain expertise (esp. govt)	Very important	Need to focus on key indicators; key variables at key locations. Multiple sensor measurements at key sites. Need to ensure quality control and archival
Adaptation		
Investigate climate adaptation options	New approaches may be required to be developed to meet the challenges of climate change.	
Important and Ongoing Activities that Should Continue		
Research		
Beaufort Sea Gyre	Changing regime for Offshore O&G operations	WHOI/IOS programs active since 2003; Amundsen and international research programs; good coverage for average parameters
Coastal Erosion	Coastal erosion can affect where and how infrastructure in support of the oil and gas industry will be built or maintained.	Need thermodynamic/mechanical; need thermal and seabed data; acceleration to be determined (BREA/underway); repetitive mapping at 5 years (LIDAR)
Wind driven Wave for shelf and offshore	Important changes in wave regime for O&G operations	BREA program (W. Perrie) Waves in ice: ONR funded work; industry and ArcticNet activities; D. Dumont/UQAR; IOGP JIP application to oil in ice

Traditional Knowledge	Importance to Oil & Gas Activities	Current or Required Research
Important and Ongoing Activities that Should Continue (cont'd)		
Modeling		
Climate coupling - Regional	200 km	Ongoing – EC, CIS, UM, UA, BIO (CONCEPTS/EC/DFO)
Climate coupling - Local	30 km	UM/UAF – just starting; very high res. for ice
Regional Atmospheric		Industry high res. forecast model; contact John Fyfe/EC
Local Atmospheric		Mesoscale met. models – under development and ongoing
Ice (1st year/multiple year)	Albedo feedbacks required	Average responses; CIS model improvements underway; ice features require new approaches
Ecosystem function	Provides information on ecosystems to help guide industry activities, especially in areas of high ecological significance.	ArcticNet – IRIS underway;

Conclusion of Workshop:

Workshop participants were thanked for their valuable participation. Participants were informed that the results of this workshop and comments provided on the Draft Assessment Report by other experts will be used in developing a final report on the potential effects of climate change on oil and gas activities in the Canadian Beaufort Sea and future research recommendations.

APPENDIX E Workshop Participants

Table E-1 Workshop Participants

Name	Affiliation
Barrie Bonsai	Environment Canada
Mike Fournier	Environment Canada
Tara Paull	AANDC
Jenifer Johnston	IRC
Steve Baryluk	JS/IGC
Matthew Asplin	University of Manitoba/CEOS
Lauren Candlish	University of Manitoba/CEOS
John Alikaulik	IGC
Kevin Hewitt	Chevron
Darrel Christie	EISC
Gerry Simon	ConocoPhillips Canada
Brian Sieben	GNWT/ENR/Climate Change Unit
David Barber	University of Manitoba/CEOS/ArcticNet
Humfrey Melling	DFO/Institute of Ocean Sciences
Breanne Reinfort	University of Manitoba/CEOS/ArcticNet
Wendy Smith	Imperial Oil
Don Forbes	NRCAN/GSC Atlantic
Norm Snow	JS
Frank Pokiak	IGC
Gerald Inglauyasuk	IGC
Dave Fissel	ASL
Resha Ali	Stantec
Doug Chiperzak	Stantec