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Arctic Potential: Realizing the Promise of U.S. Arctic Oil and Gas Resources
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CLIMATE CHANGE AND PROJECTED IMPACT ON ARCTIC ICE CONDITIONS

Prepared for the

Technology & Operations Subgroup

On March 27, 2015, the National Petroleum Council (NPC) in approving its report, *Arctic Potential: Realizing the Promise of U.S. Arctic Oil and Gas Resources*, also approved the making available of certain materials used in the study process, including detailed, specific subject matter papers prepared or used by the study's Technology & Operations Subgroup. These Topic Papers were working documents that were part of the analyses that led to development of the summary results presented in the report's Executive Summary and Chapters.

These Topic Papers represent the views and conclusions of the authors. The National Petroleum Council has not endorsed or approved the statements and conclusions contained in these documents, but approved the publication of these materials as part of the study process.

The NPC believes that these papers will be of interest to the readers of the report and will help them better understand the results. These materials are being made available in the interest of transparency.

The attached paper is one of 46 such working documents used in the study analyses. Appendix D of the final NPC report provides a complete list of the 46 Topic Papers. The full papers can be viewed and downloaded from the report section of the NPC website (www.npc.org).

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Topic Paper

(Prepared for the National Petroleum Council Study on Research to Facilitate Prudent Arctic Development)

5-1	**Climate Change and Projected Impact on Arctic Ice Conditions**
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SUMMARY

The purpose of this paper is to describe i) the recent changes observed in climate, ii) the technologies that helped observe the changes, iii) the technologies that will help in the future to further monitor these changes and iv) the range of scenarios that climate models project for the US Arctic.

Climate Change

Present Observations

Sea ice Extent:

The retreat of Arctic sea ice has been one of the clearest observations of climate change. The over 30-year record of passive microwave data shows a precipitous decline in summer sea ice extent from a nominal 8 x 10^6 square kilometers to typically less than half this area during the last decade. Although the errors in the passive microwave sea ice concentrations are large due to the presence of melt ponds on the surface, and weather obscuring the surface, the record of sea ice extent (SIE, e.g. ice concentrations more or less than some percentage) is indisputably decreasing. While the decrease has been more pronounced in the summer, the decrease in sea ice extent has been observed in every season and in every decade since 1979 (IPCC AR5).

The recent persistence of record SIE minima or near-minima has been attributed to the depletion of multi-year sea ice. Using a simple model that tracked buoys (sea ice) on the Arctic Ocean, Rigor and Wallace (2004) showed that the area of ice older than 10 years decreased from over 80% of the Arctic Ocean to less than 40% of the Arctic Ocean from 1989–1994 due to changes in wind attributed to extended high Arctic Oscillation (AO) conditions. These winds blew almost half of the older, thicker sea ice (3-5 meters thick) out of the Arctic Basin, leaving extensive areas of younger, thinner sea ice throughout the Arctic Ocean. During ensuing summers, this younger thinner sea ice simply did not have enough mass to survive even a colder summer melt season, which in turn produced more areas of younger, thinner sea ice. This feedback is compounded by the positive ice albedo feedback and faster drift and export of sea ice from the Arctic Ocean. Today, over 90% of the sea ice pack is less than 3 years old (1 – 2 meters thick). Rigor and Wallace (2004) concluded that only persistent low-AO conditions over a number of years would allow the sea ice to recover. Although the debate is ongoing, there is some evidence that high-AO conditions are related to a warming climate, and thus the recovery of Arctic SIE is unlikely in the near future.

Recent efforts to predict summer SIE have shown that the current condition of Arctic sea ice preconditions the Arctic for recurring record and near-record summer minima. Specifically, positive feedbacks tend to maintain the current "regime" of sea ice, e.g. in a younger, thinner ice regime ice albedo, faster ice motion, etc. tend to melt and export more ice, so there is a tendency to produce more open water and younger ice. While in an older, thicker sea ice regime, the opposite feedbacks occur, the thicker/brighter sea ice tends to suppress melt, and the slower drift tends to keep ice in the basin, thus promoting the retention of older, thicker sea ice. However, the summer weather is still important in forcing the full extent of the summer retreat. The weather may act to sequester sea ice in the Arctic Basin, or blow it out. The winds may also pile sea ice up against once coast or another, and may form large floebergs that may be a hazard to operations and navigation. These results imply: 1) Given the increased variability of sea ice, i.e. continuing presence of thick sea ice in areas prevailing with younger sea ice, and the faster drift of these areas of sea ice, it is all the more important to be able to predict weather and ice drift on short time scales; 2) our ability to predict sea ice on longer time scales is limited by our ability to predict the weather on these scales.

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Figure 1. Age and thickness of sea ice

Theoretical Level Ice Thickness:

A theoretical level ice thickness can be found by summing freezing degree days (FDD) and using this in an empirical equation (commonly called Lebedev's equation) in the form of

$$\text{Thickness (cm)} = A * \Sigma FDD^{B}$$

where A and B are constants determined by the best fit of the data. A FDD is defined as the difference between the average daily temperature and the freezing temperature of sea water. So if the average daily temperature was -20 °C, the FDD for the day would be 18 (assuming sea water freezes at ~ -2 °C). The ice thickness determined from this relationship is representative of ice grown in an environment in which ice does not move, such as in a lagoon or in landfast ice, and may not be representative of level ice in the offshore due to ice movement causing deformation and re-growth in leads.

Leidersdorf, et al, 2012 used Barrow Airport from winter 1970-71 through 2011-12, A = 0.94, B = 0.58 and the annual FDD, determined theoretical annual level ice thickness values as shown in Figure 1. As can be noted, ice thickness is on a decreasing trend: starting with a value near 175 cm in 1970-71 to a value near 150 cm in 2010-11. The year 2011-12 had a higher value and is somewhat of an anomaly. The trend over the data record is a decrease of -0.54 cm/yr.

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Figure 2. Theoretical level ice thickness values from Barrow Airport air temperatures. From Leidersdorf, et al, 2012.

While an increase in air temperature could explain the decrease in ice thickness, snow fall is also an important factor that could decrease ice growth as it acts as an insulator. Brown and Cote 1992 analyzed ice thickness from 4 sites in the Canadian Arctic from 1950 to 1989 using a 1-dimensional heat transfer model found that snow cover depth was an important factor that accounted for 30% to 60% of the variability in the data record and that snow cover density accounted for another 15 to 30%. Air temperature accounted for less than 5%.

In Figure 2, Leidersdorf et al 2012, analyzed the snow fall as measured at Barrow Airport during the freezing period (1 October through 31 March). As can be noted, snow fall has increased from the late 1980s to the early 2000s.

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Figure 3. Measured snow fall at Barrow Airport. From Leidersdorf et al 2012.

Thus while the increase in air temperature may account for the decrease in ice thickness, the increase in snow fall may play a more important role. Of course, the increase in air temperature may play a secondary role in that it may melt thin ice exposing the ocean surface to evaporation which in turn could cause an increase in snow fall.

Arctic ice thickness:

Technology and logistics capability for wide-ranging, all-season surveillance of sea-ice thickness lags far behind that for mapping the presence, concentration and type of sea ice, which is generally accomplished from orbital platforms. This is mainly because sea ice is opaque to electromagnetic radiation that might otherwise be used to map its thickness from aircraft or satellite. It is acoustic remote sensing from submerged platforms that has been most useful in providing information on sea-ice thickness and it's variations during the past half century. Data from upward-looking sonar deployed for navigational purposes on nuclear submarines (USA, Russia, UK, and France) in the Arctic extend as far back as the late 1950s. Information from self-contained Ice-Profiling Sonar (IPS) has been routinely obtained from fixed sub-sea moorings since about 1990.

There are many papers that document the decline in the average thickness of Arctic pack ice during the last 2 ½ decades. That of Kwok and Rothrock (2009) is a recent synthesis of information on change in the thickness of ice in the central Arctic. It combines data from points where later (1993-97) submarine surveys cross earlier (1958-76) tracks (Rothrock et al. 1999) and data for the 2000s derived via the laser altimeter on ICESat (Kwok et al. 2009). Tables in Kwok et al. (2009) indicate that ice thickness decreased by more than 40% in all sub-regions during the 25 years between the first and second periods of submarine survey, although Tucker et al. (2001) provide evidence that this change, at least along 150°W to the Pole, occurred quite abruptly between the late 1980s and the early 1990s. The change between the second and third periods, scaled to the original, was much smaller, averaging 6.5%. Thickness did decrease in some sub-regions (notably Canada Basin and North Pole) during the time of ICESat coverage.

Maps of ice draft for the “old” Arctic regime were prepared by Bourke and Garrett (1987) from submarine sonar transects acquired between 1960 and 1982. These reveal that the predominantly multi-year ice of the central Arctic at this time averaged 3-8 m in draft, whereas the peripheral areas of first-year ice averaged 1-3 m. As noted elsewhere in this chapter, the extent of decades-old ice has decreased since 1989 from over 80% of the Arctic Ocean to less than 40%. Clearly the halving of multi-year ice coverage and its replacement by much thinner first-year ice can account for an appreciable fraction of the observed decline in average sea-ice thickness. Subsequent to this replacement, a greater fraction of the sea surface was exposed to insolation each summer after much of the surrogate first-year ice had melted. The result has been an increase in absorbed solar energy which in turn has further increased ice loss, an effect called positive albedo feedback (Perovich et al. 2011).

More attention has recently been directed towards the loss of Arctic sea ice than towards its creation. It is not often acknowledged that as multi-year ice coverage of the Arctic Ocean has shrunk about 45%, from 7 to 4 million km^2, the annual production of first-year ice has grown 100%, from 3 to 6 million km^2. Some of first-year ice melts in the summer, some drifts out of the Arctic before it melts and some survives to join the second-year ice population on October 1.

Records of first-year fast-ice thickness in coastal waters of Canada and the Russian Federation extend back a half century. The Canadian observations, which have included data on snow depth, reveal that snow-depth variability has been the principal determinant of variation in ice thickness at winter’s end over this time (Brown and Coté 1992; Dumas et al. 2005). The long time series from both Russia and Canada reveal only weak (cm per decade) trends in thickness over 4-5 decades, both increase and decrease depending on trend in snow accumulation (Polyakov et al. 2003; Steiner et al. 2014: fig. 12). Data, such as exist, suggest that climate change has not strongly impacted the thickness of nearshore first-year fast ice. There are long records of measured first-year pack-ice thickness only from the southern Beaufort Sea (since 1990) and the northern Chukchi Sea (since 2003). Melling et al. (2005) used the first 12 years’ observations from the Beaufort to demonstrate negligible trend in first year ice thickness there during 1991-2003. Analysis of the first 17 years (to 2008) has yielded the same result (Melling et al. 2012). Thickness measured over 10 years record in the northern Chukchi Sea is also without trend. Therefore data, such as exist, suggest that climate change has not strongly impacted the thickness of first-year pack ice.

Canadian scientists have been seeking thick multiyear ice within and along the islands of the Canadian High Arctic, where it is found drifting southward from the heaviest ice region mapped by Bourke and Garrett (1987). It should be noted that this region is identified as the last holdout of thick multiyear ice in multiple studies discussing the decrease of MYI extent. Johnston (2011) discovered that very thick multi-year ice floes (with ridges 5-15 m deep) can still be readily found in these areas two decades after the abrupt thinning of the mixed ice population of the central Arctic Ocean. Her observations suggest that such extreme multi-year ice features are still produced now under much the same conditions as in the past.

Melling (2014) has conducted a programme of systematic observation using sub-sea sonar to acquire continuous observations of drifting multi-year ice within three pathways of transit across the Canadian polar shelf, Nares Strait, Penny Strait, Byam Martin Channel. The data from the western channels reveal not only that the average thickness of the pack is statistically identical to that measured in the 1970s (Melling 2002), but that the probability distribution of thick ice is also unchanged. There are no prior data for comparison in Nares Strait, where very thick floes are also plentiful. The tentative conclusion of these studies is that the extreme multi-year ice features continue to be produced in northern Canadian, likely via the ridging process.

The critical concerns for development in the Canadian (and US) Beaufort Sea are therefore: a) the continued development of the thicker ice in the Canadian Arctic Islands region, b) the rate at which these features degrade during transit from their region of formation in the north to the regions of development and c) the recurrence interval of these hazards within the regions of development.

Coastal Shore Erosion:

Overeem, et al 2011 investigated the increase in open water duration and wave height as it affected coastal erosion along the Alaskan coastline. Using SSMIS estimates of sea ice concentration, they determined the change in open water start and end dates for three cells near Point Drew for the 30 years of data. Using a 1D wave model and wind speeds from Barrow, calibrated to three years of data at Point Drew, they determined the wave climate for the 3 cells. They noted that with the increase in open water, the wave climate also increased, especially in the fall months when the "cumulative wave height" was determined (see Figure 1). They did note that the effect of storms was more significant than the increased fetch in the wave climate. A comment was made that the wave climate of 2007 (then the record lowest sea ice minimum extent) was not at its 30 year maximum. This pointed out that storms may be more important than fetch in wave height generation.

From observations at Drew Point, Overeem et al 2011 noted that coastal erosion was active in mid-summer when the water was warmer and more likely to melt the ice in the coastal bluffs. One storm, which accounted for 46% of the cumulative wave height for that year, created extensive bluff notching (waterline region washed/melted away) and block failures (overhanging blocks fall into water). Using the model data with the observations, they noted a 2.5 times increase in the exposure of permafrost bluffs to seawater, and a 1.6 increase in erosion rate compared to an earlier study by Jones, et al, 2009 (8.7 m/yr in 1979-2002 compared to their observations of 13.6 m/yr).

Changes as observed by Alaskan Natives:

Alaska Natives who subsist off the land and ocean in the Arctic must monitor seasonal changes to keep their activities safe and productive. As the seasonal environmental changes are observed and reported by hunters (things such as: dates of lake and river freeze-up, the onset of sea ice formation, spring break-ups and "brown-ups" -the springtime exposure of tundra from beneath snow cover, etc), hunters can compare recent general environmental conditions to those of years' past. Local observations generally validate the measured data; that is, for the past 30-50 years it is getter warmer overall, that freeze-up has been occurring later and break-up has been occurring earlier over the past several decades. In addition marine mammal hunters observed and have corroborated the satellite-observed reduction in multiyear sea-ice cover and its attendant effects (eg more first-year sea ice, potentially less stable landfast sea ice, longer "shoulder seasons" of broken sea ice cover in fall and the generally more rapid retreat of deteriorating first-year sea ice cover in late springtime-early summer).

Less uniformly-reported and perhaps more prone to local variability- as well as variability by species- is the effect of climate change on animal populations and individual community's subsistence efforts. For example, how has the shortened sea ice season and reduction in multi-year sea ice cover over the past 30-50 years affected marine mammal populations and subsistence hunting? Is it better or worse for the animals? Better or worse for the hunters?

So far, ice cover reduction seems good for some animals like the bowhead whale, whose numbers and perhaps range are both observed to be expanding. Disclaimer: some may attest this to an overall rebound of the species after the end of Yankee whaling.

There have been no reports of reduction in ice seal abundance in the Arctic.

Technology and Results Available:

ICESat: ICESat laser altimetry data provided estimates of sea ice freeboard and thickness in the Arctic. The satellite was operational from 2003-2008 and collected data for ~30 days during fall and winter months.

Arctic sea ice thickness from ICESat data were compared to measured ice thicknesses from declassified submarine sonar data (1958-2000). The peak winter thickness of 3.64 m in 1980 decreased to 1.89 m by the winter of 2008, a net decrease of 1.75 m or 48% in thickness, an average thinning of 17.1% per decade. ICESat data show that the average thickness at the end of the melt season decreased by 1.6 m or some 53% of the thickness in over 40 years (Kwok and Rothrock 2009).

IceBridge: The Operation IceBridge mission, initiated in 2009, collects airborne remote sensing ice thickness measurements to bridge the gap in polar observations between the ICESat mission which ended in 2009 and the upcoming ICESat-2 mission planned for early 2016. IceBridge has collected data over various regions of the Arctic such as Beaufort Sea, Canadian Arctic and Greenland. Sea ice thickness from IceBridge data have been derived by Kurtz et al, 2013 and Kwok et al, 2012. It also has contributed to the validation of CryoSat-2 data by planning coincident underflights after launch of the satellite.

Cryosat 2: CryoSat-2 is a SAR/Interferometric Radar Altimeter (SIRAL) which has extended capabilities to provide sea-ice freeboard and thickness estimates in the Arctic.

Satellite records between 2003-2008 (ICESat) and 2010-2012 (Cryosat-2) show a decline in sea ice volume during both fall and winter season (4291 km^3 and 1479 km^3 respectively).

Pan-Arctic Ice-Ocean Modeling and Assimilation system (PIOMAS) is a numerical model with components for sea ice and ocean and the capacity for assimilating observations. PIOMAS model shows a decline in ice volume of 2644 km^3 and 2091 km^3 during the same autumn and winter time periods considered in satellite records (Laxon et al, 2013).

Arctic Climate Patterns:

Although long-term decline of the overall Arctic sea ice can be attributable to global warming forcing according to the CMIP multi-model-ensemble simulations (e.g. Zhang and Walsh 2006), the time varying declining rates, interannual or decadal variability, and regional redistribution of Arctic sea ice are obviously driven by the atmospheric circulation. The Arctic Oscillation (AO), or the North Atlantic Oscillation (NAO) over the North Atlantic sector, represents the predominant variability of and changes in the northern hemisphere atmospheric circulation, measuring departures of the circulation from its long-term climatology. The AO is defined as the leading EOF/PC mode of long-term observed monthly sea level pressures north of 20N (Thompson and Wallace 1998). The spatial pattern of the AO is characterized by three stationary centers of action (the center with maximum variance of variability), representing the three prominent atmospheric circulation systems including the Iceland low, Azores high, and Aleutian low. The intensity of the polar center is negatively correlated with that of the two lower latitude centers. The AO index depicts temporal variation of this intensity or the amplitude of the AO spatial pattern, and has demonstrated large interannual and decadal fluctuations during the time period of instrumental observations.

The driving role of the AO or NAO in sea ice variability and changes has been detected and documented. Data analysis and ocean-sea ice modeling investigations (e.g., Rigor et al. 2002; Zhang et al. 2003) indicate that the positive polarity and upward trend of the AO result in an overall decrease in Arctic sea ice extent and volume, which well explains the large sea ice reduction observed from the late 1980s to the mid-1990s when the AO transitioned from a negative phase to an amplified positive phase. Meanwhile, the AO also plays a significant role in regional sea ice changes (Zhang et al. 2003). When a positive AO occurs, anomalously anticlockwise sea ice motion emerges. Associated thermodynamic and dynamic effects interplay to cause a major reduction of sea ice in the eastern Arctic Ocean, but an increase in sea ice appears in the western Arctic Ocean. Phase transition of the AO from negative to positive also increases sea ice export through both the Fram Strait and the Canadian Arctic Archipelago, contributing to multi-year sea ice loss. In addition, Rigor et al. (2002)'s analysis reveals an across-season negative correlation between winter AO and summer sea ice, providing predicative information for seasonal forecast. Nevertheless, prediction or projection of AO is still challenging due to strong internal dynamics and lack of understanding of mechanisms.

In spite of the significant role of AO in sea ice variability and changes described above, rapid changes in sea ice or extreme sea ice loss events for a particular time period may not be able to be explained well by the AO. Since the late 1990s, the AO/NAO has gone to neutral and even negative values (e.g. Overland and Wang 2005). However, Arctic sea ice decrease has continued and even tremendously accelerated since the mid-1990s, evidenced by the consecutive breaking of historical records of low sea ice extent, in particular in summer 2007 and 2012 (e.g., Comiso et al. 2008; Zhang et al. 2008). The driving role of the AO in underlying sea ice changes was substantially weakened (e.g., Zhang et al. 2008). Data analysis detected an additional departure of the atmospheric circulation from the AO during this time period, showing a shift from the conventional tri-polar AO spatial pattern to a dipolar pattern with one center of action occurring over the area from the Aleutian islands to the Beaufort Sea and the other over the Eurasian coast (Figure 1; Zhang et al. 2008). This transformed pattern, named the Arctic Rapid change Pattern (ARP), shows a negative polarity from the late 1990s to the end of 2005, providing an accelerating impetus for the observed rapid decrease in Arctic sea ice. The swift phase transition of ARP from negative to positive from 2006 to 2007 played a decisive role in forming the record low sea ice extent in September 2007. A number of other studies also identified a dipolar pattern by using the data within the Arctic region – named the Arctic Dipole (AD; e.g., Overland and Wang 2010), which obviously shows a strong projection on the hemispheric scale ARP pattern. Prediction or projection of occurrence of the ARP, including timing and amplitude, would help to prepare for extreme sea ice loss event. But there has been no research on this topic.

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Figure 4. The AO/NAO has experienced a drastic shift from the tri-polar spatial pattern to the dipolar pattern since the late 1990s.

Numerical Climate models:

Arctic warming is proceeding at a pace 2-3 times faster than the mean global temperature and is resulting in significant changes to Arctic sea-ice, coastal and permafrost systems. Climate models are valuable tools for projecting future change and the Arctic has been a recent focus for both the climate and forecast modeling communities. One of the most significant changes in the Arctic is the loss of Arctic sea-ice, with a record ice minimum extent observed in 2012 and significant loss of ice volume over the past several decades. Climate models project this trend to continue, leading to seasonally ice-free conditions (ice-free in summer) by 2050, with some models predicting this to occur as early as 2040 (and as late as 2060). The loss of sea-ice has several implications. First, the trend towards thinner ice even before these ice-free conditions will result in increased variability in ice extent and decreased ice predictability as the thin ice responds more effectively to local weather and ocean conditions. Second, as the Arctic ice retreats, wind over the exposed ocean results in increased wave action in response to storms with implications for commercial transport, resource extraction, search and rescue, and coastal erosion. Finally, a loss of sea-ice has impacts on global circulation through ice-albedo feedbacks and polar amplification of warming.

Another significant Arctic change is on the land surface and permafrost regions. Model projections currently estimate a continuing warming and degradation of the top 2-3m of permafrost and a continued increase in thaw depth. An ensemble of climate models project a reduction in permafrost area of ~20% in the 2016-2035 time period for a variety of different warming scenarios. These changes in permafrost will have significant impact on Arctic infrastructure and may accelerate warming through methane release and vegetation changes.

Improving future projections of Arctic climate change require improvements across all components of a fully coupled climate model. Although the model are increasingly skillful on mean projections like total ice extent and volume, regional variations, forecasts of specific ice-free regions and coastal impacts require better spatial resolution. Sea-ice and the land surface will be responding more strongly to atmospheric conditions and better representations of Arctic mixed-phase clouds and cloud cover are required. Aerosol transport into the Arctic, interactions with clouds and deposition on the surface of snow/ice would also improve future projections. As sea-ice transitions to a thinner, seasonal-ice regime, better process-level understanding of sea-ice behavior, including ice hydrology, surface melt ponds and other processes will be critical, as emphasized by a recent National Academies report. Climate models currently do not represent surface waves and the addition of this capability will be required for wave impacts on shipping, structures and coastal erosion. The representation of permafrost in climate models, while much improved over the past few years, will still require additional capabilities to answer future questions related to permafrost thawing and related changes to geomorphology and river transport. Finally, climate modelers continue to be hampered by the lack of observations and monitoring of critical processes in the Arctic due to the difficulty in staging and maintaining instruments in this harsh environment.

After the record low sea ice extent in 2007, there has been a growing focus on improving sea ice predictability at seasonal, decadal and longer time-scales. Confidence in these forecasts depends in part on the models ability to accurately simulate hindcast conditions. Thus, evaluating model skill is important given the large role that climate model projections play in framing the debate on how best to address global environmental change. While the Coupled Model Intercomparison Project Phase 5 (CMIP5) models more accurately hindcast sea ice extent than the CMIP3 models [e.g. *Stroeve et al.*, 2012] (see Figure 1), trends from most models remain smaller than observed and the uncertainty as to when an ice-free state may be realized remains similar between both modeling experiments. In addition, the spatial patterns of ice thickness are poorly represented in most climate models (Stroeve et al., 2014). Many models fail to locate the thickest ice off the coast of northern Greenland and the Canadian Archipelago and have too thick of ice across the Arctic Ocean and the East Siberian Shelf. Part of the explanation lies in model deficiencies in capturing the atmospheric circulation pattern in the Arctic. This will lead to uncertainties in the future evolution of the ice cover.

Nevertheless, various stakeholders are interested in using the CMIP5 projections of the ice cover in their decision-making. Probability maps of ice cover (e.g. Figure 2) may be helpful in this regard. Under the RCP8.5 emission scenario major shipping routes being considered in the Arctic have a high probability of being ice-free by 2060.

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Figure 5. Comparison of September sea ice extent from observations (1953 to 2013 in black) and climate models used in the last two IPCC reports. Shown in red is the multi-model ensemble mean (red line) and one standard deviation (red shading) from 35 historical and future emission scenario RCP 4.5 CMIP5 models. Corresponding values from CMIP3 for the "business as usual" emission scenario are shown in blue.

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Figure 6. Probability of sea ice occurrence during September on decadal time-scales from the RCP8.5 emission scenario.

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.

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