

CLIMATE CHANGE IMPACTS ON NORTHERN OFFSHORE PETROLEUM OPERATIONS

SUNDT

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INTRODUCTION

For the purpose of this paper, the Northern Offshore can be considered to be those regions where ice of one form or another has a significant influence on the physical environment, and hence on the operations conducted there. This includes most of the Canadian offshore (except for Nova Scotia and the West Coast). It also includes most of the Alaskan offshore prospective for oil and gas.

Offshore petroleum operations include exploration drilling, production and transportation. As will be described, the presence of ice has a significant influence on these activities. Usually ice makes them more difficult and more costly than in southern regions. Therefore, whether global warming can lead to easier and less costly Northern offshore operations is an intriguing question which this paper will attempt to answer.

The paper will first give an overview of Northern offshore petroleum operations in the context of progress in technology, discoveries made, and future prospects. Recent studies on potential change to the ice regimes will then be briefly summarized before speculating on possible impacts.

The focus for this review will be the Canadian offshore, however the potential impacts which will be outlined will have relevance to other Arctic offshore regions including Alaska, Northern Europe and Asia.

NORTHERN OFFSHORE PETROLEUM OPERATIONS AND TECHNOLOGY

Canada's so-called "Frontier Lands" include the offshore and the Arctic regions. Areas prospective for oil and gas were first leased for exploration in the 1960's. Since that time, as shown in Table 1, over 500 wells have been drilled in the Canadian Frontiers with over 100 discoveries (although not necessarily commercial).

TABLE 1: Wells Drilled in the Canadian Frontiers

Region	Wells Drilled	"Significant" Discoveries
Beaufort Sea/Mackenzie Delta	100+	35
Arctic Islands	170	18+
West Coast	14	0
Nova Scotia	100	25+
Newfoundland	90	20+
Labrador	27	7+
Hudson Bay	5	0
	506	105

In all of the regions shown in Table 1, only the West Coast and Nova Scotia are ice free. So, as can be seen, during the past two decades or so, a large number of exploratory wells have been drilled in the ice-infested areas of Canada's offshore. This successful achievement has been made possible by new technology and operating techniques tailored specifically for dealing with ice. In some operations, the ice has been avoided; in others, structures have been designed to resist the ice; and in some cases, the ice itself has been used to drill from. In order to assess potential impacts of climate change, it is appropriate to look at these various approaches in more detail. This will be done for the Beaufort Sea where much of the activity has taken place, and where future production of hydrocarbons may commence within the next decade and continue through the first half of the next century.

TABLE II: Beaufort Sea Wells by Platform Type

		Artificial Islands (Sand/Gravel)	Caisson Structures	Drillships	Ice Platforms
Number of Wells Drilled		73	20	42	5
Water Depth Range	m	1-18.6	11.5-30	18.6-67.4	3-7.6
	ft	3-60	38-98	61-222	10-25

If we count both the U.S. and Canadian Beaufort Sea as one, then a total of about 140 wells have been drilled to date (Masterson et al, 1991). About half have been drilled from artificial islands, about one third from drillships, and the rest from caisson platforms and grounded ice platforms (see Table II). For exploratory drilling, a stationary platform relative to a point on the sea floor is required from which to drill. The time for drilling and testing of the well is usually in the 60 - 100 day range. In conventional offshore regions of the world, exploratory drilling is conducted either from drilling vessels or from temporary fixed platforms such as jack-ups or grounded barges. In the Beaufort Sea, the presence of an ice cover for at least 9 months of the year, and the variability in the open-water season, as well as the potential for the polar pack to invade the open-water region at any time, makes conventional offshore systems quite unsuitable.

In the Beaufort Sea, the sedimentary basins which are prospective for oil and gas, are an extension of those found onshore. It was natural, therefore, to start the offshore exploration in shallow water and then move into deeper water. The artificial island was chosen as the preferred concept for the shallow water regions. It had the advantage of being well able to resist ice forces as well as being conventional technology. The presence of ice for most of the year ensured that erosion was limited to the short open-water season; so investment in elaborate slope protection schemes was minimized.

The first artificial island used for exploratory drilling in the Beaufort Sea was built by Imperial Oil (Esso Resources Canada) in 1973. It was built during the summer months using a cutter-suction dredge in about 3m water depth. Local sand was the construction material and temporary slope protection during construction was achieved using sand bags (Croasdale and Marcellus, 1978). As already mentioned, since that time about 70 artificial islands have been built and drilled from in water depths out to about 19m (Masterson et al, 1991). Most islands in the Canadian Beaufort have been built during the summer using dredges. All islands off Alaska have used hauled gravel from onshore, using either barges in the summer or trucks over the ice in the winter. Using dredges and marine operations, the short open-water season is hardly sufficient to build an island in the summer. Indeed, islands at the deeper locations have sometimes taken two summers to build. This is because the amount of fill required increases dramatically with water depth, especially for shallow slopes.

It was for this reason that caisson-retained islands were developed and later the monolithic caissons. Four such systems have been developed for the Canadian Beaufort and one for the Alaskan offshore (although one of the Canadian caissons has also been used off Alaska). Some of these caisson designs make use of sand ballast to resist ice forces, others are grounded onto the sea floor using water ballast and have skirts which penetrate the sediments to enhance sliding resistance. When deployed at the deeper locations (out to 30m) these caissons can be subject to the movement of thick multi-year ice against them. They are designed for such events and have in fact demonstrated their capability to resist these massive forces (Jefferies and Wright, 1988).

In the even deeper waters of the Arctic Ocean, the use of drillships has been pioneered by Canadian Marine Drilling who commenced operations in 1976. The drillships are, of course, ice strengthened, and when the ice is managed with icebreakers, drilling can continue into freeze-up. However, it is not usually possible to drill much beyond late November or beyond when the ice is about 0.3m thick.

The summer drillship season is short, hardly long enough to drill and test one well. For most of the year the drillships remain unused in a winter harbour. In fact, most of the wells drilled have taken more than one summer season. This under-utilization is the major factor contributing to high well costs.

To extend the floating drilling season, the Gulf Oil subsidiary Beaudril designed and built a round drill ship, the Kulluk. Kulluk is designed to stay on location with 1.3m of ice moving against it. It is held on location with twelve 9 cm mooring lines. Ice management is provided by two Class 4 icebreakers and two ice-class supply ships. So far, Kulluk has drilled four wells and has a performance record that exceeds expectations (Pilkington et al, 1986).

The concepts described so far have either been designed to avoid the ice (such as the drillships) or withstand the ice, as typified by the fixed platforms and the ice-breaking drill ship. However, for both approaches the ice creates constraints which lead to high costs relative to similar operations in other parts of the world. For example, exploratory wells in the Beaufort Sea have cost as much as \$100 million. Whereas in a conventional offshore area, a well cost greater than about \$20 million would be unusual.

In an effort to lower exploration costs in the Arctic, the use of the ice itself as a construction material has been exploited. This technique was first used in the High Arctic where the combination of landfast ice and deep water enabled a rig to be placed on locally thickened ice (by flooding) and connected by a marine riser to a sea floor wellhead (Baudais et al, 1976). In the Beaufort Sea, grounded spray ice platforms have now been used at four shallow locations for exploratory drilling. Their use has resulted in halving the well costs compared to alternative technologies such as sand/gravel islands (Weaver et al, 1991; Bugno et al, 1990; and Masterson et al, 1991). Spray ice barriers have also been used to protect structures against ice loads (Jahns et al, 1986). It is forecast that spray ice structures might be built to the edge of the landfast ice and be the lowest cost exploratory platform concept in the 0-20 m water

depth. One approach to extend the use of spray ice platforms is to protect them against ablation and melting in the spring. This would extend the drilling period and allow demobilization of the rig after break-up. Research to help accomplish this has been quite successful (Poplin et al, 1991).

CANADIAN BEAUFORT: PRODUCTION PROSPECTS AND CONCEPTS

When exploration first started in Canada's Frontiers, potential recoverable reserves of about 40 Billion Bbls of oil were anticipated by some. Today, after the drilling of over 500 wells, the discovered reserves total only about 3.4 Billion Bbls. The additional potential reserves are now estimated to be about 8 Billion Bbls for a total to about 11-12 Billion Bbls (Dingwall, 1990). These amounts are quite small by international standards but are similar to the amounts in the Western Canada Basin. In the Beaufort Sea about 1.0 Billion Bbls of oil have been discovered, with another 2.5 Billion Bbls as potential. The biggest oilfield discovered to date is Amauligak with about 300-400 Million Bbls. This oil field lies in about 30m of water, 70km offshore. Development of this discovery is on hold because with current technology and oil prices it is not economic. However, it is worth noting that in conventional offshore areas, oil fields of 100 Million Bbls and less are being economically produced. It is the Arctic climate and especially the presence of ice; as well as distance from the marketplace, which lead to unfavourable economics.

Production systems that have been considered for ice-infested waters include fixed platforms, subsea technology and floating vessels. Fixed platforms such as islands, and steel and/or concrete caissons are probably feasible out to about the 50m water depth. Beyond that, some kind of sub-sea technology, as developed for other offshore regions, might be feasible. At present, floating production systems are not considered feasible for year-round production in the severe Beaufort Sea ice conditions. The concept proposed for the Amauligak discovery is very similar to the caisson technology developed for exploration (described earlier). A typical arrangement proposed for Amauligak has a monolithic concrete caisson 110m x 110m square deployed onto an underwater sand berm at -15m. It would be designed to withstand multi-year ice, 10-15m thick; interaction with ice dominates the structure's shape and costs.

Another significant cost item for Amauligak is the pipeline to shore, as well as the pipeline south up the Mackenzie valley. The pipeline to shore will have to be placed into a trench several metres below the sea floor. This is to avoid damage from ice keels which frequently scour the seabed. The possibility of using tanker transportation has been considered, but is handicapped by the need to operate through severe ice for much of the year.

This description of the development of a typical offshore field in the Beaufort Sea clearly indicates that the presence of severe ice conditions significantly influences the technology and the costs. The scene is now set for an assessment of global warming on Northern offshore petroleum operations.

THE ICE REGIME AND THE POSSIBLE EFFECTS OF GLOBAL WARMING

Close to shore in the Southern Beaufort Sea, the ice grows and decays every year. Further offshore, the permanent polar pack circulates in a clockwise direction, but it can be blown south into the nearshore regions, especially in the "open-water" season which can exist through July, August and September. Freeze-up occurs in late September or October and the annual ice grows in thickness to about 2m by the spring. Land-fast ice can extend out to about the 20m water depth by January. Its extent is quite dependent on the presence of grounded ice features out to the 20m water depth, and it seldom extends further offshore. Most of the grounded ice features are first-year pressure ridges which form before the ice becomes land-fast. First-year ridges can typically have keels extending 20m in thickness. Further offshore, they can be thicker. In the polar pack, multi-year ice predominates, and can be typically 4-5m thick. Again however, it is the ridged features which create local thickenings. These are typically in the 10-20m thickness range, but 30m thick ridges have been observed in the Arctic Ocean.

There are no icebergs in the Beaufort Sea, but very rare "ice islands" do exist. These calve from a relic pleistocene ice shelf which still exists along the North Coast of Ellesmere Island. When calved, the thickness of an ice island can be greater than 50m, and ice islands can be as much as 10km in extent.

However, the influx of large ice islands into the Southern Beaufort Sea is so rare that offshore platforms justifiably need not be designed for them. The probability of a collision is extremely low, and ice islands could be detected well ahead of a collision so that people could be evacuated and oil wells sealed off below the ocean floor.

Because the ice limits the fetch, wave heights in the Southern Beaufort Sea are generally much lower than in other seas of the world. Measurements and hindcast studies suggest a 100 year design wave of about 7m.

Given this snapshot of the current offshore environment, the key question is what changes might be expected under various warming scenarios? Environment Canada has recently attempted to answer this question through a study sponsored by the Canadian Climate Centre (CCC) of the Atmospheric Environment Service (AES) (Pilkington et al, 1991 and 1992). The study has examined the effects of global warming on first-year ice thickness, multi-year thickness, ridge consolidation, extreme ice features, open water extent and wave climate. Three warming scenarios were compared. Two were obtained from the results of general circulation models (GSCs); one being the Canadian Atmospheric Environment Service (AES) model; the other being the Goddard Institute for Space Studies (GISS) model. The third scenario assumed that the temperatures which were experienced in 1989 (which was an abnormally warm year) prevailed.

Fourteen points in the Beaufort Sea ranging in latitude from about 70°N to 80°N were examined and a one-dimensional ice growth and decay model was exercised for each scenario. The one dimensional growth model took into account the temperatures, winds and precipitation predicted by the GSC models. The effect of global warming on first year ice growth at latitude 70°N is illustrated in Figure 1. The Canadian AES model predicts a reduction in maximum level ice thickness from about 1.8m to about 1.4m. The GISS model results give a much thinner ice sheet because of the greater snowfall predicted, which in the simple 1-D model acts as insulation. In reality the weight of snow on the ice could

actually depress it sufficient to create snow ice on the surface with not as big a difference between the ice thickness calculated from the AES and GISS outputs. Further north at 80°N latitude, the results show that multi-year ice would become thinner (See Figure 2). Furthermore, the edge of the polar pack would recede from the 72°-75°N range to about the 75°-80°N. In addition, the open water season would be increased from about 60 days on average at 72°N to about 90 days (AES output) and even 150 days (GISS output). Such an increase in season and fetch would also lead to increased wave heights and these are discussed in the study. The study also examines the decay of 40m and 10m thick multi-year ice.

It is acknowledged that the study represents a very preliminary assessment of the types of changes which might occur in 2 x CO₂ scenario. The study is limited to thermodynamic modelling of the ice cover. Such models have proven to be quite reliable for stationary ice but the Arctic Ocean is a very dynamic ice regime. Ice transport and mechanical processes of ice deformation play a significant role in determining the ice regime at a given location in the Arctic Basin. Therefore, the results from this study should only be regarded as an indication of the types of changes which could occur. With this disclaimer, a summary of possible changes in key ice and oceanographic parameters is given in Table III. For the purpose of this comparison, only one of the three warming scenarios (that predicted by the AES/CCC model) is used.

TABLE III: Potential Changes in Beaufort Sea Conditions Due to Global Warming

PARAMETER	BASE CLIMATE	GLOBAL WARMING CASE (CCC OUTPUT)
Mean Air Temp - Feb - July - Dec.	-30°C +6°C -26°C	-22°C +7°C -14°C
First Year Ice Thickness (72°N)	1.8m	1.5m
Multi-Year Ice Level Thickness (80°N)	4.0m	2.2m
Typical Maximum Ridge Consolidation Thickness	16m	10m
Typical Open Water Season - 72°N - 75°N - 80°N	60 Days 0 0	90 Days 60 Days 0
100 Year Significant Wave Height (71°N)	7m	9m
90% Exceedence Annual Wave (71°N)	1.6m	1.9m

POSSIBLE IMPACTS ON OFFSHORE PETROLEUM OPERATIONS

As described earlier in this paper, both exploration and future production operations in the Northern offshore are generally made more difficult and costly because of the presence of ice. So in general, if ice conditions become less severe as predicted, then offshore petroleum operations will become easier and less costly. Admittedly, there are some techniques which are currently in use which make use of the ice. These include the use of ice roads for supply and construction, and spray ice platforms for exploratory drilling. In a warmer climate, these techniques may become less effective and might have to be replaced by marine systems.

Specific examples of easier and less costly operations will now be considered.

As shown in Table II, about 40 wells have been drilled in the Beaufort Sea using drillships. Many of these wells have taken more than 60 days to drill and test, and consequently have taken more than one season. With a nominal increase in open-water at 71°N from 60 days to 90 days it is likely that exploratory drilling costs using drillships would be reduced by at least 30% and possibly 50%. It is recognized that waves might increase in magnitude because of greater fetches. However, the increase in the two-year wave from about 1.6m to 1.9m is unlikely to have significant effect on the operation of vessels which do not have to cease drilling until waves of 3 to 4.5m occur (Masterson et al, 1991).

The Kulluk, which is designed to be able to stay in a drilling mode up to about 1.3m of moving ice, will also have an extended season. In fact, at 70°N where the AES/CCC model predicts a maximum first-year ice thickness of 1.2m, the Kulluk might drill year-round. Such a capability would reduce drilling costs to about 30% of current, assuming 3 wells per year compared to one.

In general the shorter, less severe ice season would push exploration costs lower and more towards the use of floating systems. For the very shallow locations the use of ice platforms might still be possible. Alternatively the longer open-water season might allow the use of conventional jack-ups as used in other parts of the world.

However, the real interest and dilemma in potential climate change effects is not on exploration but on future production activities. As already explained, discovered offshore fields are not currently economic. Lower-cost development and transportation technology is required to enable these reserves to be produced at current price expectations. Trends in climate which lead to less severe ice conditions will certainly help to lower costs. However, in all the scenarios examined, ice will still be present, therefore conventional offshore technology will still not be possible. Offshore production platforms will still have to be designed for the "100 year" ice load. If we assume that currently such an ice load is caused by say a 16m thick multi-year floe, then this study suggests that in a 2 x CO₂ world the

equivalent design thickness would be about 10m. Ice loads are roughly proportional to ice thickness, therefore the design ice load would be reduced to about 60% of the current value. Depending on the structural configuration, this would certainly lead to a cost saving but not of the same percentage. Perhaps a more important impact on costs would be the longer open-water construction season. If this was sufficient to allow offshore construction time to be halved, then a 30-50% saving in construction costs would ensue. This is especially true for offshore pipelines which require a trench to protect against ice scour.

The nominal increase in wave heights and the significant increase in open-water season would certainly need to be recognized in schemes for development. The use of a structure placed on an underwater berm would have to be carefully reviewed because of the increased erosion capacity of storms. Structures placed directly on the sea floor might become more attractive and less costly.

It is recognized that the accompanying increase in water level would have to be accounted for. For offshore platforms this would have a negligible effect on costs. However, the design and construction of shore installation in low-lying areas will need careful consideration. This might lead to more costly arrangements than presently being considered.

Directionally we might expect a reduction in the severity of ice scour of the sea floor, which, if it could be quantified, might lead to lower offshore pipeline costs. However, such quantification is difficult and therefore no credit should be taken for this potential saving without further study.

A significant barrier to economic production of oil and gas in the Beaufort Region is the high cost of transportation. The oil and gas trunk lines to the south are unlikely to be less costly in a warmer world. On the contrary, the cost of these lines may be higher because of increased permafrost instabilities which would have to be recognized in their design. (Although an initial assessment for a gas trunk line indicated that permafrost changes could be accommodated; Nixon et al, 1990). One transportation

option for oil which could become more viable in a warmer world is the use of ice breaking tankers (EIS, 1982). In a less severe ice environment the use of such vessels would be more efficient and less costly. Even a seasonal scenario, of transportation during the open-water and less severe ice period, might be an economic production scheme.

CLOSING REMARKS

This paper has reviewed typical offshore petroleum operations in the Beaufort Sea and discussed how they might be affected in a warmer climate scenario.

In general, offshore petroleum operations in the Beaufort regions would become easier and less costly than at present. Today, activities in the North are at a very low level because it is perceived that economic development of Arctic resources is not possible with current technology and price expectations. Future activities will be very dependent on developing lower cost technology and/or finding larger reserves.

It would appear that potential global warming can only help lower exploration and development costs. However, given the uncertainties surrounding the topic, no proponent would be able to take advantage of these potentially lower costs in projects being planned now. Indeed, projects being planned in the near future would have to assume the worst of both worlds. Fortunately, in the context of the Arctic offshore, the cost of allowing for the negative effects of potential changes in climate appear to be limited to recognizing a slightly increased wave height and open-water duration as well as a slight increase in water depth. These changes should not overly-burden the costs of any planned offshore project.

This paper has not addressed Canadian East Coast petroleum activities. However, it should be pointed out that Environment Canada has also conducted a study to assess potential changes in the ice regime off Canada's East Coast (Arctic Sciences, 1991). There was a concern that global warming could lead to a greater number of icebergs on the Grand Banks as Greenland glaciers surged and created more

icebergs at source. However, the study has not confirmed such a possibility. In fact, the results suggest that sea ice and icebergs should be less severe on the Grand Banks, but there are still many uncertainties associated with such a prediction.

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Figure 1

Possible Effects of Global Warming on the Growth of First-Year Ice at 70°N.

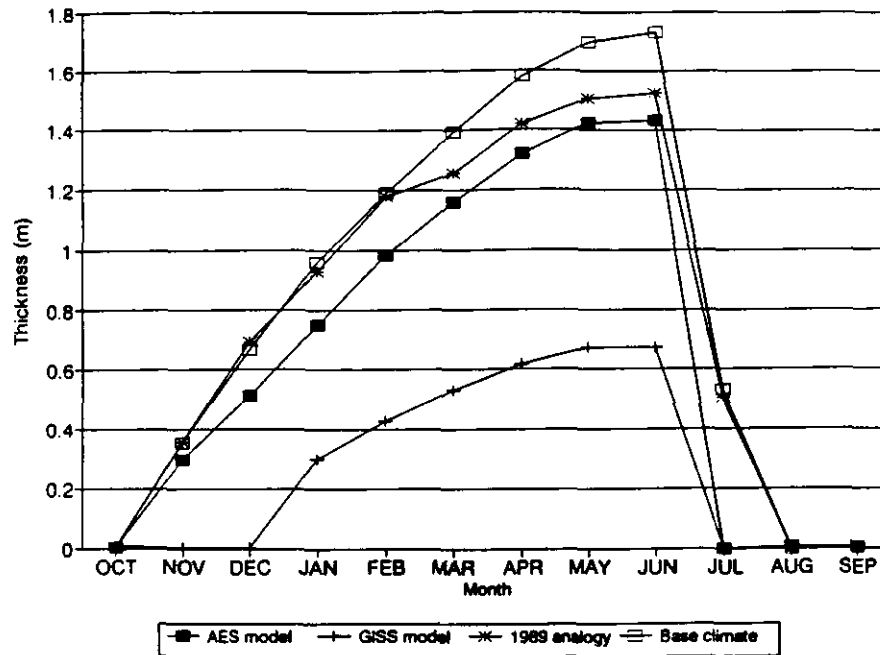


Figure 2

Possible Effects of Global Warming on Multi-Year Ice Thickness (80°N).

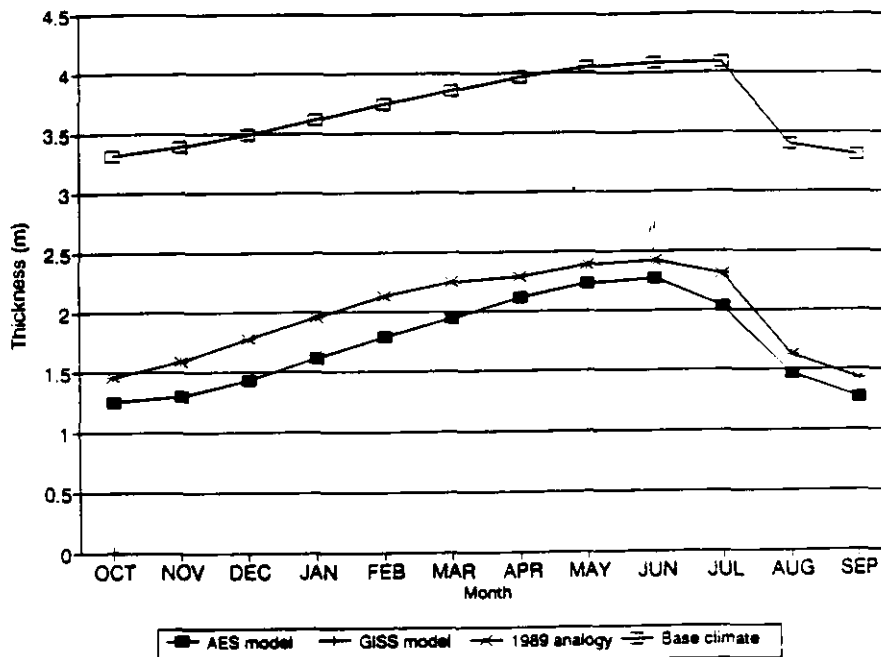


Figure Captions

Fig. 1 Possible Effects of Global Warming on the
Growth of First-Year Ice at 70°N.

Fig. 2 Possible Effects of Global Warming on
Multi-Year Ice Thickness (80°N).