Shipping in the Canadian Arctic

Other Possible Climate Change Scenarios

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Abstract— In this paper, we will review the results of several studies of significance to the question of future shipping conditions the Canada's Northwest Passage. As will be shown, these studies raise significant questions around the estimation of the impacts of predicted lighter ice seasons from Global Climate Models and introduce further plausible scenarios that should be considered as well when planning adaptation strategies for marine transportation in the Canadian Arctic.

Keywords-Sea-ice; Shipping; Northwest Passage; Climate Change

I. Introduction

The five Global Climate Models (GCM's) adjusted to current ice conditions compared in the Arctic Climate Impact Assessment (ACIA) project a slight decline in the winter maximum ice extent (March) over the next hundred years. The projected results for the adjusted minimum ice extent in September shows five quite different scenarios with the Canadian model showing the disappearance of summer ice by 2070 and the National Center for Atmospheric Research (NCAR) model ice extent remaining constant [1].

The projected decline of sea ice extent and concentrations by GCM's has raised many questions about the potential of the Northwest Passage (NWP) becoming a viable shipping route. An increase of shipping traffic through the NWP combined with the ability to finally access and exploit large natural-gas reserves within the Canadian Arctic [2] has the potential to cause significant impacts on the Arctic environment and its people.

The NWP is a potential shipping route between Europe and Asia that is 9000 km shorter than the Panama Canal route and 17,000 km shorter than the Cape Horn route [3]. The NWP lies within the centre of the Canadian Arctic Archipelago and is in

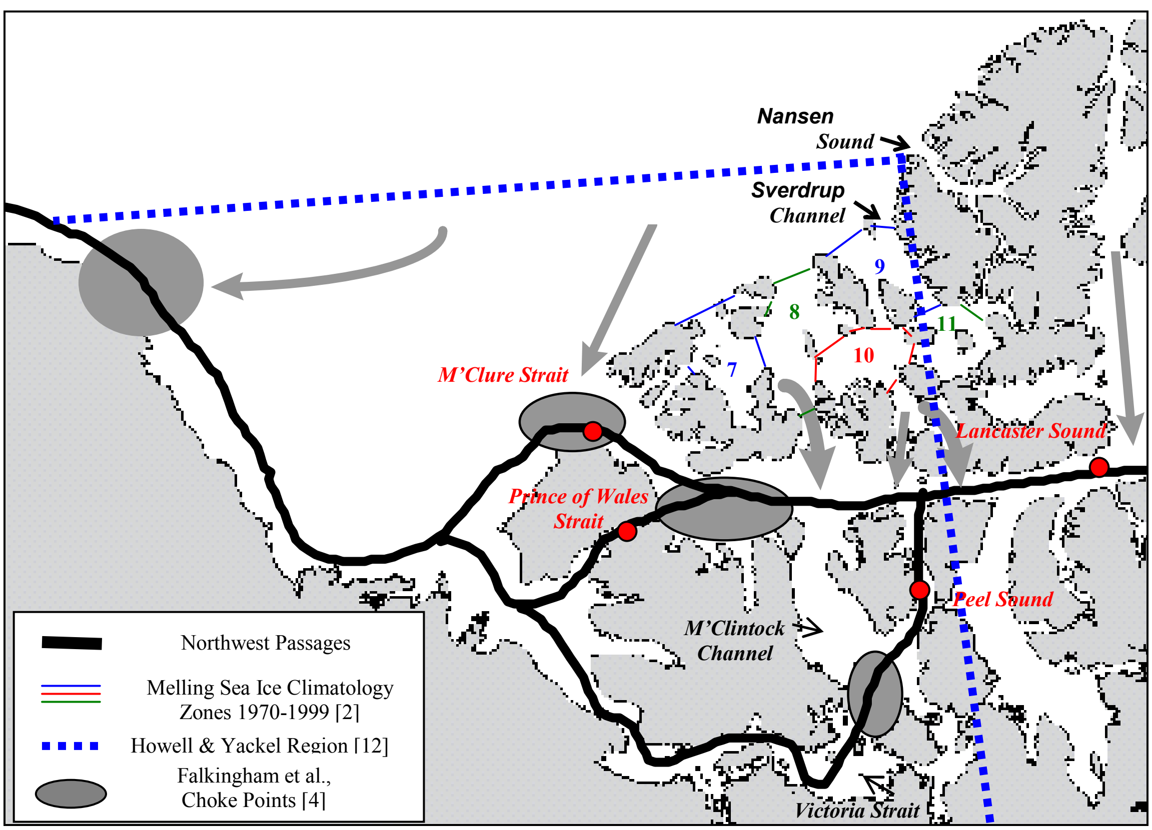

Figure 1. Northwest Passage and Regions in the Canadian Arctic

fact a collection of possible routes through the Canadian Arctic (Figure 1). In the west there are three feasible paths: M'Clure Strait, Prince of Wales Strait and Peel Sound. In the East, the passage is traditionally limited to Lancaster Sound. The Beaufort Sea region generally becomes ice free in August-September, while M'Clure Strait can remain blocked with Old Ice (OI) in most years. In all areas marine navigation demands the utmost caution as old ice presents a particularly dangerous hazard for even ice-strengthened ships. Icebreaker assistance is often essential [3].

The domain and resolution of GCM's provide sea ice predictions for the Arctic Ocean, but are generally inadequate to represent the Canadian Arctic Archipelago and the narrow passageways between islands, which encompass the NWP. The Canadian Ice Service (CIS) is leading a 3 year project, funded by the Canadian Climate Change Action Fund (CCAF) to provide decision makers with a range of possible sea-ice scenarios for the NWP and to assess any related impacts to sea ice transportation. This will be accomplished by drawing upon a new regional climate model for the Canadian Arctic Archipelago, work by several Canadian sea-ice scientists, our long experience in providing ice information, local traditional knowledge and case studies involving two Canadian Arctic communities (communities still to be determined). Recent studies using the CIS digital ice chart archive (1968 – present) are summarized and presented here, introducing additional sea-ice scenarios for future shipping in Canada's Northwest Passage.

II. QUEEN ELIZABETH ISLANDS: ICE CLIMATE (1970-1999)

The region to the north of the NWP, the Queen Elizabeth Islands (QEI), acts as a barrier between the Arctic Ocean and the NWP. Sea ice within the Arctic Ocean circulates in an anti-cyclonic gyre maintaining high ice pressure and shear along the northwest perimeter of the QEI and thereby creating the thickest and most heavily ridged sea ice in the world [5]. Old ice (OI) from the Arctic Ocean drifts into the QEI from the west, blocking the narrow passages between islands. Ice concentrations in the QEI are extremely high resulting in limited and incomplete navigation and scientific study [2].

Melling provides a thorough overview of the QEI ice climate (1970-1999) based on the CIS digital ice chart archive and over 123,703 ice thickness measurements from the 1970's. This analysis divided the central QEI into 5 zones with Zones 7, 8 and 9 bordering the Arctic Ocean and 10 and 11 boarding the exits from the central QEI to the NWP (Figure 1) to determine typical change in sea ice conditions during the annual freeze-melt cycle. Melling finds:

- Zones 7, 8 and 9 show losses of OI and FYI in the range of 5-12% and 19-40% respectively. It is expected this difference is predominantly due to in-situ melting of FYI, which is easier to melt than OI. The entrance to Prince Gustaf Adolf Sea is much wider than the other narrow channels along the northwest coastline allowing a higher rate of import from the Arctic Ocean into Zone 8 [6].
- Zones 10 & 11 show significant annual loses of sea ice as the seasonal ice arches and bridges formed between islands during freeze up collapse in the summer season to allow import of ice from Zones 7, 8, and 9 and then export into the NWP. This seasonal export of hazardous old ice into the northern shipping routes is well known to mariners [7]. It feeds the early-autumn outflow of old ice from Lancaster Sound.

The conventional wisdom based on GCM predictions is that with climate change the navigation season will lengthen with lighter ice conditions due to earlier break up and later freeze up. Both Melling and Falkingham feel that warmer temperatures, whether atmospheric or oceanic in origin are melting greater amounts of FYI in the QEI. FYI controls the supply of the OI from the Arctic Ocean to the NWP and a reduction will allow more OI from the Arctic Ocean to enter the Archipelago in greater quantities. Thus, it may be more likely that there will be only a minor lengthening of the season as OL drifts into the QEI to fill in the open water gaps.

III. EVIDENCE OF INCREASED AMOUNTS OF OLD ICE IN THE CANADIAN ARCTIC

A paper in review by Crocker et al., studied the Canadian Ice Service (CIS) digital ice chart archive for 1968-2000 based on the regions in Figure 2, [8]. The Canadian Arctic Archipelago (CAA) regions were defined by east-west and north-south pairs, since it was unclear prior to analyzing which was the best method. Statistically significant trends are listed in Table I.

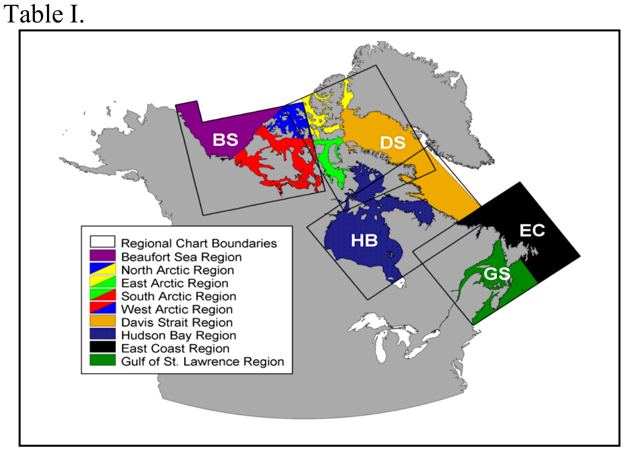

Figure 2. Ice chart boundaries (thick black lines) and 9 sub-regions [8]

TABLE I. SEA ICE TRENDS IN THE CANADIAN ICE SERIVCE ARCHIVE (1968-2000) [8]

Regions	All Ice	OI	FYI
Beaufort Sea			
Western Arctic			↓
Eastern Arctic	↓		↓
Northern Arctic			↓
Southern Arctic			↓
Davis Strait			↓
Hudson Bay	↓		

The trend towards decreasing FYI is already apparent in all four regions of the CAA. Evident in this 32-year record is the large variability in sea ice conditions, which can almost double in cold years and then halve in warm years [3]. Shippers in the NWP will continue to be faced with a wide range of possible ice conditions and it is important to remember that this significant variability will remain [3].

Jeffers et al., [9] studied the most recent fracturing of two ice barriers in Nansen Sound and Sverdrup Channel along the NW coastline of the QEI (Figure 1). In 1998, one of the warmest years on record in the Canadian Arctic, both barriers broke. A collapse of both barriers occurred only once before (in 1962) during the period of record (1960-2003) [9,10]. The removal of old ice barriers in 1998 was associated with above-normal temperature and persistent winds from the south. The final break-up and northward motion of ice occurred with gale force winds during the passage of several strong low pressure systems [10].

Alt, Wilson and Agnew [9,10,11] have been tracking ice in these regions since the barriers broke in 1998. They are studying such events for clues to future ice conditions under a global warming scenario. Specifically, they determined the extent to which the collapse of these barriers allows more than usual amounts of very thick, OI from the Arctic Ocean to pass into the Arctic islands. Utilizing CIS digital ice charts from 1997 to 2003, Table II describes the gains and losses of OI from the Sverdrup/Peary Channel region (almost equivalent to Zone 9). In 1998 there was a loss of 60% of OI, 36% occurring in the summer (a combination of melt and export to the south) and another 30% occurring in the Fall predominantly due to export of inter-island ice to the Arctic Ocean. In 1999 we see a large import of OI (33%) and 18% of the FYI surviving the season to become OI combined with melt and export to give a net increase of 32% OI. In 2000 import in the summer was almost balanced by export to the south in the fall, suggesting this would be the first year that OI from the Arctic Ocean would reach the NWP. The lag effect of the warm summer of 1998 resulted in an increased import of OI in the following years. By 2003 we see the region recovering to somewhat normal conditions.

Howell & Yackel reviewed the three western NWP shipping routes (1969-2002) by assimilating the CIS digital ice charts into a navigation Ice Numeral called AIRSS, used by mariners in Canada to calculate whether a route is safe or not depending on vessel type [12]. The ice re-enforced vessel class three (CAC3) was selected which permits some navigation through lower concentrations of OI only when it is unavoidable. Their region includes the QEI as well as the Beaufort Sea (Figure 1).

Howell & Yackel found M'Clure Strait (MS) to be the most difficult route over the time series, and Peel Sound (PS) the least difficult, depending on the amount of OI present. OI often plugged the entrance to M'Clure Strait (MS) and Prince of Wales Strait (POWS) in the first 10 years of the time series (1969-1979). However, in the last 10 years of the time series (1991-2002) the route through MS shows less OI until it veers southward along Banks Island (Figure 3).

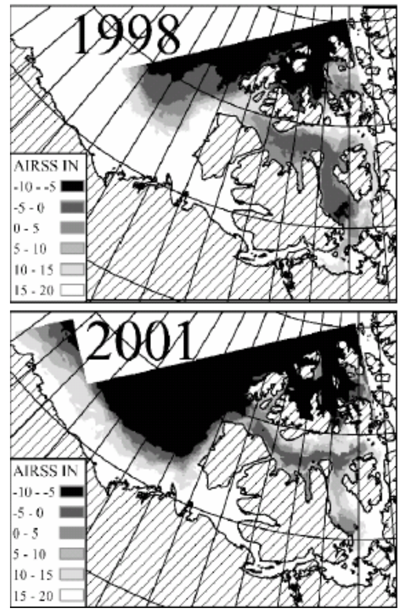

Figure 3. CAC3 ship class average AIRSS IN's for the Western Arctic summer shipping season. 1998 represents a light ice year and 2001 represents a recent heavy ice year. From Howell & Yackel [12]

POWS has shown a decrease in OI over the time series and although a longer route, may provide a safer alternative to MS if the Beaufort Sea pack ice does not extend too far south. The third possible route, PS, is the longest and encounters the least difficult ice, but this region has also seen an increase of OI in Victoria Strait from 1991 – 2002 [12].

It is expected that the increase in OI along Banks Island is likely a result of the decrease in FY fast ice around Banks Island allowing the Beaufort Sea Pack ice to extend further south (Figure 3). The reasons for this may be as Howell and Yackel found, the increase in OI was not detectable in the study region until late 2000, while the full impact was felt by 2001. This is in agreement with Melling who also suggests a delay of 2-3 years before old ice from the Arctic Ocean reaches the

TABLE I. PERCENTAGE OF OLD ICE IN SVERDRUP AND PEARY CHANNELS (1997-2003)

	Spring	Summer		Birthday	Fall			Spring - Fall
	June 25	Sept 30		Oct 1	Nov 29			
Year	Total Old Ice	Melt & Export	Import	FYI = OI	Melt & Export	Import	Total Old Ice	(-) Melt & Export (+) Import/Freezing
1997	92	-12	10	0	-7	2	82	-7
1998	85	-36	0	0	-30	6	22	-60
1999	24	-18	33	18	-2	1	56	32
2000	55	-4	19	19	-16		72	18
2001	73	-2	0	13	-1	2	83	12
2002	78	0	3	8	-14	4	78	1
2003	80	0	8	0	-26		61	-18
Mean	69	-10	10	8	-14	3	-3	65
Mean (1969-2003)	79							76

NWP after an extreme year such as 1998 [2]. This recent southern shift in the pack ice may impede access to the western entrance of all three NWP routes [12].

An increased incidence of warm summers anticipated with climate warming may cause a reduction in FY fast ice permitting old ice to drift into the NWP, thereby increasing the rate of, supply to and thickness of ice within the NWP. OI is extremely strong and dangerous to all ships, even icebreakers, and the increase of this ice in the NWP will result in increased hazards to the marine environment and its users [13].

IV. INCREASE IN CHOKE POINTS ALONG NORTHWEST PASSAGE ROUTES

Winds and ocean currents can drive sea ice against coastlines and into narrow channels, creating high-pressure zones capable of crushing ships and creating barriers to navigational pathways. Some of these "choke points" are impassable, and ice breaker assistance is usually required. Even in a generally ice free Arctic, lighter ice conditions would make the regions even more susceptible to winds and ocean currents creating locally hazardous congested areas [3].

Possible incursions of old ice from the Arctic Ocean will mean that choke points will continue and become more hazardous with the increased presence of thick OI [13]. Falkingham et al., shows where expected choke points would occur (Figure 1), all appearing in the three western routes of the NWP.

Howell & Yackel found more OI accumulating in Victoria Strait along the PS route in the warm summer of 1998 than in the heavy ice summer of 2001 (Figure 2), which is in agreement with Falkingham's choke points (Figure 1). Old ice may have been imported into this region from the break-up and export of the OI from the QEI. Agnew et al., suggests that the southern Archipelago, particularly M'Clintock Channel will act as a large drain trap for old ice moving out of or through the QEI [11].

Increased drifting OI creating choke points may be a fact in future navigation in the NWP, or it could be the kind of navigation to expect in the interim as the ice free summers predicted by GCM's are reached.

V. CONCLUSION

The GCM's predicting an ice-free Arctic by the middle of this century may lead many into a false sense of optimism regarding the ease of future shipping in the Canadian Arctic. Sea ice conditions are highly variable and there will still be summers of occasional heavy ice conditions. Studies using the CIS digital ice chart archive are indicating a reduction in FYI in the QEI allowing more OI to reach the NWP and a southern shift of the Beaufort Sea pack ice. Future navigation in the NWP may see a blockage of the western NWP routes by the southern shift in pack ice and an increase in drifting OI creating choke points in narrow channels and significant navigation hazards. It is important to remember that with our present, imperfect ability to predict future impacts on Arctic sea ice, there are a number of plausible climate change scenarios [13]. The Canadian Ice Service led CCAF project is attempting to synthesis all sea-ice related expertise, including model results, in order to better understand the impacts of a warmer climate on shipping in Canada's NWP.

ACKNOWLEDGMENTS

Many thanks to Bea Alt and Allain Cardinal for their critical review and production of the CIS statistics and ongoing curiosity and enthusiasm. Thank you to Steve Howell for reviewing this paper and for helpful insight and advice.

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