

Winter shipping in the Canadian Arctic: towards year-round traffic?

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Abstract: with the rapidly melting sea ice in the Arctic, and developing shipping traffic, emerged the idea, popular with the media, that sea ice would soon be completely dominated by first-year ice, and would thus be comparable to ice present in the Gulf of St. Lawrence: this would allow for the setting up of shipping year-round along Arctic passages. In fact, contrary to this idea, even with the vanishing of multi-year ice, ice conditions will remain very different in the Arctic from ice prevailing in the Gulf. Besides, naval technology certainly helps overcoming challenges of ice navigation, but they do not mean it is economically or technically much easier. Year-round shipping in the Arctic remains a difficult challenge to overcome.

Keywords: Arctic, shipping, sea ice, Northwest Passage, ice class, ice dynamics.

Climate change and the melting of Arctic sea ice are now well documented; scenarios of developing Arctic shipping have emerged anew, rekindling the goal of European projects of the 16th-19th centuries to discover a shorter route to Asia. The more recent *Manhattan* project sought to develop a commercially viable tanker route across the Northwest Passage, and was, like earlier attempts largely ill-fated. As recently as the early 1980s, projects of year-round shipping in the Canadian Arctic were contemplated (Dey 1981), echoing the Soviet achievement between Murmansk and Dudinka. Only in the Soviet Union, as early as the 1930's by dint of huge investments in Arctic ports and heavy icebreakers in the context of a planned economy, did Arctic shipping develop before the effects of climate change. Now, every summer when the official statistics about the decline of the sea ice are published, the media trumpet the oncoming age of Arctic shipping, an idea resting, often without any deeper analysis (Hassol, 2004; Lasserre and Pelletier 2011), on the fact that Arctic routes are much shorter than through Suez or Panama between northern Europe and northern Asia, and therefore they would automatically attract shipping firms.

The melting of sea ice did not only rejuvenate ancient ambitions about transportation in and across the Arctic; it also immediately proved to be a political issue that triggered assessment reports, notably from the Arctic Council (Hassol, 2004; Arctic Council 2009). Growth of shipping in the region underlines the question of what the

status of the Northwest and Northeast Passages will be (Byers 2009; Lasserre 2010c): international straits, as claimed by the United States or the European Union? Internal, and thus subject to their sovereignty, as claimed by Canada and Russia? Neutral, if ships navigate across the Arctic Ocean? The question of the development of Arctic shipping remains controversial as experts' analyses do not converge (Howell and Yackel 2004; Gedeon 2007; Loughnane 2009; Lasserre and Pelletier 2011; Lasserre 2014). The concept of Arctic shipping is wide in scope in the literature, especially in the media: it often encompasses commercial shipping (bulk, liquid and solid; containers; heavy lift; vehicles), cruise shipping, fishing and mineral exploration. In this paper, only commercial transportation shipping is considered: cruise shipping does not consider developing service in the winter for commercial and technical reasons (Lasserre and Têtu 2013); and commercial fishing vessels are non-existent during winter in the Canadian Arctic.

The acceleration of sea-ice melt and the disappearance of multi-year ice, now well-documented (Howell et al 2009; Lasserre 2010a), gave birth to the idea, regularly repeated in the media (for ex. *Free Republic* 2007; *The Guardian* 2008; *USA Today* 2013, *Times Union* 2014) and even by Canada's Prime minister¹ (Harper 2006), that sea traffic would soon develop year-round in the Canadian Arctic. This is already the case in the Russian Arctic, where traffic between Murmansk and Dudinka remains active, with the help of powerful icebreakers (nuclear and diesel), all through the winter since 1978 (Mulherin 1996; Brigham and Pedersen 2009). The idea that the gradual melting of Arctic sea ice would soon lead to the development of significant year-round transit shipping in the Canadian Arctic is not merely a recurring media discourse: several academics adopted the view that increasingly thinner ice would no longer be a major obstacle to commercial shipping in the near future. Several articles considered year-round Arctic shipping a credible option in profitability simulations (Kitagawa 2001; Juurmaa 2006; Somanathan 2007 and 2009; Mejlaender-Larsen 2009; Wergeland 2013). According to Louis Fortier, ArcticNet's Scientific Director, climate change effects would make Arctic ice conditions very similar to ice found in the Gulf of St. Lawrence, where commercial shipping is conducted all year round (Fortier 2008). In these conditions, it would reportedly be a matter of time before year-round commercial shipping, especially transit shipping, takes off in the Canadian Arctic (Charron 2005; Borgerson 2008; King 2009; Byers 2009b, 2014; Gunnarson 2014). These views seemed all the more credible as Russia's Arctic Institute announced Russia could begin offering year-round transit along the Northern Sea Route (NSR) as of 2013 (RIA Novosti 2012), a proposal that has not materialized yet, although development projects of natural gas in the Yamal peninsula seem to rest on the idea of year-round destination shipping (MOL 2014).

¹ « ...the Northwest Passage is becoming more accessible every year: Some scientists even predict it will be open to year-round shipping within a decade. »

This idea of an imminent increase of winter commercial traffic in the Canadian Arctic rests on the notion that navigation conditions are indeed now very similar to those observed in the Gulf, and that ice conditions are the determining factor of Arctic shipping. To what extent is this accurate? And what challenges does winter navigation in the Canadian Arctic pose to shipping? This paper will critically explore the question of whether winter ice conditions are now similar in the Gulf of St. Lawrence and to what extent they could allow for the development of commercial shipping in winter. First, a comparison is drawn between Arctic winter ice and Gulf ice; the paper then analyses navigation conditions and assess to what extent commercial shipping could be considered, with an exploratory approach based on the literature but also on empirical accounts from employees from the Canadian Coast Guard and from shipping companies (NEAS, Fednav) already active in the Canadian Arctic.

Does Arctic ice now resemble Gulf ice? Evolution of ice physical parameters.

Sea-ice cover is contracting from values observed in the past decades. The sea ice extent trend through February 2014 is -3% per decade relative to the 1981 to 2010 average, a rate of decline of -46 100 square kilometers per year. However, unlike the summer, where ice loss has accelerated over the past decade, trends for winter months have been fairly consistent (NSIDC 2014); besides, the average decline rate remains much more moderate for winter sea-ice (-3% per decade) than for summer sea-ice (-18% with the 2012 value, -6,4% with the 2013 value) (NSIDC 2013).

Ice coverage is diminishing more quickly in the Russian Arctic than in the Canadian Arctic as evidenced by chronological series published by the National Snow and Ice Data Center (NSIDC). Even at its February-March maximum extent, the ice now barely forms in the Barents Sea, leaving the approaches of the Northern Sea Route up to Novaya Zemlya Islands and the Kara Gates virtually ice-free. Ocean currents flush what remains of multi-year ice away from the Siberian coast, where sea ice is now composed of first-year ice (Maslanik et al 2011; NSIDC 2013), although first-year ice could prove very thick (between 120 and 200 cm) in the Kara, East Siberian and Laptev Seas at the end of the 1990s (Brigham et al 1999). However, recent observations point to cyclical variations in Barents Sea winter sea ice extent (Miles *et al* 2014). In the Bering Sea, winter sea ice shows no recent trend towards decline, apart from an exceptionally light ice cover this past winter 2014 (NSIDC 2014).

The evolution of the sea-ice melt is not similar in the Canadian Arctic. There, patterns of sea ice show that, despite a significant retreat of global Arctic sea ice surface in the summer, ice remains more extensive in the Canadian Arctic than off the Siberian coast and with significant infiltration of multi-year ice within the archipelago (Howell et

al 2009; Sou and Flato 2009; Lasserre 2010a; Desjardins 2012). However, both the Canadian and the Russian Arctic show a trend towards an accelerated melt of the ice cover. The increased melt led to significant changes in the Canadian Arctic waters, such as the opening of M'Clure Strait for the first time in 2007 and the subsequent repetition of straits opening for a few weeks in the summer time. Ice thickness and age are decreasing, implying first-year ice may soon largely dominate even in the Canadian Archipelago (Fowler et al 2008; Comiso et al 2008; Lasserre 2010a; Rampal *et al* 2011; Maslanik et al 2011), making it reportedly more similar to Gulf ice. The argument goes on to say, since Arctic ice is made from salt water, its structure is less solid than ice from the St. Lawrence river, made from freshwater: breaking ice for an ice-strengthened ship will thus be easier in the Arctic, at the very least no more difficult than in the St. Lawrence where traffic is active all year long (Fortier 2012). Nonetheless, the thickness of Arctic ice, as well as the deformation and motion patterns that are prevalent in many waterways, add to the challenge for navigation.

Empirical evidence does suggest Arctic ice does indeed consist more and more of first-year ice. However, there are still major differences between Gulf ice and ice found in Baffin Bay and in the Canadian archipelago (Table 1). Indeed, first-year ice in the Canadian Arctic can grow over 2 metres in some areas. This is due to the fact that the region still has a freezing period that is longer than in the St. Lawrence, with temperatures far lower.

Insert Table 1 here.

It appears from this comparison of the present dynamics of winter ice in the Arctic and in the Gulf of St. Lawrence, that despite climate change, ice conditions remain very different between the two areas. True, ice may be thinner and less strong in the Arctic than it was before, but it remains much thicker than in the Gulf. Besides, climate change may precisely introduce conditions adverse to marine shipping.

First, the melting of glaciers causes icebergs and growlers (pieces of ice floating less than 1 m above the sea surface, usually the result of the breaking apart of icebergs) to be more numerous. Growlers are particularly hazardous, as they can be difficult to detect due to their small size, whether they are freely floating or trapped in sea ice (also see Table 1) (Arctic Council 2009; Julien 2009; Lasserre 2010a; Harsem et al 2011).

Second, there is a noticeable evolution in pressure ridges frequency. Pressure ridges are accumulation of ice forced up by pressure of moving sea ice, often up to 10 to 12 meters thick, on average between 5 and 30 m (Leppäranta 2011; Strub-Klein and Sodom 2012). The record floating ridge size is from the Beaufort Sea, with a sail height (above the surface) of 12 m and a keel depth of 45 m (Wright et al 1978; Weeks 2010;

Leppäranta 2011). Arctic ridges are statistically thicker than subarctic ridges, although ridges in the Sakhalin area can be very tall (Strub-Klein and Sudom 2012). The thinning of Arctic ice led to a substantial reduction of the dimensions of pressure ridges, since the ice layers they were formed from is increasingly thinner (Wilkinson et al 2006; Wadhams 2012). However, other researchers also point out that pressure ridges are likely to occur more often in the Arctic, especially in the Beaufort Sea, Bering Strait, north of Novaya Zemlya and over the area of the Transpolar Drift, because of the thinning of sea ice and the consequent increased ice mobility (Rampal et al 2009; Stern and Lindsay 2009; Spreen et al 2010; Spreen, Kwok and Menemenlis 2011; Kwok, Spreen and Pang 2013) and reduced strength in ice (Rampal et al 2009; Harsem et al 2011; Strub-Klein and Sudom 2012). Ice deformation, despite uncertainties in the measure, seems to have increased by about 51% per decade since 1979 (Rampal et al 2009), a fact already taken into account by the oil and gas industry when analysing the profitability of energy exploration in the Arctic (Harsem 2011).

This increased mobility of sea ice, which could be one of the consequences of climate change, as well as the higher frequency of pressure ridges, will present navigation with renewed challenges, as pressure ridges are of great concern to mariners in the area (Timco and Gorman 2007; Kubat and Sudom 2008). This is due to the fact that ridges resulting from ice deformation represent very strong barriers and are barely passable, even with very strong icebreakers (Julien 2009; Desjardins 2012). As an example, the a DAS-equipped ship (double acting ship, seen Table 2) can churn its way across ridges 15 m thick, but this is a lengthy process (Lasserre 2010b) that can lead to significantly high costs for the operator.. Transit or destinational traffic is therefore still confronted with difficult ice conditions.

Arctic winter ice thus provides for very demanding and difficult shipping conditions, even for powerful ice strengthened cargo ships. More specifically, vessels performing destinational shipping must often transit through a shear zone to reach a coastal port. The shear zone is where the mobile sea ice pack grinds against the land fast ice, resulting in pressure ridges that can consolidate into a highly compacted ice formation. For example, in 2008, the MV *Arctic* endured very difficult compression ridges in the shear zone close to Deception Bay (servicing Raglan's nickel mine). After a long and demanding passage from Quebec via the Hudson Strait, fuel reserves were insufficient for safe planning for the southbound voyage. Another Fednav vessel, the MV *Umiak-1* provided fuel resupply for the safe completion of the MV *Arctic*'s voyage. In the winter of 2012, the *Umiak-1* was heavily delayed as a result of an extraordinary complex shear zone close to Voisey's Bay (Desjardins 2012; Keane 2012, 2013).

Navigation conditions remain difficult in the Arctic

The St. Lawrence has welcomed ships year-round inland up to Montreal since 1964; in Montreal the Seaway that links the river to the Great Lakes closes down in late December until March. Shipping in the Gulf and St. Lawrence is mainly made up of minerals (Sept-Îles, Baie Comeau, Port-Alfred, Port-Cartier), cereals (Montreal, Quebec, Trois-Rivières, Port-Cartier), forest products (Baie Comeau, Saguenay), oil products (Quebec, Montreal) and containerized goods (Montreal) and through traffic along the Seaway up to the Great Lakes (see Fig. 1). The average dates of the first and last occurrence of ice in the St. Lawrence have not changed much over time since the beginning of the 20th century. What did change in recent years is the amount of ice (both in terms of extent and thickness) in the Gulf and the river (Dufresne 2014; Mercier 2014). However, that has not led to a significant increase in winter traffic. For most transported goods (containerized goods; oil products; agricultural products, minerals, forest products), the volume is roughly evenly spread throughout the year and there is no sign of any correlation in winter traffic in recent years with the trend in reduced ice volume, a fact confirmed by major port authorities (Gosselin 2014; Matta 2014; Ouellet 2014) as well as professional organizations (Boissonneault 2014; Laliberté 2014; Mercier 2014) or the Canadian Coast Guard (Dufresne 2014). For a few products like coal and iron pellets, port operations are more difficult in winter and lead to a decreased level of activity, but this is not because of navigation constraints due to the presence of ice. The same observation can be made regarding traffic on the St. Lawrence Seaway, between Montreal and the Great Lakes, in December before the annual closing down late that month: there is no correlation between the extent of ice (in formation in December) and traffic (Elliott 2014). It seems, for shipping along the Seaway before winter closure, or in the Gulf and St. Lawrence (navigation year round) that the relevant factor is not ice, but commercial operations (Gosselin 2014; Matta 2014; Ouellet 2014; Dufresne 2014). Winter traffic exists in the St. Lawrence not because of less extensive ice cover but because there is a strong economic rationale, with large cities, industries and economic centers upstream, as well as a vast network of navigation aids and maritime infrastructure. These economic factors are the main drivers, and they do not exist in the Canadian Arctic.

The extreme cold remains a major difficulty for winter Arctic shipping. Despite climate change, very low temperatures will recur and will severely challenge materials, equipment and crew. Low temperatures also force shipping companies to invest in winterized ships for very cold temperatures.

To reflect safety concerns with regards to this issue, several major classification societies (DNV, Lloyds, American bureau of Shipping) have agreed, in the frame of the IMO *Guidelines for Ships Operating in Arctic Ice-covered Waters*, to create the winterized Arctic notation, alongside the ice-class classification that reflects the ability of the hull to navigate in ice. This norm is among the several classes of Winterization norms

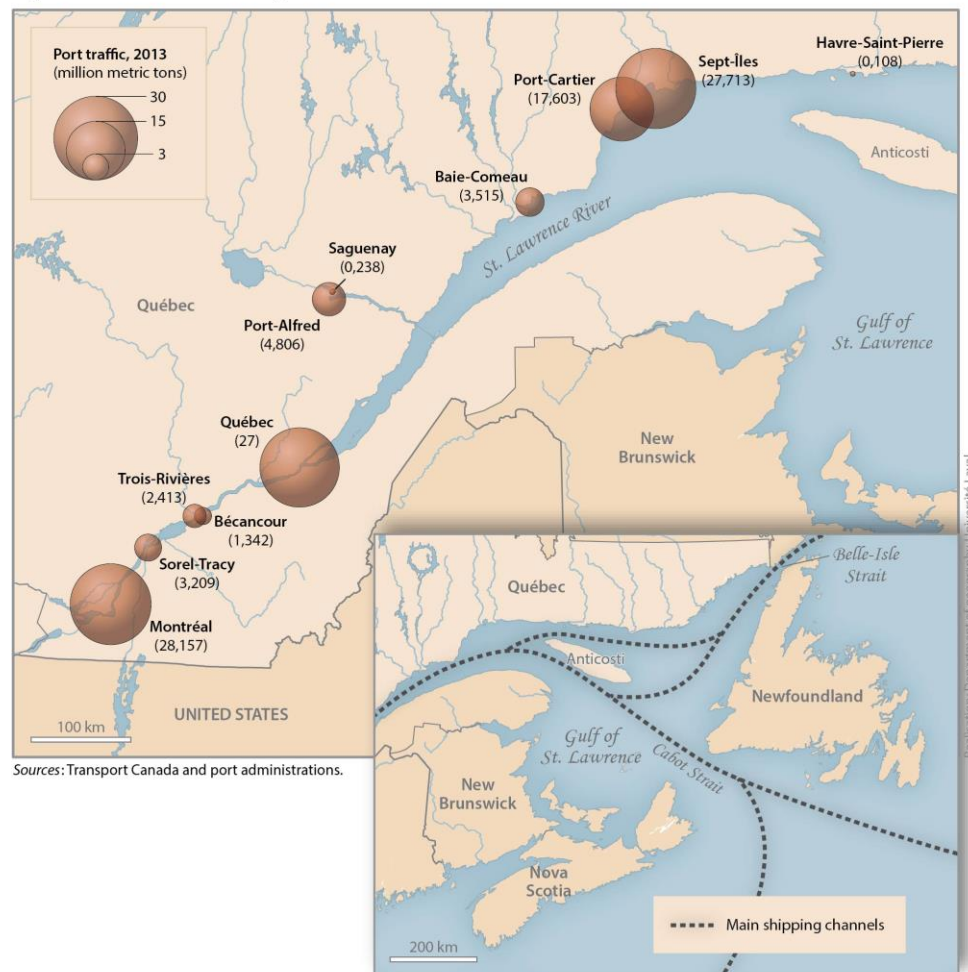
$H(T_x)$ (hull) and $A(T_x)$, $B(T_x)$, $C(T_x)$ (equipment) (T_x being the average air temperature to withstand), see for instance Lloyds' *Ice and Cold Operations Guidelines* (Bridges 2006), and also Sharp 2006; Magelssen 2007; Koren 2007; Hasholt 2011.

Paradoxically, icing due to freezing spray, a serious challenge as it can affect stability of the ship and hinder normal functioning of several devices, used to be more of a problem in winter in the Gulf than in Arctic waters, as sea ice is discontinuous in the Gulf and thus spray was frequent (Julien 2009). However, icing is increasingly possible in the Arctic in localized areas of open water and must be avoided whenever possible. Its occurrence is increasing as zones of open water are becoming more frequent in the Arctic during winter, namely in the lower latitudes of the region such as in Hudson Strait. Temperatures are so low in the Arctic during winter that even small zones of open water can cause substantial icing if winds are favourable. This risk is unpredictable and requires that the ship be equipped with de-icing features (included in strong winterization norms) that are often not enough to efficiently replace the use of hammers... Shipmasters, contrary to common wisdom, then try to avoid ice-free sea zones whenever the sea is rough and temperatures are low, a counterintuitive adaptation of navigation management to this risk.

Darkness is also a limitation: large commercial ships are much less maneuverable and poor visibility due to winter darkness limits the possibility to change course and avoid major obstacles such as compression ridges (O'Connell 2008). Fog, strong winds and blizzards are also very common in the Arctic and can severely hinder visibility.

These physical constraints are thus still major challenges to winter shipping in the Arctic. They underline the fact that equipment is part of the solution, but seamanship and ice navigation skills are also a crucial element.

Figure 1. Port traffic and navigation in the Gulf and St. Lawrence River



Navigating thick ice: technical solutions do exist

True, shipping companies can adapt to these challenges. There are technical solutions to thick sea ice, icing, darkness and low temperatures. These adverse conditions, however, provide for a serious and challenging environment that affects the profitability of winter Arctic shipping.

Marine design technology has evolved greatly since the first attempts of navigating through ice in the Arctic, decades ago. Until the early 1970's, the ice strengthening of ships was purely empirical and vessels operating in ice were found to be very vulnerable to repeated and extensive structural damages to the hull and propulsion system. The advent of the Swedish – Finnish Baltic ice rules in 1971, developed from detailed investigations of historical structural damages, resulted in much greater reliability and durability of vessels operating in sub-Arctic ice conditions. The Baltic

rules were thereafter utilized as the basis for formulating the initial Canadian Arctic Shipping Pollution Prevention Regulations (ASPPR).

The structure of the first ships designed to ASPPR was in cases found to be vulnerable to damages caused by ice, severe at times in the Arctic. Consequently, they highlighted the very different risk to ships operating in the Arctic and being damaged by thick first-year and multi-year ice, compared to the experiences acquired in sub-Arctic first-year ice conditions. These experiences gave rise to a number of extensive full scale testing programmes, which were sponsored by the Canadian government and were being performed in the Canadian Arctic in the 80's in heavy thick first-year ice and multi-year ice conditions. The results of the full scale tests were then subsequently utilized to assist in formulating the International Association of Classification Societies (IACS) PC ice class rules criteria in the late 1990's and early 2000's (Stubbs 2013).

The late 1970's and early 1980's also saw significant technical development resulting in improved ship performance in ice. Many different bow forms emerged the likes of concave bows, Waas bow form, elliptical shape bows, reamers, etc. (Freitas and Nishizaki 1986); and, on ship propulsion, the application of geared and direct drive diesel engines driving open and nozzled propellers, podded propulsion, etc., rather than the traditional diesel-electric drives commonly used on icebreakers at the time (Sodhi 1995). The search for new and improved technologies was driven primarily by the needs of oil and gas exploration; and, competition between emerging Russian, Finnish and Canadian technologies (Stubbs 2013).

Nonetheless, high ice-class ships remain costly to build. A review of the literature shows that, depending on the ice class, construction premiums can be significant (Lasserre 2014). Besides, if most ice-class commercial ships are classified 1A or less (Baltic or Lloyd's classification system, PC7 in the new IACS - International Association of Classification Societies, see Lasserre and Pelletier 2011), navigating Arctic waters in winter requires higher ice classes, 1AS/PC6 and higher. Fednav's MV *Arctic* is nominally classified as 1AS/PC4; the *Umiak I* is also equivalent to PC4. The Mary River iron mine, on Baffin Island, was to be serviced year round by cargo ships with an ice class of PC4 (Lasserre 2010b) before Baffinland Iron Mines Corp., owner of the mining venture, decided to opt for summer shipping only (Jordan 2013). These ships are stronger, but much more expensive to build (more steel to strengthen the hull) and operate (they are heavier and the required hull form for icebreaking is less efficient, leading to high fuel consumption) (Table 2) (see Annex 1 for a nomenclature of ice classes).

Insert Table 2.

Ice information technology is in development as well. Accessing ice information and data is crucial to the safety and efficiency of a voyage (Uuskallio 2011). Having tools that provide ice detection in real-time, such as an ice detection radar, is also essential. The physical environment of the Arctic often leads to poor visibility, while ice conditions require increased caution from the navigator. Ice navigation systems are becoming more and more available, in various cost range and level of efficiency. Defining the needs of a vessel in terms of ice navigation support is done by assessing the area of interest, the time of the year when navigation will occur and the amount and type of ice that is expected to be encountered. An ice detection radar alone can be sufficient when navigating in open water with possible ice encounters (O'Connell 2008), or when navigating in proximity of ice zones. However, when navigating through ice and in particular during winter time, it is essential to have a system that also allows receiving ice and weather information in order to perform strategic route planning, so as to try and avoid ridges or, to the contrary, take advantages of leads in the ice. As an example, the IceNav system combines both functions within one system, providing a complete tool for both strategic and tactical planning (Bourbonnais 2013).

Technology does not solve everything

However, it is unlikely that we will see year-round transit navigation in the Canadian Arctic, despite the above-mentioned technological innovations. Even if there are technical solutions that enable navigation in thick ice, it does not mean shipping in winter-ice will be profitable or attractive for shipping companies, because ice thickness is not the main Arctic shipping driver.

Arctic shipping is driven primarily by Arctic natural resource development, as shown in a host of studies including Lasserre (2004), the Arctic Council's Arctic Marine Shipping Assessment (2009), Lasserre (2010c), Lasserre and Pelletier (2011). True, Arctic sea ice change (in extent, thickness and age) provide for greater marine access and potentially longer navigation seasons; thus the general idea that commercial shipping could develop quickly. However, this idea is challenged by several observers as Arctic shipping conditions remain adverse and not necessarily profitable (Guy 2006; Verny and Grigentin 2009; Lasserre and Pelletier 2011; Humpert and Raspotnik 2012; Carmel 2013). Besides, much more than shorter routes that could prove useful for transit, it is the globalization of the Arctic and the linkage of Arctic natural resources to global markets. It is therefore destinational traffic that is already supporting the expansion of Arctic shipping now, as testified by Fednav's winter shipping projects in the Canadian Arctic (Arctic Council 2009; Lasserre 2009, 2010b, 2010c; FNI-DNV 2012; Pizzolato *et al* 2014). Should a segment of the shipping market be interested in year-long shipping, it is the destinational traffic, rather than transit.

The literature shows an ongoing reflection on the profitability of Arctic shipping has already highlighted that shorter routes or thinner ice are not enough to sustain profitability.

First, delays are too unpredictable for the container shipping industry, which generally works on schedules that leave little room for flexibility, a feature several shipping firms explicitly underline when considering navigation in the Arctic (Guy 2006; Very and Grigentin 2009; Lasserre and Pelletier 2011). Sea ice conditions and the availability of a shorter route are not the only factors that shipping companies take into account (Pizzolato *et al*, 2014)

Second, for winter navigation, high ice-class ships, above the classical Baltic 1A or 1AS, would be required to make this transit. These ships are costly, and this offsets the benefit of shorter distances.

Third, an economic element must be factored in. Among the deal-breakers when it comes to shipping in the Arctic is the high fuel consumption cost. Ice deformation, which could likely increase due to a more extensive first-year ice cover (Stern and Lindsay 2009), results in motion processes and features like ridges that require significant ramming. This, in turn, leads to very heavy fuel consumption. Icebreaking requires a lot of power, especially when ramming is involved. This is the case when the ice is deformed and presents thick ridges, hummocks or shear zones. Plus, the thicker the ice, the heavier is the fuel consumption. Icebreaking ships, having a hull form that is less efficient for open water, consume significantly more fuel than regular cargo vessels. While operating in ice-covered waters, the consumption can easily be 1,5 to 2 times the open water consumption (Keane 2012, 2013; Lasserre 2014)².

Fourth, and more importantly, ice conditions in the routes in the Northwest Passage are still too severe even for ice capable ships to traverse at a reasonable speed and in a predictable manner, considering the great distance that they would need to cover. Even promoters of shipbuilding technology reckon that winter navigation remain difficult (Uuskallio 2011). A liner service in winter time would experience high investment costs; unpredictable delays; high fuel consumption rates; factors that would severely impair the profitability of transit shipping along Arctic passages (Lasserre 2014).

Conclusion

² In the literature, Dvorak (2009) underlines consumption increases fast when using power to break ice: +46% for a PC3ship at nominal power. Professors Notteboom and Guy also underlines fuel consumption is much higher when navigating in ice. Prof. Theo Notteboom, professor in maritime transport, Antwerp Maritime Academy, personal communication, Oct. 14, 2012; Prof. Emmanuel Guy, holder of the Maritime Transportation Chair, Université du Québec in Rimouski, personal communication, Oct. 12, 2012. See also Notteboom and Vernimmen 2009.

The media and some observers have suggested that climate change and the associated accelerated reduction of multiyear ice, will facilitate year-round commercial shipping, both for destination and transit, in the next few years. In this respect, a comparison with the Gulf of St. Lawrence was portrayed as relevant, since this area faces difficult ice conditions during winter yet has a long history of successful winter navigation.

In fact, climate change, if it indeed leads to the elimination of multiyear ice, provides for the increase of the frequency of other forms of dangerous ice conditions – growlers and bergy bits for example - and for the increased frequency of ice deformation and ridges associated increased ice mobility. Therefore, there remain significant differences in winter ice conditions between the Canadian Arctic and the Gulf of St. Lawrence, making the comparison for practical purposes irrelevant. Besides, not only is ice still different in the Arctic and in the Gulf, sea ice is not the only factor that Arctic shipping boils down to. Shipping companies factor in several other management and economic elements.

The severity of Arctic conditions suggests that it would be preferable to look at the Arctic as a destination, not as an area of transit or thoroughfare. Transit shipping appears less attractive in the Arctic than destination shipping, because constraints of just-in-time make it difficult for shipping companies to consider operations to be profitable, in the summer time, even more so when considering year-round shipping. However, the servicing of natural resources exploitation sites (destination shipping), where just-in-time is not relevant, appears to gain potentially more interest in developing year-round traffic when profitable, depending on the local conditions. However, commercial shipping, in the Arctic and elsewhere, is driven by the market: trade can only be viable if the value of commodities being shipped can withstand the associated expenses. Arctic shipping, in particular winter shipping, will continue to bear a major cost component as winter ice conditions remain adverse.

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Table 1. Comparison of winter sea ice characteristics, Gulf of St. Lawrence and Canadian Arctic.

Characteristics	Gulf of St. Lawrence	Canadian Arctic
Ice thickness and age	<p>Seasonal ice only.</p> <p>Ice thickness can reach 1,2 m but is generally below 1 m.</p> <p>No glacial ice reaches the Gulf.</p> <p>Ice is thinner in the river: less than 1 m.</p> <p>(Also see Morse et al, 2003).</p>	<p>Both seasonal and perennial ice, although the extent of perennial ice is decreasing.</p> <p>Seasonal ice thickness generally varies between 1,2 and 2,5 m thick. Ice thickness depends on degrees-days and thus ends up thicker in the Arctic as much colder conditions still prevail. (Also see Kjerstad 2011).</p> <p>Perennial ice thickness is generally between 2,5 and 5 m thick. Old ice floes are often embedded within the seasonal pack due to summer drift, in particular in the channels of the Northwest Passage (Howell et al, 2013).</p>
Glacial ice	None	<p>Glacial ice (icebergs, bergy bits and growlers), extremely hard, is often found in the Canadian Arctic Archipelago and in Baffin Bay because of increased glacier movement in Canadian islands and Greenland.</p> <p>(Also see Snider 2006; Lasserre 2010a; Kjerstad 2011; Gagnon and Wang 2012).</p>
Ice strength	<p>Fresh water (river) ice; stronger than sea ice.</p> <p>Also see Kjerstad (2011).</p> <p>Frequent periods of above 0°C temperatures allow the ice to soften and therefore reduce the strength of the ice.</p>	<p>Sea ice; weaker than fresh water (river) ice.</p> <p>However, very cold temperatures over a few weeks lead to an increase in the strength of the ice.</p> <p>Ice, thinner than in the past, is now more mobile, which lead to more pressure ridges and shear zones.</p>

General weather in winter	<ul style="list-style-type: none"> - Storms weather and variable temperature are expected all season long (mid-December to late March). - Freezing-degree-days: Iles de la Madeleine: 692,79 Ile aux Coudres: 986,54 - Freezing spray is sometimes experienced. 	<ul style="list-style-type: none"> - Stormy weather and cold temperature are expected all season long (mid-November to mid-May). - Freezing-degree-days: Pond Inlet : 5 736,1 Kuujuaq: 3 196,28 - Blizzards, freezing spray and icing are common (Niini 2006).
Deformation patterns	<p>Historically: ridging of the ice cover due to pressure, leading to 2-3 m thick ridges, occurring during two months, mid-January to mid-March.</p> <p>Nowadays: much less ridging occurs now that the ice cover is sparser.</p>	<p>Ridging of both the seasonal and perennial ice covers due to pressure and ice movement, leading to 3-20 m thick ridges. Trend in an increase in the occurrence of pressure ridges. (Also see Rampal et al 2009; Spreen et al, 2011; Uuskallio 2011).</p> <p>Shear zones are also observed at the confluence of landfast ice and mobile pack. Much of the shear zone is composed of hummocked ice, a moving limit very difficult to break through. (Also see Johnston, 2005; Keane, 2009).</p>
Support resources in winter	<p>Icebreaker, tug and Coast Guard support are available.</p> <p>Navigational aids and charting are adequate.</p> <p>A network of ports along the waterway.</p>	<p>No icebreaker or Coast Guard support in winter.</p> <p>Few navigational aids and incomplete charting.</p> <p>No port infrastructure.</p>
Overall level of difficulty for navigation	<p>Medium.</p> <p>Access to support infrastructure, periods of mild conditions.</p> <p>Icebreaking capabilities are required sporadically over short distances.</p>	<p>High.</p> <p>Remoteness, lack of support infrastructure, highly dynamic ice and climate conditions.</p> <p>Strong icebreaking capabilities are required at all times over long distances.</p>

Compiled from interviews with Captain Stéphane Julien, Canadian Coast Guard, January 21, 2009; Luc Desjardins, Canadian Ice Service, Environment Canada, May 7, 2012; Georges Tousignant, VP Operations, Nunavut Eastern Arctic Shipping (NEAS), December 11, 2012; Tim Keane, Manager Arctic

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Table 2. Estimates of capital cost premium for a commercial ice-class ship depending on the ice class, from selected simulations.

Authors	Type of ice class	Cost premium
Mejlaender-Larsen 2009 Wergeland 2013	“Ice-class”	+ 10 to 35%
Liu & Kronbak 2010	1B	+20%
Kitagawa 2001 Mulherin et al 1996	PC7	+20 to 36%
Schøyen and Bråthen 2011 Mulherin et al 1996	PC7 to PC4	+20%
Dvorak 2009 Mulherin et al 1996	PC6	+1 to 20%
Det Norske Veritas 2010	PC4	+30%
Det Norske Veritas 2010	PC4 and DAS	+120%
Dvorak 2009	PC3	+6%
Somanathan et al 2009	PC2	+20%
Srinath 2010	PC2	+40%
Chernova and Volkov 2010	“High ice class” and DAS	+30 to 40%

Acronyms :

PC : Polar Class (see Annex 1 for a nomenclature of ice classes for ships) on a scale from 1 (strongest ice-breaker) to 7.

1B : a quotation from the Baltic ice-class system; 1D is the weakest ice-strengthening; then 1C, 1B, 1A, 1AS.

DAS : double acting ship. DAS is a type of icebreaking commercial ship designed to run ahead in open water and thin ice, but turn around and proceed astern (backwards) with azipod thrusters in heavy ice conditions. Such ships can thus theoretically operate independently in severe ice conditions without icebreaker assistance but retain better open water performance than traditional icebreaking vessels thanks to their traditional bow design.

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Annex 1

In the literature, many ice-class systems coexist, and the equivalence among these different systems proves to be complicated, especially for shipping firms and insurance companies: let us mention the Canadian ice-class system (CAC1, CAC2, CAC3, CAC4, Type A, B, C, D, E), the well-known Baltic system (1AS, 1A, 1B, etc.), Lloyds, Russian, Japanese, American, etc. (Lasserre 2010b). The International Maritime Organization *Guidelines for Ships Operating in Arctic Ice-covered Waters* (IMO, 2002) and *Guidelines for Ships Operating in Polar Waters* (IMO, 2009) are both recommendatory only in nature. The IMO is developing a mandatory Polar Code. Parallel to IMO efforts to implement unified guidelines for shipping in polar waters, the International Association of Classification Societies (IACS) set up unified criteria for ice classification in 2006 (IACS 2007) summed up in the Polar Class (PC) notation. The Canadian Arctic Class (CAC) classification will be replaced by the IACS/Polar Class (PC) notation (Transport Canada, 2009).

Approximate equivalence of ice class classification systems

	Ice-breaking ships							Ice-strengthened ships					
Baltic								1AS	1A	1B	1C	1D/II	II
Russian, old rules													
Commercial vessel							ULA —	ULA -UL —	UL —	L1 —	L2 —	L3 —	
Icebreaker				LL1	LL2	LL3		LL4					
Russian, current rules													
Commercial vessel					LU9	LU7/ LU8	LU6	LU5	LU4	LU3	LU2	LU1	
Icebreaker				LL9	LL8	LL7		LL6					

Lloyd's Register	LR3	LR2		LR1. 5		LR1		1AS	1A	1B	1C	1D	100 A1
Canadian Arctic Shipping - CASPPR		CAC 1		CAC 2	CAC 3	CAC 4		A	B	C	D	E	
IACS - International Association of Classification Societies			PC1	PC2	PC3	PC4	PC5	PC6	PC7				
American Bureau of Shipping		A5		A4	A3		A2	A1	A0	B0	C0	D0	

Sources:

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