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Navigating pressured ice: Risks and hazards for winter resource-based shipping in the Canadian Arctic

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ABSTRACT

Year-round shipping is becoming common in the Canadian Arctic, a region rich in increasingly accessible natural resources. Currently, an average of two round-trip winter voyages (four single transits) (January, February, March) are made annually through the Hudson Strait to service the Raglan nickel mine in Deception Bay, Quebec. During these winter transits it is common for vessels to encounter pressured ice and become beset (stuck) for hours to days at a time. Pressured (or ridged) ice is one of the most challenging navigational hazards in the Arctic as it is difficult to predict or even detect until a vessel comes into direct contact with it. Using ship logs from 33 one-way winter transits through the Hudson Strait during winter months between 2005 and 2014, we evaluate the temporal and spatial frequency of vessel besetment events and relate these events with satellite based imagery of the region in order to examine the potential of satellite-based detection of ridges for the possible future development of real-time or prediction analytics for ridging events. Results indicate that on average the ship was beset 42% of each transit while in the Hudson Strait and often became beset in areas and times of the year associated with high ridge densities. These findings provide a basis for improving observation and prediction of hazardous ice conditions through the use satellite imagery and historic analysis of besetting events, though additional research is needed.

1. Introduction

Resource development is a key economic driver in Canada's Northern territories and growth in the sector is expected to continue as a warming climate facilitates increased access to the abundant stores of oil, gas, and minerals in the region (AMAP, 2007; Fenge, 2009; Fournier and Caron-Vuotari, 2013; Prowse and Furgal, 2009; Stephenson and Smith, 2015; Têtu et al., 2015). Transport Canada (2015) recently estimated the potential expenditures within resource development transportation corridors in northern Canada to be over CDN$276 billion. Despite the economic opportunities, extraction and transportation of natural resources from Arctic Canada is both challenging and risky. There is a lack of major infrastructure in the region, which necessitates the movement of raw materials, often by sea, to southern refineries and fully serviced ports. Further, the climate is harsh and the open-water shipping season is very short. Thus, some fully operational mines engage in year-round shipping using ice strengthened vessels during the harsher winter months (January, February and March) to break through sea ice and to track into and between open water leads. Not surprisingly, the highest percentage of shipping accidents occurs during these winter months when consolidated ice is present and when wintertime temperatures and related ocean dynamics contribute to the regular development of pressured (or ridged) ice (Valdez Banda et al., 2015). Pressured ice, and the subsequent ridging that it causes, is one of the most hazardous navigational challenges for transiting vessels as it is difficult to detect until a ship is in contact with it often causing ships to become beset (stuck) in the ridged ice for hours to days at a time (Kubat and Sudom, 2008; Pärn et al., 2007; Valdez Banda et al., 2015). Ship besetment is not only dangerous for the safety of the crew and the vessel, but also causes significant time delays and lost revenues and further creates increased potential for major environmental disasters.

To date, the risks associated with winter resource shipping have been well managed by shipping operators in Canada. The Raglan Nickel mine, operated by Glencore Xstrata, in Deception Bay, Quebec, has been consistently serviced via winter voyages from

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Quebec City through the Hudson Strait from as early as 1998, without any major catastrophic incident (T. Keane, pers. comm., 5 July 2016). However, ships have regularly become beset in pressured ice during these voyages and given the proposed increase in newly operational mines that plan to engage in winter shipping (e.g. Baffinland's Mary River Iron Ore Mine), it is possible that we will see more major incidents in the future (Agnico Eagle, 2013; AREVA, 2011). Thus, there is a pressing need to better understand the risks presented by pressured ice for resource-based ship navigation in Arctic Canada and to identify possibilities for better detection and prediction of pressured ice conditions. There have been no previous studies examining the temporal and spatial patterns of vessel besettings in a particular region for multiple years. Previous studies on pressured ice and ridges have tended to focused on ridge geometry and vessels loads (Dalane et al., 2015; Ekeberg et al., 2015; Gorbunova and Shkhinek, 2015), or hindcasting ice pressure during single besetting events (see Kubat et al., 2011, 2012). One study in the Baltic Sea examined the more widespread implications of ridged ice on shipping incidents generally, but did not delve into ridging patterns beyond identifying the presence or absence of ridged ice (Pärn et al., 2007).

This study responds to this now pressing need to understand the effects of ridged ice on ship besettings over time by focusing on the Hudson Strait, a region with a long history of winter shipping and besetment events. As such, the study addresses two main objectives: 1) to inventory and analyze the frequency of ship besetting events in the Strait from 2005 to 2014 (temporally and spatially), and 2) to examine the utility of using satellite imagery to identify and potentially predict the presence of pressured ice for the purpose of ship avoidance.

2. Sea ice ridges and shipping in the Hudson Strait

Previous studies of ice as a navigational hazard for shipping in Arctic Canada have enhanced understanding of the risks for summer time shipping (see Pizzolato et al., 2014; Stephenson et al., 2011; Stewart et al., 2007, 2012). However, limited attention has been paid to off-season winter transportation risks including the implications of pressured ice. Pressured ice occurs where ice is mobile and is compressed by convergent forces such as winds, tides and currents causing a buildup of pressure and the formation of extremely strong ridges that are very challenging to navigate and often cause besetment (Kubat et al., 2012; also see Bradford, 1972; Marchenko, 2008; Parmerter and Coon, 1972; Timco and Burden, 1997; Weeks and Kovacs, 1970; Weeks, 2010). Typically, ridges that are formed are made up of larger blocks of ice that are sometimes visible, however, when pressure is being built up through shearing forces, the ridges are usually very straight and made of up very well ground up ice that is more difficult to distinguish (Parmerter and Coon, 1972). As ridges age and persist through the summer melt season, they smooth and individual blocks are no longer visible (Kwok, 2014). Pressured ice is particularly hazardous considering it is almost impossible to accurately predict, project, or even detect until a vessel comes into direct contact causing besetment for hours to days at a time. Ship besetment is very serious presenting implications for ship safety, environmental sustainability, and voyage efficiency (Kubat and Sudom, 2008; Kubat et al., 2009, 2012). Becoming trapped in ice can cost operators up to CDN$50,000 a day in lost revenue and operational expenses (T. Keane, pers. comm., 5 July 2016).

Most attempts to study pressured ice and ridge formation have been carried out at scales of a few kilometres, and while these attempts have yielding important scientific information, the reality is that ships experience pressure at a scale of only a few metres, thus models that have been created are not always useful to ship operations or for predicting ship-scale pressured ice events (Kubat et al., 2012; see example of model in Mårtensson et al., 2012). Other studies have focused on the geometry and loads of single pressure ridges (see Dalane et al., 2015; Ekeberg et al., 2015; Gorbunova and Shkhinek, 2015). Kubat et al. (2011, 2012) are some of the few who have developed a model that hind-casts pressure at a more relevant ship scale by examining historic conditions after an actual besetting event (also see Montewka et al., 2015; Pärn et al., 2007; Valdez Banda et al., 2015). Kubat and Sudom (2008) further surveyed ship captains and operators about their navigational data needs again finding that the lack of forecasting or predictability of ridges to be one of their most highly ranked concerns. Currently data on water currents, waves, storms, winds, air temperatures, and ice type, distribution and concentration are easily accessible to ship operators but information on ridging is not available for navigational decision-making (Kubat and Sudom, 2008).

In this study we examine besetting events at a ship scale within the 400 km long and 150 km wide Hudson Strait, which represents an important link between Hudson Bay and the Atlantic Ocean (Fig. 1). In the summer (end of July to mid-October) and shoulder seasons (early summer and early fall) the Strait is an integral part of the Arctic Bridge, a transport route, between Churchill, Manitoba, Canada and Murmansk, Russia where regular shipments of grain and other cargo have been historically shipped to markets in Eastern Canada and other ports abroad (Stewart and Lockhart, 2005). The Strait is important for community re-supply serving communities along the coasts of Quebec and Nunavut (NEAS, 2014). Cruise ships and yachts regularly use the region during open water season (Stewart et al., 2010) and there are operational and proposed mines that also utilize the Strait to transport supplies and export extracted natural resources (Agnico Eagle, 2013; AREVA, 2011). It has been estimated that the potential resource development expenditures within the Strait alone could amount to over CDN $8.5 billion (Transport Canada, 2015).

In the winter there is much less ship traffic with the only regular voyages made by the vessel *MV Arctic* to service the Raglan mine and by the *MV Nunavik* that services the Nunavik Nickel Mine (Fednav, 2014b). The *MV Arctic* is an ice strengthened vessel with a Polar Class 4 rating, which means it is safe for year-round shipping in thick first year ice that may include some multiyear ice (IACS, 2011). It can transport Ore, Bulk goods and Oil (therefore falling under the OBO classification). The vessel carries ore south from Deception Bay to Quebec City and transports supplies and fuel from Quebec City north to the mine (Têtu et al., 2015). It typically makes two round trip voyages (four transits) to the mine during the winter season between the months of January and March. The ship has regularly encountered pressured ice and ridges throughout the Strait during these winter voyages.

The Hudson Strait is ice covered for approximately 8 months of the year. Ice formation begins in the western half of the Strait in mid to late November, moving from west to east, and land-fast ice first appears along the coast and ice formation continues into the centre of the Strait until the entire area is covered (Crane, 1978). From January to April, there is 9–10 tenths ice coverage throughout the Strait. In the winter, all of the ice, except for the land-fast ice along the coasts, is highly mobile. Leads, or areas of open water, are created as ice floes move apart, while ridges form as ice floes are forced together (Saucier et al., 2004). There is an intense shear zone created at the entrance to Deception Bay. This is where the mobile pack ice in the Strait comes into contact with the land-fast ice that has formed within the bay. This is typically an area with high amounts of ridging, and where the *MV Arctic* often encounters difficulties (P. Bourbonnais, pers. comm., 28 January 2014). Ridging is also very prevalent between Charles Island and Deception Bay, where ice is forced through a bottleneck between the island and the coastline (Mussells