POAC'13
Espoo, Finland

Proceedings of the 22nd International Conference on
Port and Ocean Engineering under Arctic Conditions
June 9-13, 2013
Espoo, Finland

ANALYSIS OF BESETTING INCIDENTS IN FROBISHER BAY DURING 2012 SHIPPING SEASON

Ivana Kubat, Mohamed Sayed, and M. Hossein Babaei
Ocean, Coastal and River Engineering
National Research Council, Ottawa, Ontario, Canada

ABSTRACT

This paper examines the build up of ice pressure in Frobisher Bay. Ice conditions during the summer of 2012 were particularly severe and resulted in a relatively large number of besetting events. Observations were collected from four vessels and describe the conditions, which correspond to 10 besetting events. The salient factors that influenced the besetting events are examined. A summary of the observations is given, including estimates of ice cover coverage and thickness, ridge sail heights, wind conditions and level of pressure severity. For all events there was full ice coverage (95 to 100%). Reported ridge sail heights were consistently 1.2 m, with widespread rafting.

A hindcast of ice stresses and deformation examined in detail a besetting incident of the *Umiavut* on 10 July 2012. The distributions of ice thickness, concentration, pressures and ridge thickness are presented. Critical values of the pressure and ridge thickness, which correspond to the besetting, are also given. The present work additionally addresses some of the environmental forcing patterns that give rise to ice pressure and pose risk for vessels in Frobisher Bay.

INTRODUCTION

Pressured (or compressive) ice has gained increasing recognition as a major threat to navigation in northern regions. The terms ice *pressure* and *compression* have been used interchangeably over the recent past. We will use the expression *pressured ice* in this paper. The present work examines events of ship besetting that took place over Frobisher Bay during the summer of 2012. The ice conditions over the Bay were relatively severe over the shipping season. That posed challenges along the shipping route that is used to supply the town of Iqaluit. Consequently, a number of besetting events took place.

Captains of the ships and Ice Service specialist, who encountered pressured ice conditions, were interviewed. Their observations of ice conditions and ship performance were documented. This paper summarizes the information regarding besetting events and the associated environmental conditions. Furthermore, the paper presents a detailed analysis of one besetting incident using a hindcast of ice deformation. The aim is to quantify pressured ice conditions, and subsequently develop a reliable approach for predicting the threat of besetting.

The present work is a continuation of an effort that has addressed the impact of pressured ice on shipping over various regions in Canada. Documenting observations and experience of ship captains in dealing with pressured ice as well as events of besetting is an important component of the on-going work. For example, Kubat and Sudom (2008) surveyed ship Captains and documented their views of the factors that may pose a threat to safety and performance to navigation through pressured ice. Those views were also summarized by Kubat et al. (2012). Additionally, previous work includes the development of a database of vessel besetting in pressured ice (Kubat et al., 2011a).

The approach of using ice dynamics modelling to quantify ice conditions that lead to besetting was employed by Kubat et al. (2011b) and (2012). They examined hindcasts of ice deformation over the Gulf of St. Lawrence and the Strait of Belle Isle, which corresponded to besetting events. The studies revealed that the pressure (mean normal compressive stress), ridging and compressive strain rates are correlated to the threat of besetting.

Pressured ice effects are obviously experienced over almost all ice covered waters. Leisti et al. (2011) reported on a major study of the impact of compressive ice on shipping in the Baltic. There are also two major European Union (EU) projects that address the subject of pressured (or compressive) ice: SAFEICE (2007) and SAFEWIN (http://www.safewin.org/). The first project has been completed, the second is ongoing.

Although the present work concerns meso-scale ice conditions, there is a class of related studies that deal with the effects of the local-scale pressure along the sides of the ships. Those studies include ice basin modelling of the performance of ships in compressive ice by Suominen and Kujala (2012). Numerical simulation of ice pressure effects at such small scales were also reported by Kubat et al. (2011c) and by Sayed and Kubat (2011).

The following sections of the paper will start by reviewing the reported events of ships besetting in Frobisher Bay during the summer of 2012. A hindcast next examines ice deformation and stresses, which correspond to one of the events. The analysis concludes by evaluating the relevant parameters of ice cover deformation that led to besetting.

BESETTING EVENTS IN FROBISHER BAY DURING THE SUMMER OF 2012

Appreciable number of ships regularly transit through Frobisher Bay during the summer season to deliver supplies to the town of Iqaluit. Ice conditions over the Bay were relatively severe during the 2012 season. As a result, several events of besetting took place. Typically, Frobisher Bay would be clear of ice or would have low ice concentrations during July. However, in July 2012, much higher ice concentrations of 10/10 covered large portions of the Bay. Special ice warnings were issued by Canadian Ice Service (CIS) for the Frobisher Bay during June, July and August 2012. At the Prairie and Northern Region Canadian Marine Advisory Council and Canadian Coast Guard (CCG) post-Arctic meetings, the Iqaluit community members cited heavier ice conditions with excessive ridging near the port. Also the CCG and shipping industry representatives cited unusual and difficult ice conditions near Iqaluit and over the entire Frobisher Bay.

Observations from 4 vessels experiencing 10 besetting episodes between 30 June and 16 July, 2012 were collected. The locations of those events are shown in Figure 1. Characteristics of the vessels are summarized in Table 1. Table 2 lists the besetting events and the locations, dates, prevalent wind conditions, and ice conditions as recorded using the IMO egg code convention (see Environment Canada’s MANICE, 2005). The distance from the southwest coastline is included in Table 2, since the risk of besetting is highly influenced by that variable (Kubat et al., 2012). The vessels were beset in ice over periods ranging from 3 to 10 days. All vessels had to be escorted by CCG icebreakers. In many instances, as soon as the icebreaker ceased the escort operations, the vessel became beset again. In some cases the vessel got beset also in the track behind the icebreaker while being escorted. Durations of besetting events were influenced by the availability of icebreaker escort. The icebreakers were busy assisting several vessels that were simultaneously beset.

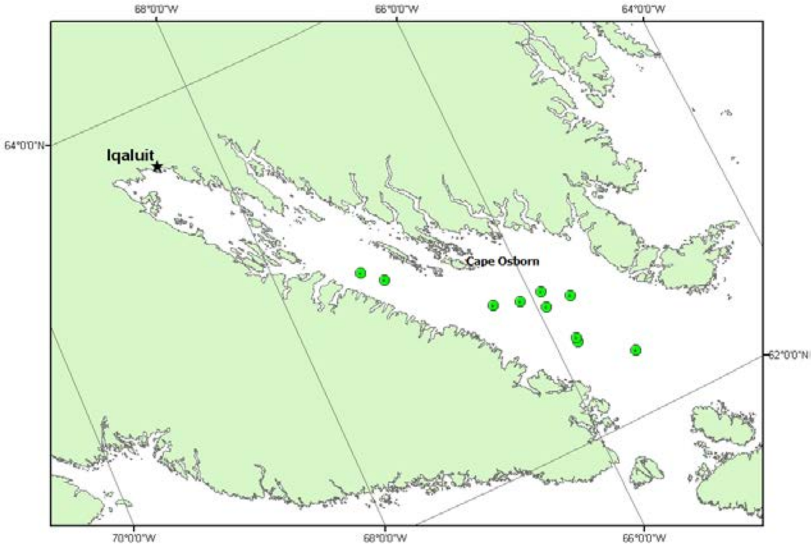

Figure 1: Map showing locations of reported besetting events in Frobisher Bay between 30 June and 16 July 2012.

Table 1. Vessel characteristics.

Vessel	Power (kW)	Length (m)	Breadth (m)	Depth (m)	Remarks
Alsterstern	6,600	154.2	23	11.7	Tanker
Nanny	4,050	110.6	19	10.1	Tanker
Tuvaq	11,480	151.5	22.2	12	Tanker
Umiavut	4,474	113	18	11.3	Cargo

In 2012 prevailing Northeast wind caused delay of ice clearance in Frobisher Bay before beginning of the shipping season. Between 30 June and 16 July the Bay was almost completely covered by ice. The winds have been generally from easterly direction which contributed to keeping the ice in the Bay. The ice field has been largely influenced by the surface currents which are driven by the tidal streams in and out of the Bay. This tidal current effectively moves the ice field as long as there is no obstruction such as fast ice, land, or greater influence (e.g. high winds, wind driven current). In areas where there are geographical obstructions the flow appears to be "choked" and therefore ice pressure increases. This appears to be the case in the area of the Bay west of Cape Osborn where the Bay narrows and where a number of vessels got beset in June and July 2012 (personal communication with Captain Banton). Note that in the model Cape Osborn is not included as a boundary, i.e. the bay is island-free.

In all cases, ice concentration was high with reported coverage of 95 to 100%. All events also correspond to observed ridge heights of 1.2 m (4 feet). In some instances, ridges of 3 m height were observed at some locations. Rafting was also observed in most cases. In one instance, the vessel was stopped upon encountering pieces of multi-year ice.

The summary of the observations indicates that besetting in Frobisher Bay coincides, as expected, with heavy ice coverage with 1.2 m ridge heights. Wind is an obvious factor as well. Although an Easterly or North-Easterly wind is likely to amplify pressure conditions, some events corresponded to South-West wind. Moreover, two events took place although wind was calm. Ice pressure persisted after wind had already abated. The apparent wind observations which conflict with expected trends illustrate that the processes of pressured ice development and ship besetting may be complex and involve numerous factors such as ocean and tidal currents, boundary conditions, ice dynamics, etc. (in addition to wind). Therefore, simple predictions of pressured ice conditions based on the value of onshore wind may not be adequate in certain situations.

Table 2. List of besetting events, locations, dates, wind, and ice cover conditions.

Beset Event	**Date and Time**	**Location**	**Wind**	**Distance to the southwest coastline**	**Ice Cover Type** **MY = Multi-year ice** **FY = First-year ice**
Alsterstern 1	July 5, 12:30Z	62'15" N 65'23" W	10 knots SW	NA	3/10 MY ice; 4/10 Thick FY ice; 3/10 Medium FY ice
Alsterstern 2	July 8 14:30Z	62'23" N 65'47" W	4 knots 320 deg	18.8 km	3/10 MY ice; 4/10 Thick FY ice; 3/10 Medium FY ice
Alsterstern 3	July 11 16:00Z	62'24" N 65'48" W	calm	19.7 km	3/10 MY ice; 4/10 Thick FY ice; 3/10 Medium FY ice
Alsterstern 4	July 12, 12:00Z	62'34" N 65'55" W	calm	28.6 km	3/10 MY ice; 4/10 Thick FY ice; 3/10 Medium FY ice
Nanny 1	July 6 16:15Z	62'38" N 66'06" W	5~10 knots E	25.1 km	3/10 MY ice; 4/10 Thick FY ice; 3/10 Medium FY ice
Nanny 2	July 15 21:30Z	63'01" N 67'16" W	19 knots 140 deg	8.9 km	3/10 MY ice; 4/10 Thick FY ice; 3/10 Medium FY ice
Nanny 3	July 16 13:00Z	62'57" N 67'06" W	14 knots 150 deg	11.7 km	3/10 MY ice; 4/10 Thick FY ice; 3/10 Medium FY ice
Tuvaq	June 30 Late AM Z	62'04" N 66'20" W	5~10 knots SE	30.3 km	5/10 MY ice; 5/10 Thick FY ice
Umiavut 1	July 10 12:10Z	62'34" N 65'41" W	10 knots NW	38.7 km	3/10 MY ice; 4/10 Thick FY ice; 3/10 Medium FY ice
Umiavut 2	July 12 14:00Z	62'38" N 65'54" W	calm	35.1 km	3/10 MY ice; 4/10 Thick FY ice; 3/10 Medium FY ice

ANALYSIS OF A BESETTING EVENT, 10 JULY 2012

The besetting of the *Umiavut* on July 10 is examined in detail in this section. A hindcast of ice deformation was conducted in order to determine the magnitude of pressures, ridging and other variables that caused the besetting. An image of the *Umiavut* during that incident is shown in Figure 2. The wake behind the escort vessel is evidently closed. The image shows that there was full ice coverage. The observations indicate that ridge heights were approximately 1.2 m and that there was substantial rafting.

Figure 2: The *Umiavut* during the besetting incident in Frobisher Bay, 10 July 2012, courtesy Mr. Denis Lambert, CIS.

Initial Ice Cover and Environmental Forcing

The initial ice cover used in the hindcast was obtained from the Canadian Ice Service (CIS) digital daily ice chart issued for 9 July 2012 at 18:00 Z. Figure 3 shows an image of the ice chart that was used to generate the initial ice conditions. According to the ice chart the Bay was covered by $3/10^{th}$ of medium first year ice, $4/10^{th}$ of thick first-year ice and $3/10^{th}$ of old ice. Initialization of the ice thickness for the ice dynamics model was discussed in detail by Kubat et al. (2010). Briefly, ice thickness and concentration for each cell of the computational grid were extracted from the digital ice chart. According to MANICE (2005), each ice type in the ice chart corresponds to a range of thicknesses. The initial thickness values were obtained by calculating weighted averages from ice concentration and the mean thickness (for each ice type).

The water current was obtained from the Bedford Institute of Oceanography (BIO). The surface current is extracted from the output of the Canadian East Coast Ocean Model (CECOM), Tang et al. (2008). The forecasts are produced at 6 hour intervals at a resolution of 0.1 x 0.1 degree. Wind velocities were obtained from Environment Canada's Regional Deterministic Prediction System (RDPS). The wind input has a resolution of 10 km at 60^{o} N, and is available at 3 hour intervals. The ocean currents and wind velocities were interpolated spatially and temporally to the computational grid of the ice dynamics model, and synchronized to start the hindcast at 18:00 Z on 9 July 2012.

Ice Stresses and Deformation

The ice dynamics model has been discussed in previous publications (e.g. Kubat et al., 2010). The model solves the conservation of mass and momentum of the ice cover, as well as an extended von Mises yield criterion. The model includes a thickness redistribution formulation of Savage (2008). The grid used in the present analysis has a resolution of 1 km. The time step was 5 minutes.

The results of the ice dynamics simulations are illustrated by plotting distributions of the thickness multiplied by concentration at the time of the besetting in Figure 4. The corresponding distributions of pressure (mean normal compressive stress) and ridge thickness are shown in Figure 5 and Figure 6. As expected the ice thickness, pressure and ridge thickness all increase in the vicinity of the southwest coastline. The *Umiavut* was in the outer zone that experienced increasing values of those variables.

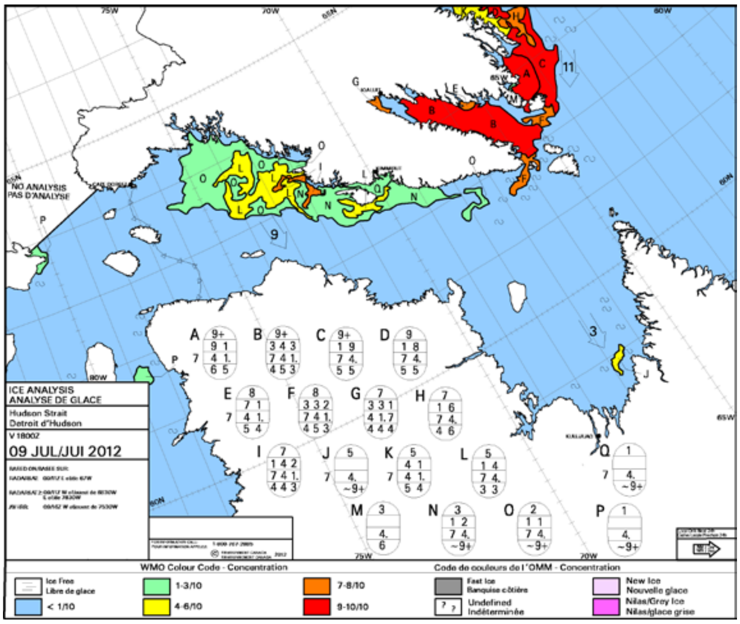

Figure 3: Image of the ice chart showing ice conditions used to initialize the ice dynamics model.

Previous examination of pressured ice conditions (Kubat et al., 2012) has shown that besetting events correspond to critical values of pressure and ridge thickness. Evidently, the *Umiavut* experienced sufficiently large values of the pressure and ridge thickness to cause besetting. Those critical values are: pressure of 21 kN/m (Figure 7) and ridge thickness of approximately 5 m. Obviously, there may be a different combination of those two variables that produce besetting (e.g. lower pressure with higher ridge thickness). The present estimates, however, provide a basis for predicting the threat of besetting.

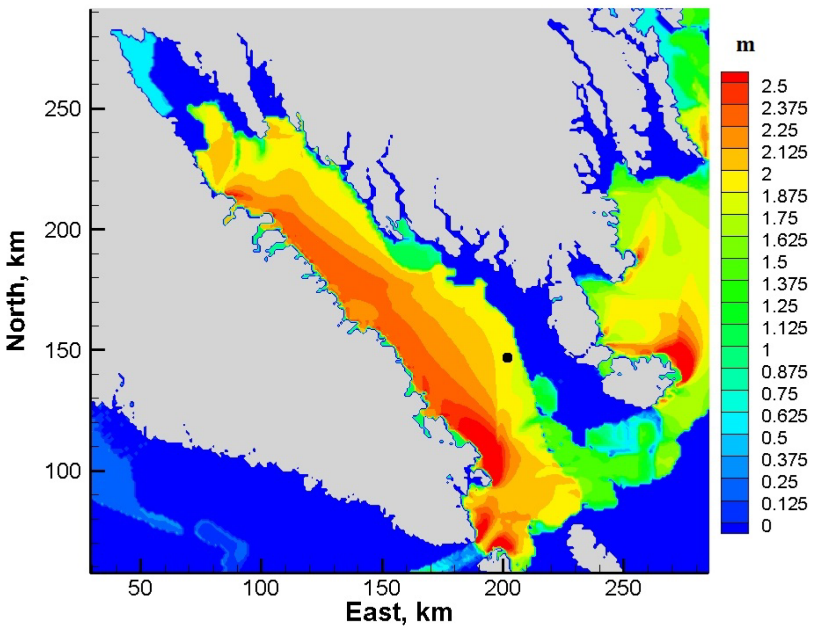

Figure 4: Distribution of ice thickness x concentration at besetting time, 10 July 2012, 08:10 local time (12:10 Z).

For comparison with other locations, we note that Kubat et al. (2012) estimated such critical values for two different vessels that were beset in the Gulf of St. Lawrence on 9 March 2005. The critical pressure values were 12 kN/m (CCGS *Amundsen*) and 9.5 kN/m (M/V *Alida Gorthon*), and the critical ridge thickness was 10 m for both vessels. Those estimates are of the same order as the present estimates. It is important to emphasize that the critical values are expected to depend on the ship characteristics (e.g. the power and hull form).

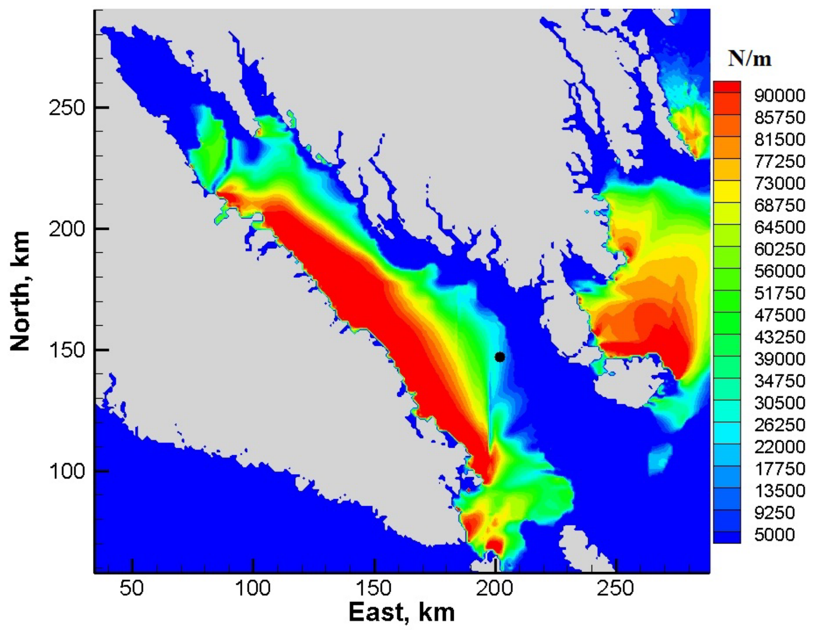

Figure 5: Pressure distribution at besetting time, 10 July 2012, 08:10 local time (12:10 Z).

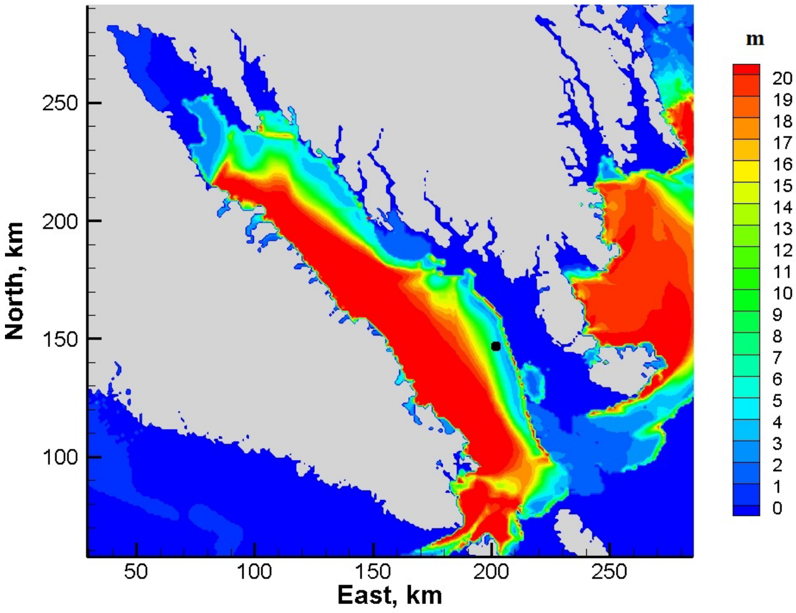

Figure 6: Ridge thickness distribution at besetting time, 08:10 local time (12:10 Z).

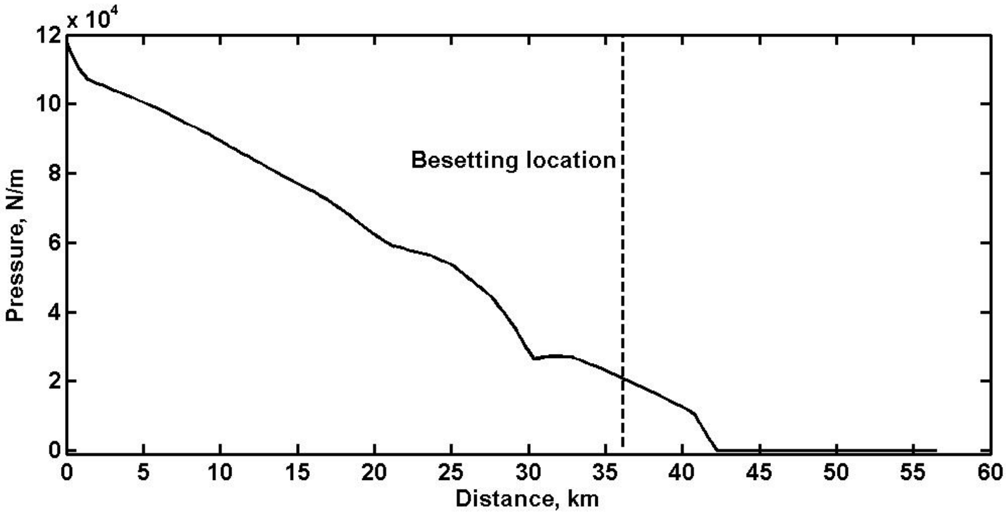

Figure 7: Ice pressure versus distance from the southwest coastline at the time of besetting, 10 July 2012 at 08:10 local time (12:10 Z).

Ice Pressure Conditions in Frobisher Bay

The present ice dynamics simulations illustrate the manner in which pressure builds up and the patterns specific to Frobisher Bay. The environmental conditions that may lead to severe conditions are illustrated by plotting wind and current distributions at the time of besetting of the *Umiavut* in Figure 8 and Figure 9, respectively. The wind velocity vectors are superimposed on the ice cover (thickness x concentration) for both plots. Only these two plots are included here for brevity, although the evolution of those distributions over time is important. The plots show that pressure builds up as wind blows against the coastline (primarily the southwest boundary), and water current moves into the Bay (flood tide).

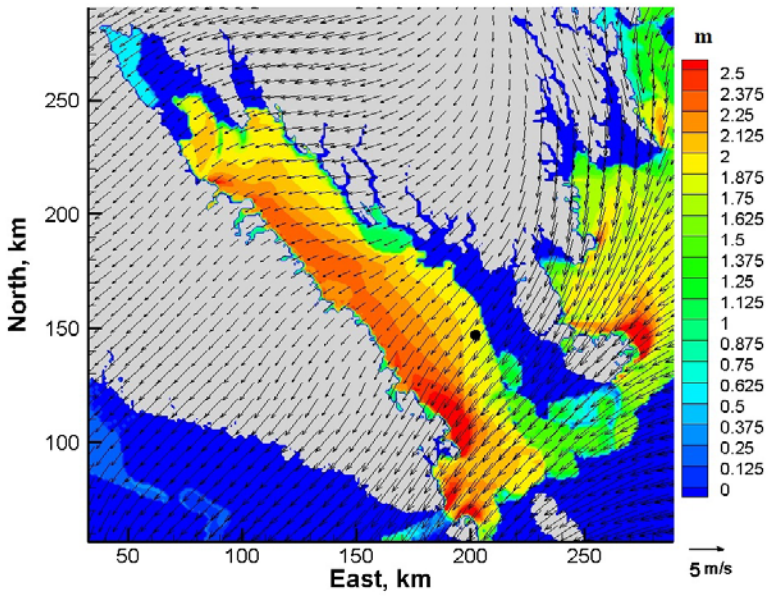

Figure 8: Surface wind velocities and ice concentration x thickness at the besetting time of the *Umiavut*, 10 July 2012 at 08:10 local time (12:10 Z).

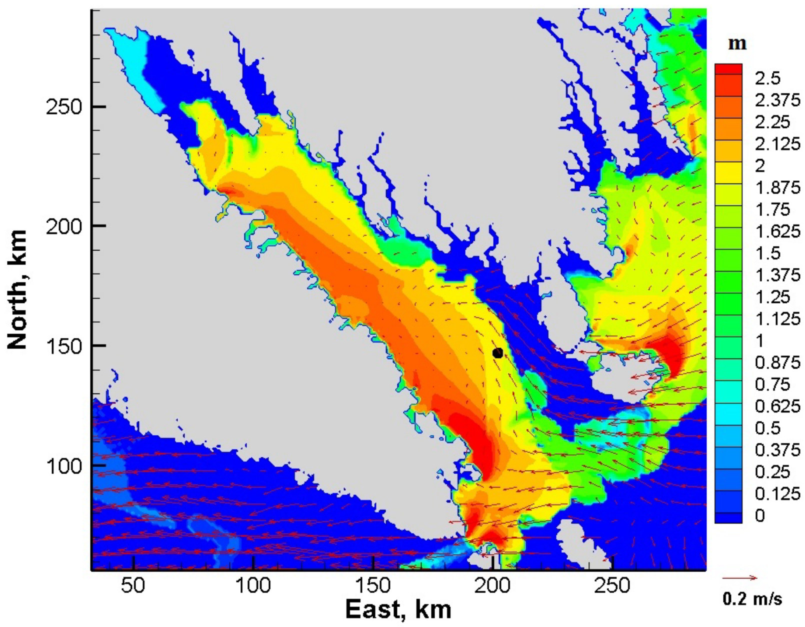

Figure 9: Surface water current at the besetting time of the *Umiavut*, 10 July 2012 at 08:10 local time (12:10 Z).

Proximity to the coastline is another significant factor that influences the risk of besetting. Obviously, pressures, and consequently ridge thicknesses, increase closer to the coastline. Keeping a sufficiently large distance from the coastline may reduce the risk of besetting. Of course shipping may be restricted to navigation channels, which can limit that option. The effect of the distance from the coastline is illustrated in Figure 7. The plot of pressure versus distance shows that conditions closer to the coastline would have been much more severe than what the *Umiavut* experienced. Staying further 6 km away from the coastline (distance of approximately 42 km), if possible, may have avoided besetting.

SUMMARY

The preceding results and discussion have examined the build up of ice pressure and besetting events in Frobisher Bay. Ice conditions during the summer of 2012 were particularly severe and resulted in a relatively large number of besetting events. Observations were collected from four vessels and describe the conditions, which correspond to 10 besetting events. A summary of those conditions was given. The observations include estimates of ice cover coverage and thickness, ridge sail heights, wind conditions and level of pressure severity. For all events there was full ice coverage (95 to 100%). Reported ridge sail heights were consistently 1.2 m, with widespread rafting. In most instances, appreciable onshore wind was reported. In two isolated, cases, however, wind was calm during the besetting episodes. Earlier wind and current action could have cause pressure build up, which did not dissipate. This illustrates the complexity of the processes of ice pressure formation.

A hindcast of ice stresses and deformation examined in detail a besetting incident of the *Umiavut* on 10 July 2012. Simulations were carried out using an ice dynamics model produced the distributions of ice thickness, concentration, pressures and ridge thickness. Critical values of the pressure and ridge thickness, which correspond to the besetting of the *Umiavut* were determined. Those values are comparable to previous estimates obtained for the besetting of other vessels in the Gulf of St. Lawrence. The present work also considers some of the environmental forcing patterns that give rise to ice pressure and pause risk for vessels in Frobisher Bay. Further work will be focused on understanding processes of besetting and verifying criteria for besetting for example combined effect of ridging and pressured ice influence on besetting.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the support of PERD – Marine Transportation and Safety Program, for funding this study. We thank to Mr. Denis Lambert from CIS for providing us with information on many beset events in Frobisher Bay and Mr. Georges Tousignant from NEAS for providing detailed information on *Umiavut*'s beset conditions. Thanks also belong to Captain Banton from CCG and Captain Sheppard from NEAS for providing information on conditions in Frobisher Bay in summer 2012.

REFERENCES

Kubat, I. and Sudom, D. (2008). "Ship Safety and Performance in Pressured Ice Zones: Captains' Responses to Questionnaire" Technical Report CHC-TR-059/ TP14847

Kubat, I, Sayed, M., Savage, S.B., and Carrieres, T. (2010). "Numerical Simulations of Ice Thickness Distribution in the Gulf of St. Lawrence" Cold Regions Science and Technology, Vol. 60, pp. 15-28.

Kubat, I., Lamontagne, P., and Watson D. (2011a). "Database of Vessels beset in the Canadian Arctic and Sub-Arctic" NRC Technical report CHC-TR-080, March 2011

Kubat, I., Watson, D. and Sayed, M. (2011b). "Characterization of Pressured Ice Threat to Shipping", *Proceedings of the 21st International Conference on Port and Ocean Engineering under Arctic Conditions, 2011,* Montreal, Canada, poac11-136

Kubat, I., Sayed, M., and Collins, A. (2011c). "Modeling of Pressured Ice Interaction with Ships" submitted to SNAME 2010 Transactions

Kubat, I., Babaei, M. H., and Sayed, M., (2012). Quantifying Ice Pressure Conditions and Predicting the Risk of Ship Besetting. ICETECH'12, Banff, Alberta, Paper No. ICETECH10-130-R0.

MANICE – Manual of Standard Procedures for Observing and Reporting Ice Conditions, June 2005, Revised Ninth Editions

Leisti, H., Kaups, K., Lehtiranta, J., Lindfors, M., Suominen, M., Lensu, M., Haapala, J., Riska, K. and Kõuts, T. (2011). "Observations of ships in compressive ice", *Proceedings of the 21st International Conference on Port and Ocean Engineering under Arctic Conditions, 2011*, Montreal, Canada, poac11-139

SAFEICE (2007). "Increasing the Safety of Icebound Shipping: Final Scientific Report, Vol. 1 and 2, Espoo 2007, Finland, HUT report

Savage, S.B. (2008). "Two Component Sea-Ice Thickness Redistribution Model," *Cold Regions Science and Technology*, Vol.51, Issue 1, pp 20-37.

Sayed, M., and Kubat, I., (2011). "Forces on Ships Transiting Pressured Ice Cover". *Proceedings of the International Offshore and Polar Eng Conference (ISOPE)*, Maui, Hawaii, June 19-24, 2010, pp.1087-1092.

Suominen, M. and Kujala, P. (2012). " Ice Model Tests in Compressive Ice", *submitted to proceeding of the 21st International Symposium on Ice*, Dalian China, 11-15 June 2012

Tang, C.L., Yao, T., Perrie. W., Detracey, B.M., Toulany, B., Dunlap, E., and Wu, Y. (2008). "BIO Ice-Ocean and Wave Forecasting Models and Systems for Eastern Canadian Waters". Canadian Technical Report of Hydrography and Ocean Science No. 261, 61 pp.