POAC'15
Trondheim, Norway

Proceedings of the 23rd International Conference on
Port and Ocean Engineering under Arctic Conditions
June 14-18, 2015
Trondheim, Norway

ANALYSIS OF VESSEL BESETTING OVER THE GULF OF ST. LAWRENCE AND THE STRAIT OF BELLE ISLE, WINTER 2013-2014

Ivana Kubat [1], Mohamed Sayed [1], Philippe Lamotagne[1]
[1]National Research Council of Canada, Ottawa, Canada)

ABSTRACT

The threat of compression of ice covers to shipping has been the subject of several recent studies. Research projects in Europe and Canada have examined factors that trigger ice convergence and approaches for predicting the risk of besetting of vessels, among other aspects of the problem. This paper examines incidents of vessel besetting due to ice compression which took place over the eastern Gulf of St. Lawrence and the Strait of Belle Isle.

The paper lists reported besetting incidents over these locations during the ice season of 2013-2014. The information includes the date, time, location, prevailing wind, and observations of ambient ice conditions. The distance to the nearest shoreline was also given.

Analysis of certain incidents was done by hindcasting ice drift and deformation. The results give estimates of ice pressures (ice compression) and ridge ice thickness at besetting. For incidents that were apparently triggered by onshore wind and took place over the eastern Gulf of St. Lawrence, ice pressures ranged from 24.0 kN/m to 25.7 kN/m and the ridge thickness values were from 8.2 m to 10.5 m. These values are in agreement with previous estimates obtained for besetting incidents over other parts of the Gulf of St. Lawrence and Frobisher Bay. An analysis of incidents that corresponded to wind acting nearly parallel to the shoreline in the Strait of Belle Isle produced lower values of ice pressures and ridge thickness. However, the strain rates were particularly high, which evidently caused convergence of the ice cover and prompted the besetting incidents.

INTRODUCTION

Reliable prediction of the risk of vessel besetting in severe ice conditions remains a challenge despite the obvious significant safety and economic repercussions. The threat of besetting arises when an ice cover is driven by wind and current against a barrier, such as a coastline or a narrow channel. As the ice cover converges, compression takes place and ridges form. Consequently ice resistance increases, and vessels may become beset. The risk of besetting evidently depends on ice resistance, which is a function of the compression and thickness build-up (or ridging), as well as the available power and characteristics of the vessel. Quantifying these effects is evidently complex. Local effects can also introduce additional difficulties since ice conditions and environmental forcing may encompass site-specific patterns.

In response to these problems, research projects have been actively addressing various issues of compressed ice formation and vessel besetting in such ice conditions. As an example, Leisti et al. (2011) reported on a recent European initiative to investigate the effects of ice compression on navigation in the Baltic. Other European efforts include the SAFEICE (2007) and SAFEWIN (www.safewin.org) projects. Model basin tests of ice compression were also reported by Suominen and Kujala (2012). Additionally, Montevka et al. (2015) present probabilistic models that predict vessels performance in dynamic ice such as vessel speed and likelihood of vessel getting beset in ice.

The present paper draws on results from a research project conducted at the National Research Council of Canada that aimed to quantify the severity of ice compression and the risk of besetting under ice compression. The work included surveys of ship captains (Kubat and Sudom, 2008) that identified the important factors and regional conditions which led to besetting. Additionally, a database was constructed (Kubat et al, 2011a) to record incidents of besetting and damage to vessels over Canadian Arctic and sub-Arctic waters. The database is continuously updated as new incidents are reported. The work then proceeded with analyses of the conditions leading to various besetting incidents. The approach was to employ an ice dynamics model to hindcast ice stresses and deformation patterns in the vicinity of such incidents (e.g. Kubat et al., 2012 and 2013). The results gave critical values of the variables that lead to besetting of various vessels.

The following sections of the present paper will start with a brief review of the work that identified the factors that affect the development of ice compression and the risk of besetting. An analysis of new besetting incidents that occurred over the 2013/2014 winter season over the eastern part of the Gulf of St. Lawrence and the Strait of Belle Isle is next presented. The paper concludes with a summary of the critical values of variables that influenced besetting events from various regions.

COMPRESSION BUILD UP AND BESSETING EVENTS

The survey of ship captains (Kubat and Sudom, 2008) identified the factors that assist in evaluating the ice compression build-up. The important factor was the presence of ridges and ridge thickness. Results of the survey also indicated that the risk of encountering high ice pressures at various locations and risk of vessel besetting usually corresponded to the presence of onshore wind, tidal current, and ocean swell. That risk is heightened if vessels venture closer to the shorelines. We note that the term *ice pressure* was often used in reference to compressive stresses and to convergence (strain rates). Naturally, available power of the vessel was reported as a significant factor.

These factors that influence the severity of ice compression were examined in a series of studies by Kubat et al. (2011b, 2012, and 2013). An ice dynamics model was used to hindcast ice conditions that led to reported incidents of besetting. The model has been described in a number of past publications (Sayed et al., 2002; Kubat et al., 2011b). It is based on solving the conservation of mass and momentum of the ice cover as well as a plastic failure criterion. A thickness redistribution model is also included to predict the evolution of the thickness and coverage of ridged ice (Savage, 2008). The hindcasts give the evolution of the distributions of ice thickness, concentration, stress (pressure), strain rates, and ridge thickness and coverage. The results quantified the critical values for the pressures, ridge thickness and convergence. Other issues such as the effect of the proximity to a shoreline on the risk of besetting were also established for a number of regions and for a range of environmental conditions (e.g. wind and current).

BESTTING EVENTS OVER THE GULF OF ST. LAWRENCE AND THE STRAIT OF BELLE ISLE, WINTER 2013/2014

The winter of 2013/2014 was relatively harsh over the Gulf of St. Lawrence and the Strait of Belle Isle, with several reported incidents of besetting. Figure 1, Figure 2 and Figure 3 show photographs of three of those beset vessels and the surrounding ice as icebreakers approached to commence escort operations. Table 1 lists the reported incidents of besetting. The locations of those incidents are marked on the map in Figure 4. Photographs in Figures 1, 2 and 3 correspond to events number 10, 16 and 21. The tabulated list includes the date and time of each incident and distance from the nearest coastline.

Figure 1: Event #10 – Strait of Belle Isle – February 26, 2014. Courtesy Denis Lambert, CIS

Figure 2: Event #16 - Gulf of St. Lawrence – March 4, 2014. Courtesy Denis Lambert, CIS

Figure 3: Event #21 - Gulf of St. Lawrence – March 9, 2014. Courtesy Denis Lambert, CIS

Table 1: A list of reported besetting incidents

Event ID	Vessel_Name	Date	UTC	Region	Distance from shore (km)	Wind speed observed (knots)	Wind speed forecast (knots)	Ice cover type MY = Multi-year ice FY=First-year ice
1	VLIEBORG	05 Feb. 2014	18:00	Gulf	96		15	10/10 Thin ice, ridging and snow cover
2	Federal Kibune	08 Feb. 2014	18:00	Gulf	79		17	10/10 Thin ice, ridging and snow cover
3	Lowlands Boreas	08 Feb. 2014	18:00	Gulf	31		18	10/10 Thin ice, ridging and snow cover
4	Cinnamon	09 Feb. 2014	18:00	Gulf	19		8	10/10 Thin ice, ridging and snow cover
5	Portland Bay	09 Feb. 2014	18:00	Gulf	29		9	10/10 Thin ice, ridging and snow cover
6	CCGS Sir William CCGS Sir William Alexander	22 Feb. 2014	19:30	Strait	8	18	20	9+/10 Medium FY with 3/ 10 ridging and 15 cm of snow
7	CCGS Sir William CCGS Sir William Alexander	23 Feb. 2014	11:00	Gulf	49	14	8	10/10 Medium FY with 3/10 ridging and 60 cm of snow
8	Sir Robert Bond	25 Feb. 2014	11:15	Strait	5	17	16	10/10 Medium FY with 3/10 ridging and 60 cm of snow
9	Sir Robert Bond	26 Feb. 2014	13:30	Strait	35	8	7	10/10 Medium FY,3./10 ridging and 60 cm of snow. 10/10 brash in track
10	Sir Robert Bond	26 Feb. 2014	18:30	Strait	27	20	11	10/10 Medium FY with 10/10 brash in track, 3/10 ridging and 60 cm of snow
11	Sir Robert Bond	28 Feb. 2014	15:15	Strait	52	11	9	Thick FY, 8/10 ridging, 90 cm lots of snow. 10/10 brash in track
12	CCGS Sir William CCGS Sir William Alexander	28 Feb. 2014	18:15	Gulf	17	15	21	10/10 Medium FY with 7/10 ridging and 90 cm of snow
13	CCGS Sir William CCGS Sir William Alexander	01 Mar. 2014	14:45	Strait	8	11	14	10/10 Medium FY with 4/10 ridges and 90 cm of snow
14	Bella Desgagnés	01 Mar. 2014	16:00	Strait	12	16	12	5/10 Thick FY, 5/10 Medium FY, ridges and 90 cm of snow. 10/10 of brash in track
15	Bella Desgagnés	01 Mar. 2014	18:20	Strait	11	25	12	5/10 Thick FY, 5/10 Medium FY, lots of ridges and 20 cm of snow
16	M/V Brant	04 Mar. 2014	10:00 to 15:00	Gulf	93	30	13	5/10 Thick FY, 5/10 Medium FY, 5/10 ridging and 70 cm of snow
17	Travestern	05 Mar. 2014	14:30	Gulf	48	23	16	5/10 Thick FY, 5/10 Medium FY, 4/10 ridging and 50 cm of snow
18	MSC Nita	06 Mar. 2014	18:10	Gulf	40	25	17	5/10 Thick FY, 5/10 Medium FY, 4/10 ridging and 50 cm of snow
19	CTMA Voyageur	06 Mar. 2014	19:10	Gulf	34	32	17	5/10 Thick FY, 5/10 Medium FY, 4/10 ridging and 50 cm of snow
20	AM Quebec	06 Mar. 2014	19:30	Gulf	28	35	17	5/10 Thick FY, 5/10 Medium FY, 4/10 ridging and 50 cm of snow
21	CCGS Sir William CCGS Sir William Alexander	09 Mar. 2014	11:30	Gulf	24	20	17	6/10 Thick FY with 4/10 ridging and 50 cm of snow
22	Jana Desgagnes	12 Mar. 2014	14:00	Gulf	36	20	14	10/10 Thick FY; one large floe, ridges and snow (50 cm)
23	CCGS Sir William CCGS Sir William Alexander	13 Mar. 2014	18:15	Gulf	14	10	23	10/10 Thick FY, 2/10 ridging and 35 cm snow

Two examples of the analyses, which were carried out of the incidents, are presented here. The first example concerns the events that took place on 6 March 2014 in the Gulf of St. Lawrence west of the south-western tip of Newfoundland (events 18, 19 and 20 in Table 1 and Figure 4). Table 1 provides observed ice conditions. In all cases there was relatively high ice coverage and deep snow cover. Ridges were also prevalent in many cases as well as brash ice. In addition, the table includes the values of wind speed that were measured at the vessels and those obtained from the forecasts of the Canadian Meteorological Centre (CMC). These values are included since wind appears to be the main driver of ice pressure build-up. Comparing the observed and forecast wind speed gives an indication of the expected accuracy of the predicted pressures and ridge thicknesses.

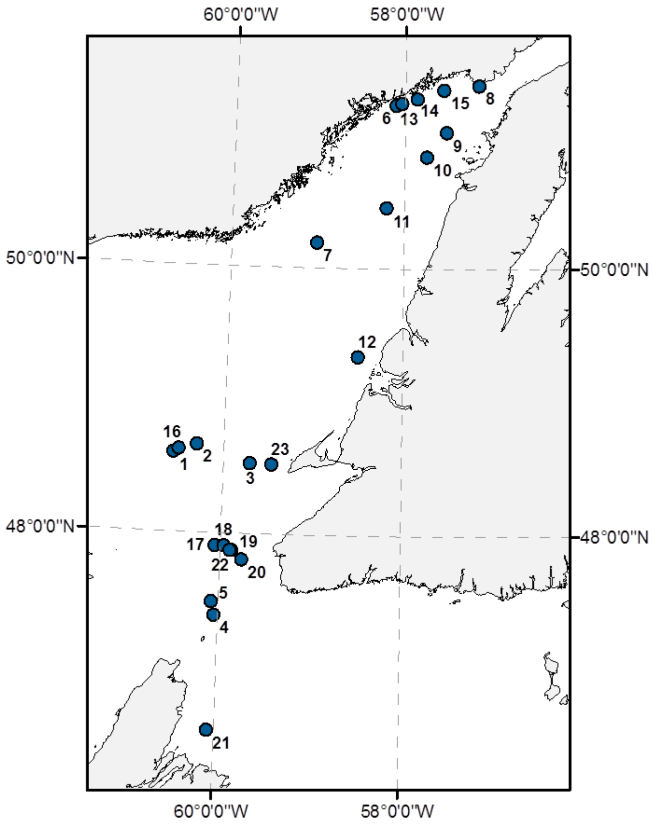

Figure 4: Locations of reported besetting events over the eastern part of the Gulf of St, Lawrence and the Strait of Belle Isle during the 2013-2014 ice season.

A hindcast was carried out starting on 5 March at 18:00Z. The input consisted of ice charts which are produced by the Canadian Ice Service (CIS), water current forecast issued by Bedford Institute of Oceanography (BIO), and regional wind forecasts from CMC. Field observations of ice and environmental conditions from the vessels were also reviewed to verify accuracy of the input.

The resulting distributions of ice pressure and ridge thickness close to the times of the events are shown in Figure 5 and Figure 6, respectively. The wind barbs and water current vectors are also displayed. Wind barbs are used to display the surface wind velocity and direction. Half of a wind barb indicates a wind speed of five knots, a full barb ten knots, and a pennant flag fifty knots (Figure 7).

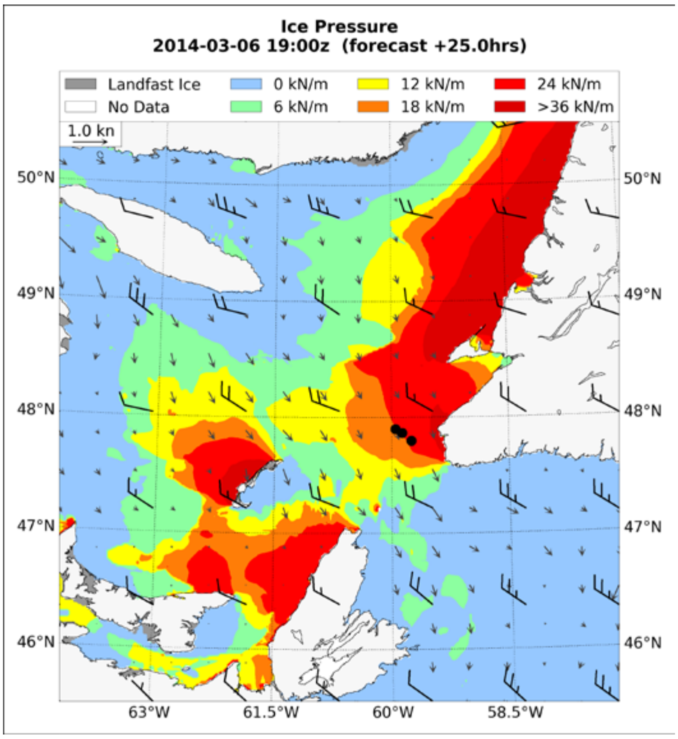

Figure 5: Predicted pressure distribution corresponding to besetting events 18, 19 and 20 (black dots)

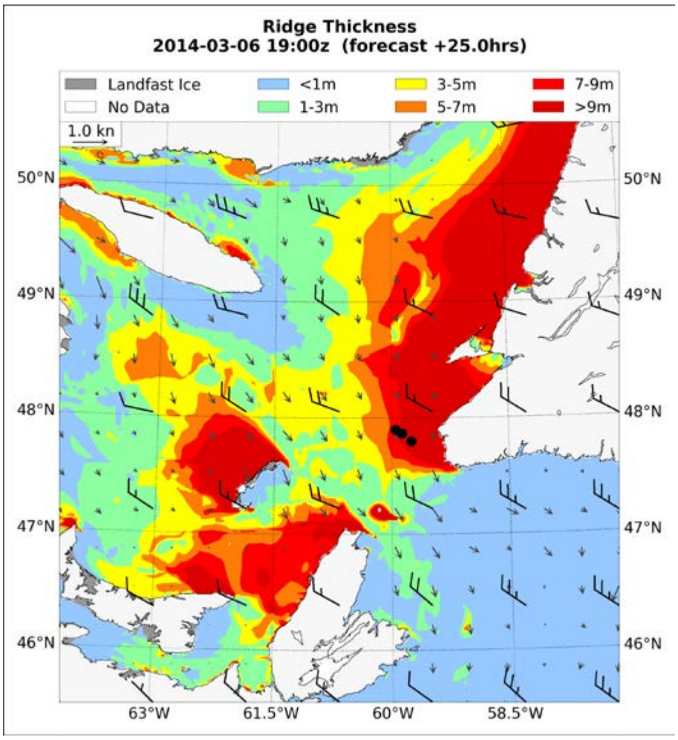

Figure 6: Predicted ridge thickness distribution corresponding to besetting events 18, 19 and 20 (black dots)

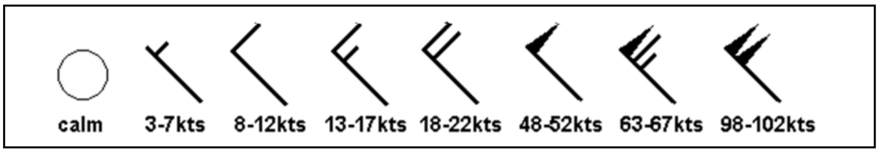

Figure 7: Wind Barbs description

The besetting events obviously occurred within a zone of relatively high pressures and ridge thickness values. It is also evident that onshore wind against the West coast of Newfoundland caused the build-up of pressure and ridging of the ice cover.

Figure 8 shows a plot of the resulting ice pressure versus the shortest distance from the shoreline along a line passing through the locations of the events. A similar plot of the resulting ridge thickness versus distance from the shoreline is shown in Figure 9. As expected both the pressure and ridge thickness increase with proximity to the shoreline.

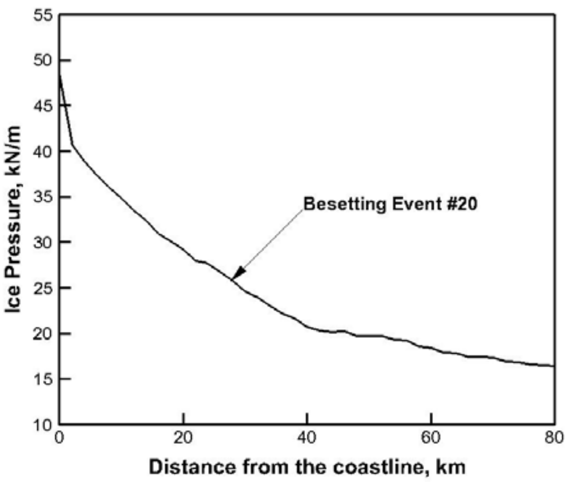

Figure 8: Ice pressure versus distance from the shoreline of West Newfoundland on 6 March 2014 at 19:00Z

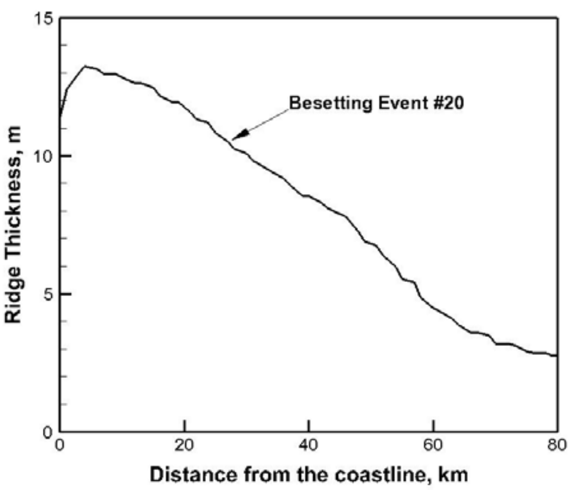

Figure 9: Ridge thickness versus distance from the shoreline of West Newfoundland on 6 March 2014 at 19:00Z

The analysis gives the critical values of the pressure and ridge thickness that correspond to besetting. Events 18 to 20 correspond to pressure values from 24.0 kN/m to 25.7 kN/m. The ridge thickness values are from 8.2 m to 10.5 m. Ridged ice thickness is a combined height of sail and keel depth.

The second example concerns events 13, 14 and 15, which took place in the Strait of Belle Isle on 1 March 2014. The predicted pressure and ridge thickness distributions are shown in Figure 10 and Figure 11, respectively. While ridge thickness is relatively large (Figure 10), the pressures shown in Figure 11 show relatively low values in the vicinity of the beset vessels. Events 13 to 15 correspond to pressure values from 0.6 kN/m to 5.6 kN/m. The ridge thickness values are from 4.1 m to 12.3 m.

The corresponding convergence strain rates are plotted in Figure 12. High strain rates are evident at the location of besetting vessels. Wind also appears to act along a direction parallel to the shoreline. This explains the low pressures (which arise in the presence of onshore wind). In this case the wind produced relatively high shear of the confined ice which, in turn, led to high ridges and triggered the besetting of the vessels.

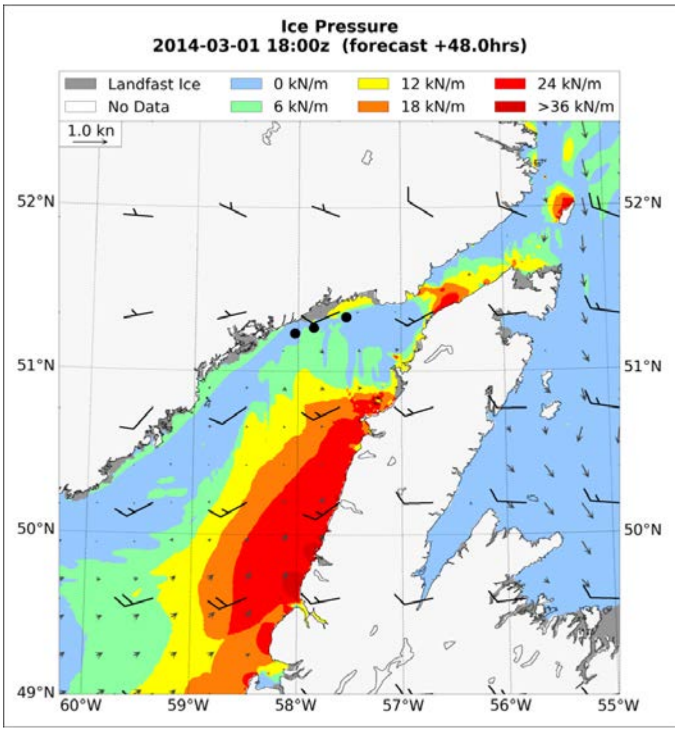

Figure 10: Predicted pressure distribution corresponding to besetting events 13, 14 and 15 (black dots)

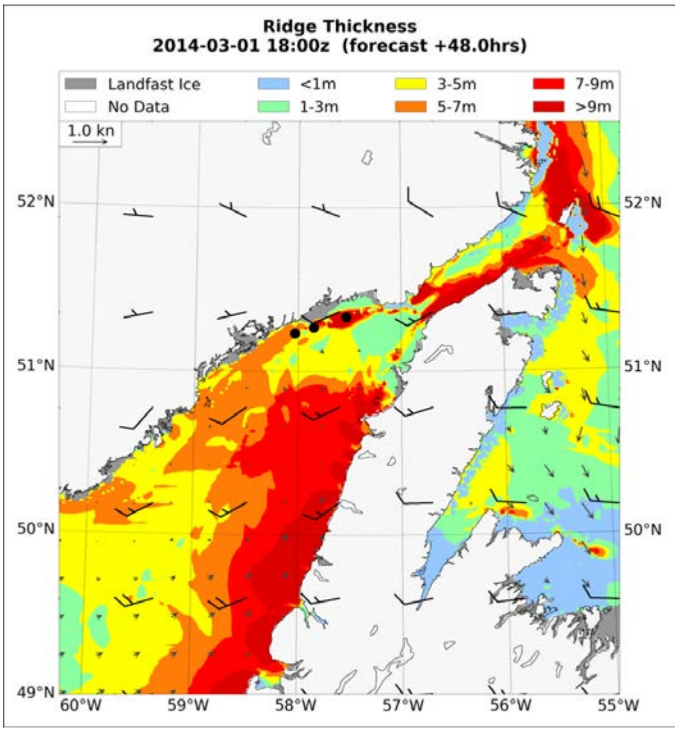

Figure 11: Predicted ridge thickness distribution corresponding to besetting events 13, 14 and 15 (black dots)

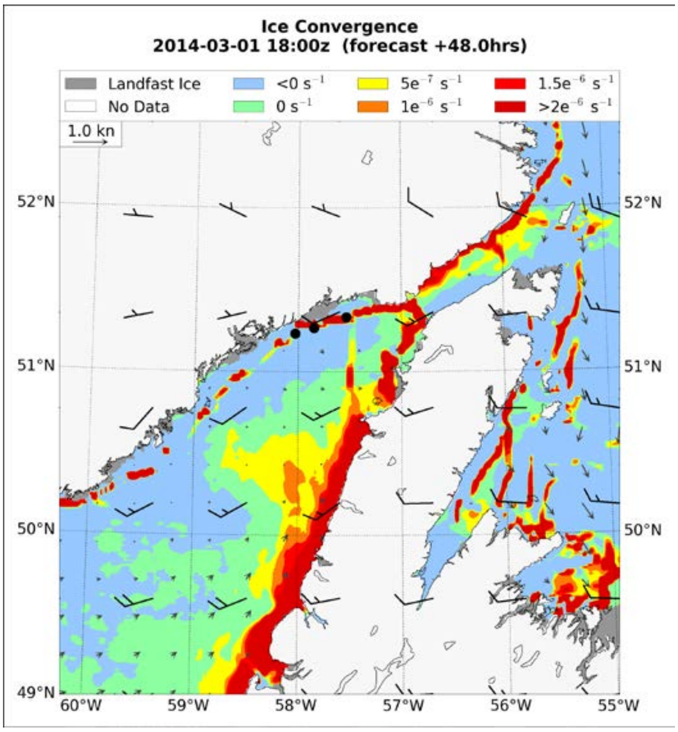

Figure 12: Convergence strain rates corresponding to besetting events 13, 14 and 15 (black dots)

SUMMARY OF BESETTING CONDITIONS AND COMPARISON TO PREVIOUS CASES

The resulting pressure and ridge thickness values are listed in Table *2*. Previous analyses of besetting events over the Gulf of St. Lawrence (Kubat et al, 2012) and Frobisher Bay (Kubat et al., 2013) are summarized in Table 3. They correspond to pressure and ridge thickness values that are within the same range of the present analysis.

As noted in the above section, strain rates and convergence of the ice cover also contribute to the risk of besetting. Moreover, vessel logs and discussions with ship captains indicate that additional factors can play a role. For all incidents reported in this paper, snow cover was relatively large. Brash ice was also observed at several locations. The presence of deep snow and brash ice may significantly aggravate the risk of ice compression and vessel besetting. These issues will be considered in future work.

Table 2: Summary of calculated ice pressure and ridge thickness in the vicinity of beset vessels

Event ID	Vessel_Name	Ice pressure kN/m	Ridged ice thickness (m)	Horse Power
13	CCGS Sir William Alexander	0.6	5.1	8973
14	Bella Desgagnés	5.6	4.1	8320
15	Bella Desgagnés	3.2	12.3	8320
18	MSC Nita	24	8.2	-
19	CTMA Voyageur	24.6	9.5	4590
20	AM Quebec	25.7	10.5	-

Table 3: Summary of predicted ice pressure and ridge thickness in the vicinity of beset vessels – results from previous analysis

Vessel_Name	Date	Location	Ice pressure kN/m	Ridged ice thickness (m)	Ice Conditions Description
M/V Alida Gorthon	March 2005	Gulf of St. Lawrence	9.5	10.0	10/10 Thin FY, significant ridging and heavy ice pressure
CCGS Amundsen	March 2005	Gulf of St. Lawrence	12.5	10.0	10/10 Thin FY, significant ridging and heavy ice pressure
MV Umiavut	July 2012	Frobisher Bay	21.0	5.0	3/10 MY ice; 4/10 Thick FY ice; 3/10 Medium FY ice

CONCLUSION

This paper presented a description and analysis of incidents of vessel besetting in the eastern part of the Gulf of St. Lawrence and the Strait of Belle Isle during the ice season of 2013-2014. A relatively large number of incidents was reported over that season due to severe ice conditions. The listing includes for each incident the date, time, location, prevailing wind, and observations of ambient ice conditions. The distance to the nearest shoreline was also given.

Analysis of three besetting events that took place in the eastern Gulf of St. Lawrence on 6 March 2014 shows that the corresponding ice pressures and ridge thickness values were relatively high. The pressures ranged from 24.0 kN/m to 25.7 kN/m and the ridge thickness values were from 8.2 m to 10.5 m. Ridged ice thickness is a combined height of sail and keel depth.

Another analysis examined three incidents that occurred in the Strait of Belle Isle on 1 March 2014. For those incidents ice pressures and ridge thicknesses were smaller that the above values. The pressures were between 0.6 kN/m to 5.6 kN/m, and ridge thickness values were from 4.1 m to 12.3 m. The analysis revealed, though, that there was considerable shear as wind acted parallel to the shoreline. Relatively high strain rates and convergence apparently triggered the besetting events indicating that the strain rates (or convergence) is crucial in addition to ridging and pressure. It is important to note that this behaviour is not necessarily indicative of all ice compression events in the Strait of Belle Isle. Other events may correspond to compression due to onshore wind.

Results of the present analyses were also compared to previous studies of besetting incidents over other parts of the Gulf of St. Lawrence and Frobisher Bay. The estimates of ice pressures and ridge thickness values were in agreement. Further work will be focused on understanding processes of besetting and verifying criteria for besetting. For example combined effect of ridging and pressured ice, convergence, and snow cover 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 the Gulf of St. Lawrence and the Strait of Belle Isle. Thanks also belong to the Canadian Coast Guard (CCG) Ice office in St. Johns, Newfoundland to Paul Veber, Superintendent of ice operations and his team as well as CCG Captains Dave Fowler and Andrew McNeill for information concerning besetting events in the two regions and feedback on the model performance.

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., 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., 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.

Kubat, I., Sayed, M. and Babaei, H. (2013). “Analysis of Besetting Incidents in Frobisher Bay during 2012 Shipping Season”, Proceedings of the 22st International Conference on Port and Ocean Engineering under Arctic Conditions, 2013, Espoo, Findland, Poac2013-164

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

Montewka, J., Goerlandt, F., Kujala, P., and Lensu, M. (2015) “Towards probabilistic models for the prediction of a ship performance in dynamic ice”, Cold Regions Science and Technology, Volume 112, April 2015, Pages 14-28

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., Carrieres, T., Tran, H. and Savage, S.B. (2002). “Development of an operational ice dynamics model for the Canadian Ice Service,” Proc. Int. Offshore and Polar Eng. Conf., ISOPE, Kitakyushu, Japan , May 26-31, pp. 841-848

Suominen, M. and Kujala, P. (2012). “ Ice Model Tests in Compressive Ice”, 21st International Symposium on Ice, Dalian China, 11-15 June 2012