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Interactive comment on "Toward a method for downscaling sea ice pressure" *by* Jean-Francois Lemieux et al.

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Response to reviewer 2

We would like to thank reviewer 2 for his comments. Based on the comments from the reviewers, we have simplified and made the numerical experiments more uniform. First, the thickness of the level ice is 2 m for all the experiments. Second, the viscous coefficients (see eq. 5 and 6 in the revised manuscript) are always capped using the approach of Hibler 1979. Finally, the numerical approach was slightly modified: we seek the steady-state solution of $\rho h \partial u/\partial t = \nabla \cdot \sigma$, instead of solving directly $\nabla \cdot \sigma = 0$. Although both approaches give the same answer, the new one is more consistent with the stability analysis described in the

appendix. Because of these changes, all the numerical experiments were redone.

Reviewers 2 and 3 both had comments about mechanical closing of the lead behind the ship and that this should depend on the pressure at the boundaries (larger pressure should cause a shorter lead). To address these comments we have done additional experiments and added a new figure (Fig. 11). For the experiments of Fig.11, it is assumed that the length of the lead behind the ship decreases linearly as the pressure at the boundaries increases. Interestingly, we find that over a notable range of pressure applied at the boundaries, the maximum pressure on the ship does not vary much. This is a consequence of compensating effects: a larger pressure at the boundaries causes the lead to be shorter which decreases the stress concentration in the vicinity of the ship, making the maximum pressure weakly sensitive to the pressure at the boundary.

Below, the comments from the reviewers (1) are in normal character. Our responses (2) are in bold while changes to the manuscript (3) mentioned here are also in bold and in quotes.

REVIEWER 2

(1) The work is correctly done, but it may be a little overly enthusiastic in applying the conclusions of the analysis to ship operations in ice. The problem analysed in the paper is one in engineering; the stress field around a void and/or inclusion in a large plate under stress. A ship moving through an ice field under pressure is a much more complex problem.

(2) We agree. Note, however, that we do not consider the case of a ship moving through sea ice but only the case of a ship beset in heavy sea ice conditions. Note that we have added the following sentence in the introduction of the revised manuscript:

(3) "In contrast with studies mentioned in the last paragraph, we focus on ship besetting, rather than on a ship progressing in an ice covered region. We also study the downscaling of sea ice pressure from the km scale to scales relevant for navigation activities (tens of m)."

(1) The work merits publication but the conclusion that the ship creates a stress concentration by breaking a channel might be couched in a more conditional manner. Experience generally shows that if the channel does not close, the ship is experiencing little or no pressure. The rate of channel closing and closing distance is proportional to the ice pressure that the ship feels. A longer open channel behind the ship is an indication of lower ice pressure, not higher.

(2) We understand what the reviewer means here. But our point of view is that a ship beset might have a lead (i.e., a channel still open) behind it and that it is unclear what is the length of this lead. The numerical experiments with the ship should be seen as a sensitivity study about the impact of the lead length and ice conditions in the lead (which are unknowns). For the same large-scale pressure at the boundaries, we argue that the pressure on the ship should decrease as the lead closes (either thermodynamically or mechanically) behind the ship.

(2) To address this comment by the reviewer we have added an additional experiment for which it is assumed that the length of the lead decreases linearly as the large-scale pressure prescribed at the boundaries increases. This is described in subsection 6.2 and the results shown in a new figure (Fig. 11).

(1) Some specific corrections, improvements or comments:

(1) Larger font on some of the plots in figures would help readability.

(2) We have reworked and improved all the figures.

(1) For Fig. 1 add the surface wind scale to panel b).

(2) The reference vector is on the island on the lower-right side of the small domain.

(1) Line 51; the author should be Loset?

(2) Yes. It has been corrected.

(1) Line 175; would it complicate Fig. 2 to also show Mi and Mc on it?

(2) We have decided to simplify the way the digitized ship is defined. The ship is defined by land cells. The boundary conditions are no slip and no outflow. This is explained in the description of the experimental setup (section 3 in the revised manuscript). The masks Mi and Mc are not required anymore. Note that this leads to results qualitatively the same and allows us to draw the same conclusion.

(1) Line 211; Figure 4 a) and b) look very similar to results of finite element analysis of an elastic plate with a crack or void.

(1) Line 113; stress concentration at the tips of the lead and zero normal pressure on the boundary of the lead translate to the maximum and minimum pressures in Figure 4 c). I looks like the probability is greater than 1 for pressure 10 kN/m, check the y-axis scale. For the 10 m

grid size the 28 cells that border on the lead versus the 5122 - 40 cells in the ice field give a 28 / 262104 (1.07e-04) probability of zero pressure. This doesnt seem to agree with Fig. 4 c).

(2) This is due to the fact that we use small bins (of 0.25 kNm^{-1}) and show the probability density not the probability. For figures 3 and 4, we have verified that the sum of the PDF times the bin width is indeed 1.0.

(1) Figure 5 presents results of experiments with refrozen lead and ridged ice in addition to the 1 km lead. Not surprising is the result that there is no change of zero stress on the lead boundary or stress concentration at the tips of the lead. It seems that doubling the ice thickness from 1 to 2 m, Figure 4 versus Figure 5, the maximum stress at the tip of the leads is increased. Any explanation? Is it fair to compare maximum pressure in Fig. 6 b) with P* = 20 kN/m2 for a 1 km long lead with Figure 5. Both are for 2 m ice thickness.

(2) For both figures the thickness of the level ice is 2 m. The confusion is due to the fact that the validation experiment done just before the one for Fig. 4 was conducted with a constant thickness of 1 m. To improve the clarity of the manuscript, that experiment was redone with a thickness of 2 m. In fact, the thickness of the level ice is 2 m for all the experiments of the revised manuscript. Fig. 4 and Fig. 5 (Fig. 3 and Fig. 4 in the revised manuscript) do not show the same maximum pressure because the leads do not have the same width.

(1) For Figure 8 add a label to the x-axes, resolution and units of m. The maximum pressure of Figure 8 a) agrees with that in Figure 5 c), about 38 kN/m in both cases.

(2) Done.

(1) The pressure field in Figure 9 seems reasonable given that a relatively stiff object (the ship) is placed at one end of a long cavity (lead). Your analysis only considers pressures, the ice also deforms and the further from the tip of the crack (lead) the greater the closing of the lead and thus higher lateral pressure.

(2) We agree. The limitations of our experimental setup are discussed in the conclusion of the revised manscript.

(1) The results presented in Figures 9 and 10 are quite consistent with the analysis model of a stiff object (ship) at the end of an elongated cavity (lead) in a more compliant medium (ice field). The results are consistent with stress analysis around inclusions. The analysis is correct, but it may be premature to draw conclusions about applying the results to operation of a ship in pressured ice.

(2) We have added a few sentences in the conclusion to describe the limitations of our numerical setup.

(1) There is literature in the Arctic engineering field that considers scale effect of ice pressures. The authors could look to this literature as they continue working in this field. See for example;

Sanderson, T.J.O., 1988. Ice Mechanics Risks to Offshore Structures. Graham and Trotman, London, UK. Croasdale, K.

Croasdale, K.R., 2009. Limit force ice loads - an update. Proceedings 20th POAC Conference, Paper POAC09-030, Lulea, Sweden.

(2) We thank the reviewer for these references.

Jean-François Lemieux