We sincerely thank the reviewers for their insightful comments and constructive feedback. Their suggestions have significantly improved the quality of our manuscript. We appreciate their time and effort in reviewing our work. Below, all answers are written in cursive blue next to the original comments in black.

Answers: Reviewer 1

General Comments

Thanks for the opportunity. I enjoyed reading this manuscript.

This paper describes simulations conducted with a three-dimensional DEM-FEM sea ice model to study the dynamics of ridging. The study is grounded by a comparison of the model performance at laboratory scale with an experiment performed by Tuhkuri and Lensu (2002). The model simulations are then extended to a larger scale to see how the process scales. The authors draw conclusions about how the ridge force should scale with ice thickness in a three-dimensional setting, and about how ridge behavior might follow Cauchy-Froude scaling across scales. While I think the authors need to add some details, clarify some assumptions and couch some conclusions more carefully, their methodology is sound and the manuscript is well written and organized. Their conclusions are largely justified, in some ways provocative and worthy of publication.

Science related questions (simply in the order in which they occured to me in reading the manuscript)

I think this experiment applies to unconsolidated ridges. If that is the case, it is worth noting somewhere near the top. *- Correct. We added a sentence in the first paragraph of the introduction.*

Line 35: Definition of Full-scale. My understanding is that ridges form over a variety of scales. So, I am not clear on what 'full scale' specifically means here. A reference would be useful here, if there is observational evidence for a particular 'scale of a natural ice ridge'. From reading, it seems that for this manuscript's purposes full-scale is 10 times laboratory scale. But this should be stated upfront with some justification for the choice. *- Here 'full scale' ridges are assumed to be representative of ridges formed from typical level ice thicknesses in nature. Thus, we refer to the scaling of the thickness of level ice. Tuhkuri and Lensu (2002) chose a scaling factor 10 for their laboratory scale experiments, thus we used that factor. This information is added to the respective line.*

Line 51: DEM or FEM-DEM? I would not describe the FEM-DEM method being used here as 'rather standard', the beam component is more sophisticated than most that I am familiar with. Throughout the manuscript, the model is called a DEM. But I am not sure if DEM with FEM joints is referred to elsewhere in the literature as DEM. *- This is now addressed in Section 2. The terminology for particle-based techniques remains imprecise, with DEM, FEM-DEM, and the bonded particle method (BPM) often used for similar approaches. We opted for DEM but now clarify that term FEM-DEM is also used for models with embedded finite elements.*

Line 84: Do the authors think that the Tuhkuri and Lensu experiments captured 3-dimensional aspects of ridge formation? From the arguments later in the paper regarding the ridge force scaling linearly with h, it seems that 3-d behavior is already exhibited at the lab scale, if it is 3d behavior that leads to linear scaling of the force with h. *- Yes, we think that the three-dimensional behavior is already shown in the laboratory-scale experiments, but on a smaller range of ice thicknesses which complicates the analysis of the force-thickness relationship. We added the description 'three-dimensional' to the experiments.*

Line 93: It would be useful if the authors would comment on the implication of having one side of the ridge, being a thick unbreakable sheet as compared to two breakable sheets of equal thickness. I understand that with equal thicknesses the simulated ice rafted too much. I would like to know why that was the case. But also, this setup seems like an ice-structure interaction rather than a ridge formation between sheets of ice. For example, this setup does not allow a sail to form in addition to a keel. I imagine this might be a fair idealization as a first shot of handling this problem in 3D. I would just like to hear more justification for the setup. *- The set up is now similar to Hopkins (1998), where thinner lead ice ridges against a thick ice floe. We do not yet have a clear answer to the question related to extensive rafting. During development, we tested, for example, uneven thickness distribution across the floe as it was featured in the experiments to facilitate ridging. This proofed not to be as fruitful as hoped as it introduced more variables into the analysis of the results, and introduced artificial weak points and made our ice fail in an artificial manner.*

Line 94: Can this be read to mean that you chose the aspect ratio of your elements to get simulated ice blocks in the rubble of the ridge that had the right characteristics compared to field observations? *- We reworded the sentence in question. We chose the aspect ratio so that it was possible for the ice to fail into blocks that could have the aspect ratios observed in the field. Discrete element size (defining the smallest fragment size) was, thus, chosen so that pieces could reach aspect ratios down to 1.5 observed in the field (Høyland, 2007).*

Line 100: Please explain why an ice velocity of 0.05 m s-1 is used rather than 0.01 m s-1 Was it for computational efficiency or due to other considerations? *- Yes, the velocity was chosen to cut down the wall-clock time of our simulations and is added as reasoning to the respective sentence.*

Line 112: Please clarify if 'l' in the Froude number is meant to be a vertical length scale, horizontal, or if they're considered comparable. *- The length scale l refers to horizontal and vertical length scales likewise. We added this for clarity.*

Line 126: From the earlier statements one would conclude that the thickness of the rigid floe affects the ridging force. In the LS it was chosen to be larger than the moving floe, because there was excessive rafting if it were not. So, this statement seems in conflict with other statements, unless I'm not interpreting it correctly. Intuitively it seems like the 'l' in the Froude number might be related to the thickness of the unbreakable sheet. *- The thickness of the rigid floe does not influence the forces, it just influences the likelihood of the ice to ridge or raft. We added this to the mentioned sentence.*

Line 142: I would not say that 'F fluctuates around a mean value' in the second phase of the experiment. To my eye it increases linearly in both the experiment and in the simulations (at a lesser slope). Given this, I'm not sure how the standard deviation is calculated for the figures, and if it is representative. By eye it looks like the simulations have notably greater standard deviation than the experiments unless you include the linear trend as part of the std. *- Based on the other reviewers suggestion, we looked into the distinguishing of the phases via applying running means to the data and then comparing the slopes of these running means. For the simulations, this analysis shows a clear change in slope and thus, we argue that the splitting in stages is justified. For the experimental data, we decided to not split the data in stages. Thus, Figure 3 changes in the manuscript and we add additional analysis of the stages.*

Line 156: The plateau in W* is not visible to me. *- We agree that it is not a constant plateau, but rather periods where ridges do not grow in width. We adapted the text accordingly.*

Line 180. I think what has been demonstrated is that the model follows Cauchy-Froude scaling, but this does not necessarily mean that nature does. This conclusion should be stated a bit more carefully. *- We agree and adapted the mentioned section.*

Line 191-197. I think this is an interesting point, potentially deserving of a figure if the supplementary simulations could supply one. *- We added one additional figure to add to the discussion of non-simultaneous failure. The new figure shows snapshots of two simulations with different ridge length L to highlight the non-simultaneous failure.*

Line 222-225. Related to my previous (Line 191) comment. I do not fully understand the basis for the statement starting on line 225. I take it to mean that the ridge length was varied in FS experiments, and at a 30:1 L/h ratio, non-simultaneous failure behavior was observed. But would the non-simultaneous failure behavior differ at 100:1 or 1000:1? The author's again use the term full-scale here, but might not things change at floe scales larger than the 'full-scale' considered here. For that matter the simulated LS scale gave results quite similar to the FS, which returns to my earlier comment (Line 84). It would be good if the authors could disentangle their conclusions a bit better here with regards to scale and 3d vs 2d behavior. *- The ratio of 30:1 is the minimum we suggest to achieve non-simultaneous failure. We assume, that there is no upper limit for this behaviour. Additionally, our simulations are not large-enough (in spatial dimensions) to argue for a maximum limit. We can also not exclude that potentially other processes limit ridging forces on larger length scales. The last paragraph of the discussion is intended to highlight the possibility of experiments in large ice tank facilities, without the need of scaling the parameters to laboratory scale. We hope that with the clarification of what full scale refers to and some rewording, this statement also becomes more clearer.*

Technical corrections

Line 3: suggestion: 'at' large scale *- Changed.*

Line 6: suggestion: 'along the contact interface' rather than 'across the ridge length'. *- We appreciate the suggestion, but will continue to use ridge length as it is used throughout the manuscript.*

Line 13: no need for 'Thus' *- 'Thus' is removed.*

Line 21: 'The' first *- Changed.*

Line 24: ambiguous phrase. What are the different processes involved and how do they differ from 'the process itself'? *- Different processes are, for example, the failure of the intact ice floe and the redistribution of ice. With 'the process itself' we tried to highlight, that we explicitly simulate ridging. We adapted the sentence.*

Line 81 possibly replace 'of the amount of ice pushed', with 'the distance the ice was pushed'? *- Changed in this and all other locations.*

Line 82: Were the 3 experiments in each of the four sets (S1..S4), replicates of each other? *- Yes, all three experiments within each set used the same ice sheet and thus, have similar material properties. We added some words.*

Line 145: At what point in the experiment and simulation are the profiles taken delta=4m? 10m? Line 158 suggests it's 'at the end of the experiment' but should probably say that here. *- The ridge profiles from the experiments are measured at the end of each experiment. We agree and added context.*

Line 173: 'conducted at different scales' *- Changed.*

Figure 6, etc. The terminology 'LS simulations to FS' isn't explained anywhere. Although I'm guessing it means that the LS variables are CF scaled (Force is multiplied by λ^3 for example). *- Yes, this is what we mean with 'LS simulations to FS'. We changed the caption of all Figures where this description appears.*