Spectral attenuation of gravity wave and model calibration in pack ice
Cheng et al
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This paper documents a study of the attenuation of sea surface gravity waves by sea ice. The study involves the use of Sentinel 1A SAR imagery to extract first a wave number direction spectrum within a region of thin sea ice in the Beaufort Sea. Physical laws are introduced that use the SAR data to get the apparent wave attenuation and wave attenuation due to ice effect. A calibration scheme is then introduced that takes the modeled wave frequency spectrum, generates the wave attenuation due to sea ice, and then compares these values to the data. The calibration scheme is used to find optimal model parameters of the shear modulus and molecular viscosity to best reproduce the observed conditions. Optimal values are presented along with a detailed discussion of how they compare to previous studies. The detailed analysis of wave attenuation required to calibrate the wave model has then also been used to discuss the physics in play. A particular emphasis here, and through the analysis is on differing characteristics within the ice pack before or after lead formation. The authors do well to show the role of their work within the science of the highly complex system of wave ice interaction and the benefits of using the analysis and calibration presented. After the authors address points i have below regarding the documentation of the papers methodology I suggest it is fit for publication.


Whilst this paper well documents the technical parts of data analysis and model calibration, and throughly discusses the success, limitations and implications of their results, it is severely lacking in any general description of the methods used. I had to read the entire paper, and all the specific details of the methods before I could understand the general incentives and methods of the study. I have suggestions below for how to improve the paper to address this. Once I had worked out what methods of the paper were the various sections of the paper fell into place and the science behind the paper was well founded and thoroughly discussed. However, I still have some key questions.

1)  The paper does not clearly explain the reader the format of the data used and the extent of analysis performed for this study. Do you take the wave energy spectrum from Stope 2018b or the wave number direction spectrum? Or you start with the raw SAR imagery and repeat the same analysis as before? I spent much of section 2 asking myself this. Also the format of the introduction adds to this confusion, whilst it starts with 4 paragraphs of overview, paragraph 5 is neither an introduction to the area of interest, or a description of the data used in this paper. The rest of the paper has a similar ambiguity between the the data sources for this study, the data processed as part of this paper and previous studies that are being cited for comparison.

2) There is little description within the paper of what is being documented by each section. The brief outline on lines 103-109 is again ambiguous to what is being performed. For example 'site description and wave characteristics are depicted in section 2' does not inform me as to whether section 2 contains description of the data used in the study and how you processed it, a summary of previous studies of the region and what they found, or even a description of a model run of the region. Section 2 itself starts immediately with a definition of kr, which is clearly done, but there is no description at all of whether kr in this study is an original data source collected by the study or a previously collected data that is being analyzed here. This lack of overview is present in near all of the technical sections with the paper. I suggest adding a clear paper overview of the form; data was obtained from (here, here, etc) that we analyze thusly to extract this information. We then ran these models and using this scheme and the previously documented data we calibrated these parameters. This information also needs to be clearly defined at the beginning of each section. Once I had worked out this information for myself I was easily able to understand the technical parts of the study, which are well written.

3) There are two key values used in this study, apparent wave attenuation and the wave attenuation due to ice effect. The notation for these needs to be changed. kr is a wave number spectrum, alpha is the associated wave attenuation, but ki is just a wave attenuation whilst previous notation leads me to think it will also be a wave number. While the methods used to get these values are documented, there is no physical description of what these values represent and

why you are interested in them. A paragraph in the introduction introducing these physical values, and the other values considered in this paper (dominant wave number, wave energy spectrum for example) will greatly help a non-specialist reader. Section 3 needs an introduction explaining the differences between kr and ki, and as mentioned before, the data you use to obtain these values. Also the wave attenuation due to ice effect ki and ki^m need to have clearer definitions. I see that you have used ki as the modeled attenuation, and ki^m as that data derived value. This notation needs adjusting, the use of superscript m to define the value that is not modeled is confusing. Section 3.2 will benefit from a definition of ki at the beginning, as currently the reader has to wait till the end of the section to understand what the aim of the presented method is.

4) I suggest that the introduction section needs restructuring and expanding upon. Currently there is one paragraph on the place of wave sea-ice interaction within climate science and then a very technical description of one wave model. The paper would benefit from having first the next paragraph that explains the uses of wave forecast models, and then the technical description of WaveWatch follow. The final paragraph of the introduction needs to moved to a dedicated data description and expanded upon. It is currently unclear what SAR data used in this study is new and what has been previously published. If the SAR observational data and analysis or processing has been previously published, then a clear section citing this publication and describing the data is needed. If there is novel data work in this study then this needs to be clearly stated and the technique and data clearly described.

Specific edits:

14 'wave propagation' this is the first sentence in the paper. Please be more explicit in which waves you re discussing. Consider an additional sentence introducing ocean surface gravity waves
14 'fall 2015' pleas give a more accurate time. The study is for a single day i believe.
21 - 24 this sentence is very long. I had to re-read several times to understand what became lower where. Consider splitting.

35 These citations are 10+ years old now, the reduction and predictions have changed a lot in these 10 years.

43 Wavewatch is first introduced with a very technical description. Can you first give an overview of Wavewatch? Its uses and the incentives behind its creation. A brief description of its main physical constructs will also be useful to the reader. The ice effects as modeled by WaveWatch are described here, but I'd like to see how these ice effects sit within the whole model.

54 An introduction into how wave forecast models work would be useful here. I'd like to know how to use a wave forecast model in general, then I can better understand the context of your work in the wave sea-ice interaction aspect.
58 Here and above you mention IC3 (and IC5). You mention that they both store and dissipate mechanical energy but what are the differences between them.

77 This next paragraph needs moving to a dedicated data section. Within this section it needs to be made clearer what data was used as part of this study and why. Also I find it difficult to tell from this paragraph which data was collected together in a previous study and which data was brought together for this study. Those which were brought together here needed to be expanded upon. The benefits and limitations of each data need to be better discussed. Currently the novel method of Ardhuin 2017 and Stopa 2018a is well described, as are the reasons for its use in this paper. However there is less description for the Buoy and ice concentration data. Due to the data all being plotted together in figure 1, I am assuming that this combination of data sources is novel for this study. If this is the case please state so, and explain why the data have been chosen. If however these data have been combined before (which then explains why they are described in the introduction) then citations/descriptions of findings are needed.

Figure 1 There is no (a) label in the figure. Can you show on pane (a) how (b and c) colocate?

106 What is the methodology of calibrating IC3? Is it used extensively in this paper? If it is then a summary of the equational from is needed. If this is complicated then consider an appendix for the equations. If it is still too complicated then a paragraph explaining how it works with relevant citations is needed.

Next: a full description of wave energy spectrum E(f,theta) is needed. Either the equational form of E() needs to be added, or how it is produced by the model and how it is extracted from the data set. The source of the various E() used in this paper is a current theoretical hole for me when reading it. As it is a key value for methods of this paper, consider a paragraph in the introduction explaining how the energy spectra is calculated from observations and treated within the model you are calibrating. Some background science on ocean surface gravity waves are described, including what the wave energy spectrum is would be a useful inclusion for this paper.

Also: At this point in the paper I don't want to have to dig into section 4 to discover what modification you have had to make to the methodology of Cheng 2017. At this point I flipped to section 4 and searched for both the 'Cheng' citation and the string 'IC3' within the paper and it was still unclear to me how the methodology of Cheng 2017 worked, why you had to modify it and what those modifications are. A description of all these aspects of this study is needed, either here, or at the beginning of section 4

I started reading this paragraph hoping to understand the incentives and aims of this study and what methods were used. The paper is unlikely to have been written in a linear fashion, but please remember that the reader will read it in a linear fashion, and is likely to be unaware of all the previous work on this topic, the data you are using, the model you are calibrating and the techniques you are using to calibrate it.

110 I am assuming that this section is a description of the data used in the study. However you give no indication of this in the text. I start by asking 'the wave number spectrum retrieved from where?'. This does not get answered, so the following information is very difficult to understand.
112 This range suggests you are talking about figure 1? I should have to work this out myself.
113 fitted to which E(f,theta) from where?
115 I can't understand the direction sum of E(kr,theta) when you have not described where kr comes from and what E(f,theta) is and where that comes from. Was there a previous analysis performed to get E(f,theta)? Was that done as part of this study or previously?
117 Again I am asking whether this work of extracting kr,dominant is from this study. Was it previously done as part of Stopa 2018a/b ? Please inform the reader what work was done with the data for this study.
118 Difficult to see the variation with concentration in the figure.
120 Again difficult to see the decrease with kr on the figure. Also it is unclear what you are referring to with 'wave propagation direction'.
122 what is the meteorological convention?
126. Please give a value here for lambda_c and/or the associated limit for kr.
135 Is the frequency f estimated for all kr?

Section 3
Again this section really needs an introduction. I had to read the whole paper before I could make sense of it. Even so I still have some major questions that are easily answered by reading the paper.

157 please define the 'Pearson correlation coefficient'.
196 Power spectral density of what? I see this is mentioned in the figure, but please also define it in the text.

Figure 4. It would be nice to have an overlay square in figure 1 showing how the left column of figure 4 aligns. Please also note in the caption that the centre column is generated by pairs of data, whilst the rightmost comes from individual points.

224-229 I suggest that a version of this paragraph come at the beginning of the section. This would much ease the reading of this paper. Here I can understand clearly which values you are obtaining from where, why you chose them and what you intend to do with them. However the

picture is still not entirely clear. This style of explanation is needed for every section and sub section.

259 and figures 3 and 5. A better description of these two figure and what you wish to show with them is needed. The caption for figure 5 is not sufficient. Saying that alpha vs kr is similar to ki^m vs kr is misleading, as alpha and ki^m are not similar physical quantities.

266 Here you say that kr and ki re solved for, but elsewhere in the paper kr is given as a data source whereas ki is a model variable. Is kr now referring to something else?

278 k = kr + i ki, how are you combining a wave number from data and an attenuation factor?
279 is the alpha here the same as in equation 1? Are you using alpha from the SAR data source in these equations to calibrate the model? If yes, then clearly say so, if not, then an alternative notation is required.
280 This sentence is an important one for this paper and needs to be clearly stated in the introduction.
284 This information would be better suited at the beginning of section 4 , before equations 5.
285 are you actually running WaveWatch as part of the calibration scheme? If so which out put variable are you taking for the calibration? I am assuming that you take the model out put frequency spectrum f, and use the relevant equations from 5 to create the required ki kr.
286 You have now introduced kr^m. What is this symbol for. The m would indicate 'model' but the opposite is true for ki. However previously kr was from a data source. Please clear up all the ki kr notation. Avoid using ^m if you're not going to use it to indicate 'model'
Equation 6 Is the subscript 2 supposed to be an exponent? If not what function does it refer to?

308 I would like to see a figure of the clustering of retrieved parameters. The table plus description does not give enough information.
311-312 Sentence unclear please revise
314 Ah I see the scatter plots are in the supplementary material. They would be a worthwhile inclusion in the main paper
Table 1. Please expand the caption to say what these numbers are. They are the results of the model calibration I assume?
324 Again put the scatter plots here, they are interesting.
Figure 6. Pane b illegible and either needs redrawing in color, omitting 90% of the lines, or even not including in the paper. Caption you mention 'the data' plotted in plot a, which data? from where? section 3 I guess.
350 It is important to also mention here the limitations of using a numerical (or a more specific description of the algorithm used) parameter search/optimisation scheme. For example: no. minima for equation 6 could be found for the data at these locations.
366 I find the discussion of ki here confusing due to the mixed notation used. Why not ki^m? Also here you talk about ice effect wave attenuation, but earlier you talk about kr,dominant which is a wave number. Please can you clear up the notation for these.
394 You here introduce a data mask, though this was not previously mentioned. Does it relate to the previous sentence on data quality? In which step of the data processing was this mask used?
399 Which function are you talking about? Equation reference?

438 Can you point me back to the results to show the difference in dispersion.

Appendix
I suggest moving the appendix to the main paper section. The results here appear to be as worthwhile as others discussed. Are these results from another study and you include them in an appendix for reference?