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Discussions

Interactive comment on "Brief communication: Pancake ice floe size distribution during the winter expansion of the Antarctic marginal ice zone" *by* Alberto Alberello et al.

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R2A: The authors acquired images of pancake ice floes from a ship-based camera on July 4, 2017, in the Antarctic marginal ice zone at about 30E, 62S. An automatic algorithm identified pancake ice floes in the images, whose size distribution was then plotted. They found three size regimes: diameters 0.25 to 2.3 meters, 2.3 to 4 meters, and 4 to 10 meters (see Figures 3b and 3d). They conjecture that the small regime is driven by the growth of pancakes from frazil ice, and the large regime is driven by the welding together of pancakes.

AA: We thank the reviewer for his/her comments and constructive criticisms. The manuscript has been modified to address the comments and detailed answer to each of the comments is given below.

R2A: This paper is basically a report of data analysis. The conjectures regarding the small and large floe regimes are just that – conjectures – without supporting evidence. I have questions about the analysis, detailed below, as well as other comments. In my opinion, this paper needs major revisions.

AA: We agree with the reviewer that this brief communication reports data analysis, however, this overlooks that the present work increases knowledge on the subject as it provides the first quantitative measurements of pancake ice floes in the Antarctic marginal ice zone, as well as the first assessment of the pancake ice floe distributions (for area and diameter), based on a very large number of floes (results are statistically significant). We also compare with distributions traditionally proposed for sea ice and assess floe shape. Moreover, we point out that our conjectures (as we ourselves define them) need to be verified, and that they are based on previous work of Roach et al. (2018), in which these mechanisms are studied but without discussing the pancake ice floe size distribution and shape.

R2A: Page 1, lines 9-10. The floe size distribution (FSD) was first integrated into a sea-ice model by Zhang et al in 2015 and 2016.

AA: We added references to Zhang et al. (2015,2016).

R2A: Page 1, lines 12-15. The authors imply that there is not much "field data" available on floe sizes. I assume this refers to in-situ data such as that acquired from a ship in the ice. But there is plenty of remote sensing data, and it's not clear to me that field data is any better than remote sensing data, so the lack of field data does not seem like a shortcoming. The only advantage I can see to field data is the higher spatial resolution – in this case, the ability to identify floes as small as 0.25 m in diameter. But this advantage is not mentioned by the authors. Perhaps one of the values of this study is that it identifies floes that are smaller than in any other study. The fact that it consists of data collected in the field is not in itself a selling point, in my opinion.

AA: We understand the possible misunderstanding with the use of “field data”. We have clarified the different role played by in situ observations of smaller floes in the Southern Ocean and that there are no previous observations of pancake ice in this region, as their small scale makes them difficult to resolves from space.

R2A: Page 2, lines 2-4. This is really an oversimplification. It is certainly true that observations do not support a unique scaling exponent of the FSD – that was the subject of an entire paper (Stern et al 2018) which is cited by the authors later but not here. Only some of the 18 studies examined in that paper report "two distinct scaling exponents". The authors imply that those exponents are given by Toyota et al 2011, but other studies have found different exponents over different ranges, and some have reported that a single exponent characterizes the FSD.

AA: We rephrased the sentence to clarify this concept, also using Stern et al. (2018) as the main reference. We note that no previous works refer to pancakes, and we have further emphasized this as a novelty of our study.

R2A: Page 2, lines 5-6. "The validity of power law scaling has not been demonstrated yet and its adoption is mostly justified by the wide range of floes diameters". Actually the validity of power-law scaling has been demonstrated in some cases, and I have never seen a paper that claims that power-law scaling is justified by the wide range of floe diameters. The papers cited by the authors don’t make that claim.

AA: We thank the reviewer for helping us to clarify this point. We rephrased the section to emphasise that the alpha = 2 exponent is not universal, and the power law behaviour is not verified in all the cases reported in the literature. We also added references to Horvat & Tziperman (2017) and Herman et al. (2017) to strengthen the statement.

R2A: Page 2, lines 6-7. "Scaling parameters are typically estimated on the log-log plane with a least square fit" – it would be good to note that such a procedure leads to a biased estimate of the scaling parameter.

AA: This note has been added.

R2A: Page 2, line 12. "Existing observations do not provide quantitative descriptions of the floe size distribution for pancake ice floes", but line 19 says "Shen and Ackley (1991) reported pancake floe sizes..." so doesn't that contradict line 12?

AA: We have clarified that Shen & Ackley report a characteristic diameter only, i.e. not the floe size distribution as done in this work.

R2A: Page 2, line 26. "To our knowledge, the pancake floe size distribution has yet to be characterized." Take a look at: Parmiggiani, Moctezuma-Flores, and Guerrieri, Identifying pancake ice and computing pancake size distribution in aerial photographs, Proc. SPIE 10422, Remote Sensing of the Ocean, Sea Ice, Coastal Waters, and Large Water Regions 2017, 104220K (13 October 2017); doi: 10.1117/12.2277537

AA:. We rephrased the statement to include this reference. However, we note that the paper only focusses on development of a processing scheme for pancake floe detection. Only one image is analysed and results are reported in terms of pixels (no dimensions are reported), so the paper does not provide a quantitative characterisation of the pancake ice distribution, as we have done in this study over a larger region.

R2A: Section 2, Sea ice image acquisition. All good, nice work. I do have one comment: page 3 line 14 says that morphological image processing was used "to improve the shape of the pancake floes." I don't think "improve" is the right word! How about "to smooth"?

AA: Morphological operations are indeed used to improve or enhance the identification of the floes. We made no change in response to this comment in the manuscript but, to clarify the processing technique, we added a full list of morphological operations we adopted in the new supplementary material.

R2A: Page 4, lines 15-17. There is more than one way to define the floe diameter

D. The first study of the FSD, Rothrock and Thorndike 1984, used the mean caliper diameter.

AA: A note that the caliper diameter can be used as the characteristic dimension has been added.

R2A: Page 5, line 5. "a power law N(D) proportional to Dˆ-alpha as a benchmark and using the maximum likelihood method". Here, N(D) is the cumulative distribution function (CDF), but the maximum likelihood method yields the best-fitting exponent of the probability density function (PDF), not the CDF. If the authors used the maximum likelihood method to obtain the best-fitting exponent of the PDF (call it -beta), then they would have had to convert it to the exponent of the CDF (via -alpha = -beta + 1). Did they do this?

AA: We rephrased the statement to make clear that we used the procedure described in Stern et al. (2018), which is based on Clauset et al. (2009).

R2A: Page 5, lines 6-8. The authors note that the range of floe sizes for the large regime (4 to 10 meters) spans less than a factor of 10, and therefore "the estimation of the scaling exponent for D > 4 m is rigorously not applicable". Well, the same is true for the small floe regime (0.25 to 2.3 meters) – it spans less than a factor of 10, so apparently the estimation of the scaling exponent for D < 2.3 m is rigorously not applicable either. Doesn't that destroy the basis of the floe size analysis here?

AA: We rephrased to indicate that also in the small floe regime the range is less than a decade. However, this would only 'destroy' our analysis and findings if we were advocating that the distribution is a power law, when, in fact, we emphasise that it is not a power law.

R2A: Page 5, lines 12-13. "the steeper slope indicates that their size is governed by different underlying physical mechanisms." Or by the finite size effect, in which larger floes are under-observed because the finite size of the images makes it less likely to see larger floes in their entirety. This has been described in the literature. Can the finite size effect be ruled out here?

AA: Indeed, finite size effects can be ruled out, as the floes for which the change in slope occurs ($\sim$4 m) are considerably smaller than the image footprint ($\sim$28 m x 28 m). Even the largest floe recorded ($\sim$10 m) is less than 2 times than the dimension of the image. Therefore, we conjecture that the clipping at $\sim$10 m is due to a physical mechanism.

R2A: Page 5, Figure 3. It looks to me like Figure 3b (the area distribution, a(D)) is not compatible with Figure 3d (the PDF, n(D)). In 3b, the area distribution increases as D increases, from D=0.2 to D=3. In that range, alpha_S = 1.1 so alpha_S + 1 = 2.1 so the PDF n(D) scales like Dˆ-2.1. The area of a floe scales like Dˆ2. So the area distribution a(D) should scale like Dˆ(-2.1 + 2) = Dˆ-0.1. That means the area distribution should DECREASE as D increases from D=0.2 to D=3. But Figure 3b shows a(D) increasing as D increases over that range. Is there something wrong with the plots, or with my analysis?

AA: The reviewer's analysis is correct and we understand that the estimation of the coefficients and their application to the area distribution require further explanation. We note that the value of the exponent depends on the range over which computations are made, and, in this regard, the value 2.3 m is arbitrary. Since the CDF is concave-down, by reducing the range over which the exponent is estimated a lower slope can be obtained (eventually the exponent might drop below alpha_S = 1, thus leading to an increasing area distribution). Moreover, the discrepancy between a power law behaviour for the number distribution and the measured area distribution further demonstrates that the underlying number distribution is, in fact, not a power law (as also indicated by the goodness of fit test). We now explicitly point out this apparent discrepancy: "We also note that an increasing alpha(D) in the small-floe regime (see Figs. 3e) is inconsistent with a power law with alpha_S $\geq$ 1 and, thus, the area distribution confirms that the underlying number distribution is not a power law."

R2A: Page 5, line 13. "the majority of the large floes are composed of two or more welded, pancakes." Does this explain some of the scatter in Figure 3a, in which a welded pair of pancakes would have a large major axis (D1) compared to minor axis (D2)?

AA: We can't say with certainty if the scatter is due to welding. However, we note that the scatter is fairly homogeneous across all diameters in the range, whereas welding dominates for large pancakes only. This information was based on visual observations and we now provide a sample video of the acquired images as supplementary material to help the reader.

R2A: Page 6, lines 16-18. It's commendable that the authors applied a goodness-of-fit test, and that they admit that neither the small nor the large floe size regime follows a power law distribution according to that test. This result is actually not too surprising, given the very small size ranges over which the power laws were fit.

AA: We point out that the choice of fitting and testing a power law derives from the traditional sea-ice approach, well knowing that the range of diameters is small. A comment has been added in the revised manuscript.

R2A: Page 6, lines 19-20. "N(D) possesses a slightly concave-down curvature across all the diameter ranges (in a log-log plane)". This phenomenon has been noted, or can be seen, in many previous studies, such as Rothrock and Thorndike 1984, Toyota et al 2016, Wang et al 2016 (JGR), and Stern et al 2018, where it is discussed at length.

AA: As pointed out by Stern et al. (2018), this behaviour relates to the fact that the underlying distribution might be a truncated power law. We added a note on this in the revised manuscript.

R2A: Page 6, lines 25-29. This is a good paragraph, with entirely appropriate conclusions. Please note that it applies only to the pancake floes analyzed here, and not to the FSD in general.

AA: We thank the reviewer for the positive comment and we added a note, as suggested.

R2A: Page 6, Conclusions. This section simply re-hashes the division of the FSD into three regimes. It claims that the small and large floe size regimes are "qualitatively close to power law scalings", but that is a very dubious characterization, especially for the large floe regime, where the range of floe sizes spans less than half an order of magnitude: log(10.8/4) < 1/2.

AA: We rephrased and removed any reference to power-law behaviour. In the revised manuscript we write: “Two different behaviours are observed for smaller and larger pancakes on a log-log plane. The small-floe regime (D < 2.3 m), in which it is conjectured that pancakes are experiencing thermodynamic growth, is characterised by a mild negative slope (in terms of the floe number exceedance and probability density function), while the large-floe regime, in which floes are typically formed by welding (detected from visual analysis), is characterised by a much steeper slope noting that neither of the two regime conforms to a power law scaling.”

R2A: The authors do not give a mechanism by which the FSD of the small floe regime comes to be qualitatively close to power-law scaling. They only state that the "pancakes are experiencing thermodynamic growth". How does that lead to power-law scaling?

AA: Based on observations by Roach et al. (2018), we hypothesise that thermodynamic growth is a potential mechanism leading to the observed FSD in the small-floe regime. We rephrased the relevant section to clarify that this statement is fairly speculative and, in the spirit of a brief communication, only serves to stimulate further research. We certainly do not claim that this mechanism leads to a power law.

R2A: For the large floe regime, they write that "floes are typically formed by welding". That’s a mechanism that can be easily simulated in a numerical experiment, and the results compared to the actual (observed) distribution. I have taken the liberty of conducting such an experiment, which did not take very much time to code up – see the attached figure. I started with 20,000 floes whose sizes were distributed according to a power law with exponent -2 and ranging from 0.25 to 3.0 meters in diameter. See the black curve in the attached figure. I then simulated a welding process in which two randomly chosen floes were welded together according to D_new = sqrt(D1ËĘ2 + D2ËĘ2) where D1 and D2 are the diameters of the floes to be welded, and D_new is the diameter of the welded floe. The floes with D1 and D2 are removed from the distribution, D_new is added to the distribution, and the process is repeated 5000 times, leaving 15,000 floes. The resulting distribution is shown by the red curve. The procedure is repeated again (5000 times), leaving 10,000 floes (green curve), and again (5000 times), leaving 5000 floes (blue curve). The blue curve has some qualitative similarities to Figure 3d. This is not a very sophisticated simulation, and I am not suggesting that the authors need to do something like this, but it does demonstrate the potential for mimicking certain processes. Of course a physical model would be better, but that is probably beyond the scope of the present study

AA: The statements that large floes are formed by welding derive by visual analysis of the acquired images and observations made from the ship deck. We have added footage as supplementary material to support the statements. The reviewer's suggestion and proposed simulations are certainly interesting, and we also agree that a detailed investigation of this kind would go far beyond the scope of the present brief communication. We would like to emphasize the main aim of the work which is to report the first quantitative observations on the pancake ice floe size distribution and to stimulate further research.

In the revised manuscript we note that these results reflect observations collected under storm conditions (see Fig. 1) and thus they may not be applicable to all the sea-ice states. We indicate that simultaneous measurements of waves, floe size and heat fluxes under a number of different conditions are indeed needed to verify the conjecture that different physical mechanisms are responsible for the peculiar shape of the pancake ice floe size distribution with the intention of stimulating further research.

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Discussion paper

Please also note the supplement to this comment:
https://www.the-cryosphere-discuss.net/tc-2018-155/tc-2018-155-AC2-supplement.zip

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