Interactive comment on "Laboratory Study of the Properties of Frazil Ice Particles and Flocs in Water of Different Salinities" by Christopher C. Schneck et al.

Authors Response to **Referee #2** (received and published: 7 July 2019)

The authors wish to thank Referee #2 for the constructive comments and corrections to the discussion paper. We have responded to each of the comments from the reviewer. The comments from the reviewer are in black font while our responses are in red font.

1. **Referee #2:**
   This paper presents a set of carefully executed laboratory experiments, measuring the number density and size distribution of individual frazil ice particles, and flocs of frazil crystals in waters of salinities varying from freshwater to sea water of 35 ppt. It provides new information in that it clearly demonstrates that a lognormal size distribution is observed in waters of all salinities. These are unique and carefully repeated measurements. The paper is very clearly written and is certainly worthy of publication.
   Authors Response:
   Thank you for your positive comments and recommendation.

2. **Referee #2:**
   I have two comments that would improve the paper, in my opinion. First, the short review of frazil production in rivers seems concise and complete. However, in the ocean the authors only describe the production of frazil in polynyas. They cite Rees Jones & Wells (2018) and Langhorne et al (2015) both of which are concerned with formation of frazil in a supercooled ice shelf water plume, yet there is no description of this process. The paper ought to briefly outline the process of frazil formation in ice shelf water as it differs from frazil formation due to heat loss to the atmosphere.
   Authors Response:
   We agree that our initial submission should have discussed the process of frazil ice formation in supercooled ice shelf water plume. We will include a brief description of this process in the introduction similar to the description in Smedsrud and Jenkins (2003), Langhorne et al (2015), and Rees Jones & Wells (2018).

3. **Referee #2:**
   Second, measurements of temperature and supercooling are quoted to more significant figures than the accuracy of the measurements. This is unnecessary and misleading. Please consider rounding to the level of uncertainty of these and all derived quantities throughout the paper.
   Authors Response:
   We agree with this comment and the results in the paper will be updated so that the significant figures are consistent with the accuracy of the measurements.

4. **Referee #2:**
   Technical Corrections

p. 2, line 20 onwards: please include a description of frazil ice formation due to supercooling caused by pressure relief of upward-flowing ice shelf basal melt (e.g. see Langhorne et al (2015) and/or Rees Jones & Wells (2018) among many other references).

Authors Response:

Please see our response to comment number 2 above.

5. **Referee #2:**

p. 2, Line 30: there is quite a large body of work on dense water formation and polynyas so it seems odd to mention one Arctic polynya from a rather old reference. The statement re dense water outflow is generally true, e.g. Ohshima et al. Global view of sea-ice productionâA˘´lin polynyas and its linkage to dense/bottom water formation, âA˘´lGeosci. Lett. (2016) 3:13 DOI 10.1186/s40562-016-0045-4

Authors Response:

Thank you for providing the Ohshima et al (2016) reference. We will update the text to explain the general physics of the dense water outflow and reference Ohshima et al (2016) among others (e.g. Tamura et al., 2012; Nihashi and Ohshima, 2015)

6. **Referee #2:**

p. 4, line 6-12: as mentioned above, some processes of frazil formation under sea ice have not been discussed.

Authors Response:

Please see our response to comment number 2 above.

7. **Referee #2:**

p. 4, line 21: how does turbulent kinetic energy dissipation in the laboratory tank compare with that in the ocean?

Authors Response:

This issue was also raised by the Referee #1. Although the dissipation rates in the tank were compared to the range of values estimated in rivers in Alberta (McFarlane et al., 2015), our initial submission did not compare this value to the reported ranges of dissipation rates in oceans. In general, the dissipation rates in oceans range from ~ 10^{-2} m^2/s^3 to 10^{-9} m^2/s^3 (Banner and Morrison, 2018; Wang and Liao, 2016) with a reported lower range in the Arctic regions ranging from ~ 10^{-3} m^2/s^3 to 10^{-10} m^2/s^3 (Chanona et al., 2018; Scheifele et al., 2018). We will include a description of this limitation in the revised manuscript and will also point out the need for future experiments to investigate the behavior at very low dissipation rates.

8. **Referee #2:**

p. 4, line 27: change to “were used in experiments, either a 10 by 10 cm or a 16 by 16 cm polarizer”. I tried to imagine how both were used at once.

Authors Response:

Updated.

9. **Referee #2:**
   p. 5, line 24: please round to a smaller number of significant figures to correctly reflect the uncertainty i.e. -0.003 to +0.005
   Authors Response:
   Updated.

10. **Referee #2:**
    p. 5, line 26: round to 0.0007
    Authors Response:
    Updated.

11. **Referee #2:**
    p. 6, line 11: please round to -8.0 ± 0.2
    Authors Response:
    Updated.

12. **Referee #2:**
    p. 7, line 6: please replace "exact freezing point" with "freezing point to better than 10 mK"
    Authors Response:
    Text updated to "this method yields values of the freezing point that are within 0.01 °C or better" (Mair et al, 1941; p. 610).

13. **Referee #2:**
    p. 7, line 8-9: please round to -0.89 ± 0.02, -1.48 ± 0.02 and -2.09 ± 0.02
    Authors Response:
    Updated.

14. **Referee #2:**
    p. 7, line 22: please consider significant figures in cooling rates.
    Authors Response:
    Updated.

15. **Referee #2:**
    p. 7, line 22: what is the COV?
    Authors Response:
    The COV stands for the coefficient of variation (standard deviation over the arithmetic mean). We updated the text to include this description. The COV was used as a measure of the repeatability of the experiments.

16. **Referee #2:**
    p. 7, line 24-25: please consider rounding to 2 and 5%, and 3 and 7%
    Authors Response:
    Updated.

17. **Referee #2:**
    p. 8, line 15: "non-zero salinities"
    Authors Response:
    Updated.

18. **Referee #2:**
    p. 8, line 29-30: I didn't really understand the description of holes being filled as fig 6 clearly has holes.
    Authors Response:
    We agree that this sentence was misleading as it implied that dilation and erosion would fill all holes in the fitted ellipse. The process of dilation and erosion of the binary images is done to smooth and fill any insignificant holes (by 5 pixels) that were generated due to the thresholding of the images. This is not to fill the gaps in the flocs but to smooth the outside edges of the individual particles. We will update the text to clarify this process.

19. **Referee #2:**
    p. 9, line 29-31: why should the diameter to thickness ratio of the floc be equal to that of the particle? Please can you discuss the expected error in c and hence in volume.
    Authors Response:
    The diameter to thickness ratio was only used for estimating the volume of the individual frazil ice particles (p. 9 lines 32-33). For flocs, we assumed that their shape was approximated by a fitted ellipsoid as defined by Eq. 2. The value of *c* (the floc dimension perpendicular to the plane of the image) was assumed to be equal to the average of *a* and *b* (the major and minor axis of the fitted in-plane ellipse) but not greater than the distance between the polarizers when using Eq. 2 to estimate floc volume. Based on our visual observations of flocs, this seemed to be a reasonable assumption.

    Regarding the expected error in *c* and hence the volume of the floc: The computed eccentricity (section 7.3) for the flocs at all salinities ranged between 0.81 and 0.84 with an average value of 0.82, which translates to $b \approx 0.6\ a$ and accordingly $c \approx 0.8\ a$ and $c \approx 1.3\ b$, when *c* is assumed to be the average of *a* and *b*. The average volume of a floc in this case is $V_{mean} = 4/3\ \pi\ (0.48\ a^3)$. Next, we considered the two extreme cases where *c* is equal to either *a* or *b* (the major or minor axes). When *c* equals *b*, the volume $V_{min} = 4/3\ \pi\ (0.36\ a^3)$, and when *c* is equal *a*, then the volume $V_{max} = 4/3\ \pi\ (0.60\ a^3)$. Therefore, the expected error in estimating the flocs volume would be ±25%. If *c* is less than *b* or greater than *a* then the error would increase and this likely does occur but we think the vast majority of flocs fall within the limits, that is, have *c* values that fall between *a* and *b*.

20. **Referee #2:**

p. 12, line 29: arithmetic mean or geometric mean (which I believe is equal to the median)? For those not familiar with the lognormal distribution it might be useful to discuss the measures of the distribution (i.e. relationship of mean, median etc)

Authors Response:

The reported averages μ are the arithmetic means and the corresponding standard deviation σ. The text has been updated to clarify that these are the values of the arithmetic means. We will also include a brief description of the lognormal distribution and the parameters that define it.

21. **Referee #2:**

    p. 13, line 26: mm3

    Authors Response:

    The units of the volume are indeed mm^3.

22. **Referee #2:**

    p. 14, line 15 & p. 16, line 33: wow – fabulous. A porosity of 0.75 for 35 ppt agrees very well with estimates for frazil ice in layers under sea ice (called sub-ice platelet layer) (e.g. Langhorne et al, 2015).

    Authors Response:

    Thank you for highlighting this. We will include in the discussion section the agreement between our estimates of flocs porosities and the values reported by Langhorne et al (2015).

23. **Referee #2:**

    p. 16, line 17-18: I'm not sure why the discrepancy between present measurements and those of Clark and Doering (2009) imply the latter are inadequate? Please explain.

    Authors Response:

    Clark and Doering (2009) used a simplified criterion to identify individual flocs in the images, which was "a floc was considered to be any particle with an equivalent diameter greater than 17 mm" as quoted from their paper. Therefore, they disregarded any flocs smaller than this value and consequently they overestimated the mean sizes of flocs.

24. **Referee #2:**

    Tables 2-5: Please reconsider rounding of all quantities. What is COV? Arithmetic mean or geometric mean (which I believe is equal to median)? For those not familiar with log normal distribution it might be useful to discuss the measures of the distribution (i.e. relationship of mean, median etc).

    Authors Response:

    Please see our response to comment number 3 and 20 above.

25. **Referee #2:**

    Fig 1: clearly not a "Seabird". Would it be better labelled "temperature sensor"?

    Authors Response:

Thank you for highlighting this, we updated the label to read “temperature sensor” as suggested.

26. **Referee #2:**
    Fig 2 caption: “saline water in a confined vessel” to account for the decrease in freezing point.
    Authors Response:
    Good point. The text has been updated.

27. **Referee #2:**
    Figs 13-15: What is the value of NT in each figure? Mark the means on the distributions by vertical lines.
    Authors Response:
    This is a good suggestion and we will add the values of NT and the arithmetic means to the captions for each figure.