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The Cryosphere Discussions
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Interactive comment on "High-resolution simulations of interactions between surface ocean dynamics and frazil ice" *by* Agnieszka Herman et al.

Anonymous Referee #1

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1 Summary

This paper investigates the dynamics of the ocean mixed layer (OML) in the presence of frazil and grease ice using Large Eddy Simulation (LES). It studies the effect of wind-driven, convective and Langmuir turbulence on frazil ice, and also the effect of frazil ice on OML dynamics. The turbulent flow leads to segregation of the frazil ice and the formation of streaks of ice on the surface, which are qualitatively similar to field observations. The frazil ice can strongly influence OML dynamics, primarily through its effect on buoyancy. The study suggests several avenues for future research.

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Discussion paper

I think that the topic of the study is interesting and novel in several aspects. Previous observations have only been interpreted in a qualitative fashion and previous models have been one-dimensional rather than the three-dimensional calculations presented here. The paper is very well written and the analysis performed is thorough with most of the limitations clearly explained. There are a few relatively small weaknesses discussed below which the authors can use to revise their manuscript. However, overall, I think the paper is excellent and should be *accepted subject to minor revisions*.

2 General comments

1. **Model formulation:** there are some limitations/assumptions of the model that should be discussed more clearly or considered in further or future calculations.

   The hydrodynamic equations (1–4) assume that the concentration of frazil is small. If this were relaxed, they would need terms like $(1-C)$, where C is the total frazil concentration, in various places (see e.g. Jenkins and Bombosch, 1995).

   The frazil model doesn't consider crystal growth (which is a reasonable starting point and is well discussed). However, I didn't understand why only three crystal sizes were used rather than a much better-resolved crystal size distribution? Presumably, this is not a very expensive part of the overall calculation? Was the sensitivity to the number of crystal size classes tested? It will certainly be essential to include many more when crystal growth and nucleation are considered (as mentioned some of the cited references). Another subtle issue is the assumption that the crystals have a constant aspect ratio. An alternative is to assume they have a constant thickness, which is arguably more reasonable from a crystal growth point-of-view. The crystals remain disk-shaped because it is energetically much easier to grow radially than in thickness.

   The results presented here are clearly very sensitive to the frazil terminal veloc-

ity (figure 3). I think the authors should consider comparing their calculations with laboratory data (e.g. of McFarlane et al. 2014). They should also consider crystal-shape effects (assuming eq. 16 wasn't designed for disk-shaped particles).

2. **Sensitivity of results:** The authors choose a particular OML-average volume fraction of 0.00168 for each category, so in total 0.005 (i.e. 0.5%). This is actually rather high. I think there should be better discussion of the sensitivity of results to this choice (e.g. F_ρ must increase with increasing ice concentration, but is the sensitivity linear or are there nonlinear feedbacks?)

3. **Comparison with observations:** The paper makes some comparison with observations, particularly the streaks of ice visible at the surface. However, the comparison is mostly qualitative. This is fairly well discussed in the final section; a forward link could be added in the final paragraph of page 20.

   A more quantitative comparison would be preferable. A starting point would be to devise and calculate statistical measures of the band size and spacing in the numerical calculations and then consider whether these are affected, for example, by wind speed. This could additionally be used to compare plots in Supplementary Fig. 9 quantitatively.

3 Specific comments and technical corrections

4. **P2, L20:** 'does have influence' → 'influences'.

5. **P3, L6:** suggest adding review article Daly: Frazil ice dynamics, CRREL Monograph, 84, 46 pp., 1984.

6. **P4, L14:** suggest expanding discussion of laboratory observations.

7. **P5, L3:** explain briefly why turbulent conditions are necessary.
8. **P5, L4:** parenthetical remark a bit confusing, I would delete whole remark and instead change 'buoyancy' to 'convection' or 'buoyancy-driven convection'.
9. **P6, L10–12:** is this good for frazil, especially the bigger crystals?
10. **P12, L9:** should 'd' etc be italicized?
11. **Sec. 3.3.3:** I think this section could have had more discussion of uncertainty. I would imagine that (18) is a more robust relationship than the others.
12. **P15, L9:** where does the latitude come into the calculation? I assume only in Coriolis term but the role of rotation didn't seem to be discussed much.
13. **P15, L12:** vertical boundary conditions on frazil concentration (I saw some earlier discussion of boundary conditions for CROCO in general, but presumably these references don't say anything about frazil).
14. **P17, L1–4:** how/why were these chosen? If you turn on crystal growth in future, results will be extremely sensitive to supercooling.
15. **P17, L16:** I would make it clearer that the phrase 'this choice' is referring only to the uniform distribution, not to all the other choices.
16. **Fig. 5:** Quite busy but just about readable, consider removing intermediate U_a.
17. **P20, L12:** expand discussion of interaction with pycnocline
18. **Fig. 7:** I found the main plots confusing and think they need a clearer x-label and caption. Is this a horizontal average? Do the PDFs integrate to 1?

19. **Sec. 5.2:** This section gives an impression that buoyancy and drag are similarly important, but the graphs suggest that the all-forcing result is very similar to buoyancy, which suggests buoyancy is much more important than drag.

20. **Fig. 9:** Thin lines very hard to see and distinguish. I would make all lines thicker and use line style to distinguish.

21. **P24. L1:** Typo? (Fig. 11g)?

22. **P24. L5:** Typo in word 'important'.

23. **P28. L19:** In a different way to F_ρ?

24. **P30. L17:** Could also mention flocculation?

25. **P30. L31:** The editor may wish to consider the journal's policy about code availability. My opinion is that code by correspondence is less good (in terms of reproducibility) than code made publicly available with a doi.

26. **Supp. eq. (2):** r appears on both LHS and RHS.

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