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Interactive comment on "Frazil-ice growth rate and dynamics in mixed layers and sub-ice-shelf plumes" *by* David W. Rees Jones and Andrew J. Wells

Anonymous Referee #2

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This is an interesting and well-written paper that discusses the modelling of frazil ice formation in mixed layers at the surface of the ocean and beneath ice shelves. The presentation is generally clear and logically structured, and should be easy to follow for those familiar with earlier literature. If I have one slight criticism, it is that there are a few key papers that form the background to this work which the authors assume the reader will already be familiar with or will read alongside their paper. To a certain extent that is inevitable, and should not really be a problem, but I personally cannot easily access at least one of the key papers that I do not know, and I suspect that many might be in a similar position. While I am not suggesting adding greatly to the size of this paper with lengthy reviews of earlier work, there are a couple of places where I think a few

extra details would help. Other than that I found little to fault and would suggest that the paper is acceptable with minor revision along the following lines:

1) I found the introduction to the crystal growth parameterisations on page 3 (lines 1-20) unnecessarily opaque. I think a few more details of the Rees Jones and Wells (2015) work may have helped. I assume that the discussion of the heat flux around a disc-shaped crystal, and the relevant boundary layer thickness, at the top of page 3, comes from that work, as does the expression for f1 that comes a little later. I think a few details (with maybe a diagram) of the temperature distribution around a growing disc, to give some insight into where f1 comes from would be really informative. Also it would seem more logical to discuss this first, before the approximations, especially if it is to be denoted by the number 1. (Later on page 13, line 9, f2 is somewhat confusingly referred to as the "first" growth law, presumably because of this slightly illogical sequencing that sees f1 introduced last.) With the temperature distribution around a growing disc described and the correct boundary layer scaling justified, the approximations f2 and f3 can then be put in a better context. Don't they come from the assumption of a spherically symmetric temperature distribution, around the disc edge in the case of f2 and around the entire disc in the case of f3? 2) Sections 3 and 4 discuss applications to two geophysical situations, where an assumption has been implicitly made that all properties are either well-mixed or follow some simple self-similar shape, so that depth-integration produces simple depth-averaged properties (and products of properties). While such an assumption is quite common, it is more questionable in this case than is usual. The term ΔT in equation (14) has a pre-defined depth-dependence. Even if the layer is uniform in temperature, the super-cooling will be a linear function of depth within the layer, because the freezing temperature is pressure-dependent. Furthermore, the ice concentration cannot be well-mixed, because the distribution of crystals will be determined not just by turbulent diffusion, but also by their buoyant rise. So the concentration will be highest at the top of the layer where the super-cooling will also be a maximum. The use of depth-mean quantities is common in the literature, but I think it would be worthwhile to point out the limitations of the assumption and

the potential impact on the results. For example, could the finding that increasing D promotes “frazil explosions” (page 8, lines 22-23 and figure 3b) be an artefact of this assumption?

3) In section 4 a few words about the plume model behaviour might help to put the results presented in figure 8 into context. Referring the reader to earlier publications for much of the detail is fine, but introducing the basic concept of a buoyant flow generated by melting that subsequently becomes supercooled because of the fall in pressure as it ascends the ice shelf base would be helpful. Also it would be worthwhile pointing out that, since the plume flows along an ice-ocean boundary, it drives direct freezing onto the boundary as well as growth of frazil crystals that can be deposited if the plume flow is weak enough. This would not require many extra words but would clarify for the reader new to the concepts what the three panels on the right-hand side of figure 8 actually show.

4) Finally, some more minor comments:

Page 1, line 17: “. . . phase of ice growth in turbulent waters.”

Page 1, line 20: “. . . occurs when it is cooled efficiently . . .”

Page 2, line 6-7: Actually Engelhardt and Determann (1987) did not drill a borehole through the ice, nor did they observe the granular texture of the ice. They used a hot-water drill, so could not recover any samples, although did infer that the bottom 35 m of the ice shelf consisted of a slushy layer of unconsolidated frazil ice. The ice at the bottom of Ronne Ice Shelf was not sampled until a little later (Oerter et al., 1992, Nature, 358, 399-401).

Page 2, line 31: “. . . crystal-mass growth, with the ice crystal . . .”

Page 12, line 6: “. . . transient differences are therefore . . .”

Page 13, line 6: “ . . . order to understand better the physical . . .”

Page 17, line 9: See earlier comments (2). You mean when the plume becomes supercooled in a depth-averaged sense?

Page 17, line 20-23: Because you only discuss freezing, this comment seems a little out of place. Don’t Holland and Jenkins (1999) set the conductive flux to zero when there is freezing at the ice shelf base? Nevertheless, this comment might fit into a slightly expanded description of the plume (see earlier comments (3)).

Page 17, line 32: “. . . over O(100 km) and the plume is . . .”

Page 18, line 34: In the parentheses, should that be “(panel f)”?

Page 18, first paragraph and caption to figure 8: By “fast” and “slow” growth, do you mean f2 and f3? Perhaps you could clarify the point.

Page 18, line 35: “. . . can lead to less frazil-ice formation in total, . . .”

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