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Interactive comment on "Technical Note: On the use of the mushy-layer Rayleigh number for the interpretation of sea-ice-core data" *by* M. Vancoppenolle et al.

Anonymous Referee #2

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General comments

This manuscript considers use of a mushy-layer Rayleigh number to interpret desalinisation and fluid transport processes from sea-ice-core data. Previous theoretical reasoning and laboratory experiments have indicated that the Rayleigh number provides an estimate of the significance of buoyancy-driven convection within the interior pore space of the ice. This *gravity drainage* is a key process controlling the desalinisation of sea ice and exchange of biogeochemical tracers with the ocean. The manuscript provides a concise review of this previous work, before quantifying a selection of the uncertainties associated with the definition and application of a Rayleigh number.

Previous studies (e.g. Carnat et al 2013, cited in the manuscript and references therein) have estimated Rayleigh number profiles based on ice core data, but suggested that the precise values of the Rayleigh number carry a degree of uncertainty due to a combination of unresolved temporal variability, uncertainty in key sea-ice properties such as the permeability, and systematic sampling errors due to brine loss during ice coring. It appears that the main novelty of the present study is to add some quantitative grist to these previous observations by:

- Repeating the Rayleigh number calculations of Carnat et al. (2013), using the previous observational data but with alternative estimates of certain physical variables and heuristic estimates of salt loss during ice-coring, thus estimating the resulting uncertainty in Rayleigh number.
- Using an alternative record of ice temperature with high temporal resolution to provide partial insight into the significance of diurnal variability. This point requires some clarification on the methodology, as detailed below.

The methodology appears technically sound on the whole, but with a few methodological clarifications required as detailed below. The manuscript is attractively written, with a rather modest level of novelty. Some suggestions for increasing the impact of the study follow below, by more widely exploring the potential sources of variability in the Rayleigh number based on the current data sets.

Specific comments

1. It would be useful to discuss the vertical extent of convection that is expected in relation to particular $Ra(z)$ profiles. For example, the Rayleigh number used here

is measured relative to ocean conditions at the base of the ice. This is presumably meant to characterise convection that penetrates from levels with a supercritical Rayleigh number, and through all underlying layers down to the ocean.

If this is the case, then the maximum value of Rayleigh number is more relevant to the occurrence of convection, rather than the mean value used in figure 3. The onset of convection would be controlled by whether any layers have a supercritical value of Rayleigh number, whilst the mean value incorporates any subcritical values of Rayleigh number in levels below the supercritical layers which have no impact on any convection driven from above.

2. It is not clear exactly how the time series of Rayleigh number were calculated in figure 4(c). Whilst there is high resolution temperature data, the salinity data have much lower resolution, and there were potentially also changes in ice thickness during this period. How were the Rayleigh numbers estimated between each salinity measurement? Can you rule out similar high frequency variability in $S(z)$ between these measurements that may modify the Rayleigh number and impact your conclusions here? This impacts on whether there is demonstrated evidence of diurnal variability of the Rayleigh number, or just an indication of the possibility. And how is the “top layer" defined?

3. Regarding the temporal variations of Rayleigh number in figure 4. Do the vertical profiles of $T(z,t)$, $S(z,t)$, $e(z,t)$ and $Ra(z,t)$ show anything interesting during these high frequency variations of T? Are there any Rayleigh number maxima located below the top layer?

4. p3215, lines 8-12, comment on potential relevance of the harmonic mean of the permeability versus the minimum permeability. It would be interesting to check the sensitivity of computed Rayleigh numbers to this particular choice, and it seems you have sufficient data to explore this.

5. Section 4.2 of the cited Carnat et al (2013) also investigates spatial variability of $T(z)$ and $S(z)$ between different cores sampled in the same overall region. Whilst they didn't comment on this specifically, inspection of the relevant profiles in figure 9 of Carnat et al (2013) suggests this leads to notable variability in the Rayleigh number. A discussion of the impact of spatial variability on Rayleigh number would seem a natural addition to improve the scope of the present study of uncertainties in Rayleigh number.

Technical corrections

6. Discussion of equation 1. Perhaps emphasise that this particular definition of Rayleigh number is for convection that exchanges fluid directly with the ocean. (In principle, if the brine density profile was non-monotonic, one could also have layers of convection confined within the interior of the ice only, although I realise that strongly non-monotonic density profiles will be rare in the field).

7. p3213, line 20. It may help to elaborate on the physical rationale for assuming phase equilbrium.

8. p3214, line 18. Emphasise that this comparison is for an assumed $S = 5\,\mathrm{g/kg}$.

9. p3215, lines 5-7. Stated "marked permeability increase near $e = 5\%$". I don't see evidence for a marked increase at this particular value in figure 1(c) - the Freitag permeability shows a continuously varying permeability with $\log \Pi$ increasing most rapidly from $e = 0\%$, whilst the Eicken et al. permeability shows that Π changes exponentially throughout the range $0 \leq e \leq 0.096$. Can you reword appropriately?

10. p3216, line 27. You mention that the brine diffusivity and LIM model diffusivity span the entire range of possible choices, but both have a diffusivity smaller than

the pure-ice diffusivity over the plotted range in figure 1(d). This sentence needs rewording - you might note that using the pure-ice diffusivity instead of the brine diffusivity simply reduces all estimated values of Rayleigh number by a uniform factor of around 10.

11. p3217, line 8. Typo - should be $\nu = \mu/\rho$.

12. p3217, line 13, p3221 line 2, and abstract line 11. Recommendation of using Notz and Worster parameterisation. There are some differences in the shape of the profiles between the different formulations (e.g. the LIM version tends to predict larger Ra near the ice base than the NW08 definition, even though the two are similar higher up in the ice), and so it is plausible that one might want to justify a different specific choice in the future. It would be good to emphasise that the present choice is primarily for practical reasons based on the current state of knowledge, in the absence of a clear physical/theoretical rationale for choosing one particular formulation over another.

13. p3218, line 8, “essentially driven by relatively high temperatures". It would be useful to clarify the logical link here - do you mean high temperatures causing increased porosity and increased permeability?

14. p 3219, lines 12-14. YROSIAE data. If no reference is available, can you provide some contextual information on the ice growth conditions, sampling strategy etc so that the reader has a feeling for what these data represent?

15. Section 5. Whilst the message is implicitly there, you might add an explicit statement emphasising that one cannot rule out the occurrence of transient convective events in the time periods between cores, based only on instantaneous estimates of Ra at the time of coring - further contextual information would be required.

16. Figure 1(a) - the caption and vertical-axis label appear inconsistent.

17. Figure 1(d). It would be more intuitive to plot the pure ice and brine diffusivities for $T = 0°$C at the point with $T = 0°$C rather than at $T = -8°$C.

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