Overview

This study investigates the effects of soluble impurities, specifically KCl and $MgSO_4$, on grain growth in polycrystalline ice across a range of temperatures. The effects of soluble impurities on the microstructural properties of ice is crucial for understanding the dynamics of natural ice masses but is poorly understood, so this is an important and timely study. A particularly interesting finding is that temperature relative to the eutectic has a more significant effect on grain growth than the actual concentration of impurities, which seems to have little impact.

The manuscript is clearly written, with a thorough discussion. Some fairly minor points should be addressed, as outlined below.

I enjoyed reading this manuscript, and I hope these comments are useful.

General comments

Generally, I think it's important to acknowledge in the manuscript that these results concern a specific scenario (relatively high concentrations of two soluble impurities), and can't be easily generalised to describe the behaviour of all natural ice. So I would stop short of recommending an 'established impurity factor', as in lines 16 and 483. The results are still very valuable because they expose the relationships between grain size, temperature and concentration of these specific impurities.

In a similar vein, it would be good to see some justification of why these particular ionic species and concentrations were chosen for the study. The concentrations are high compared to what is usually seen in ice sheets (Cuffey and Paterson [2010] give a range of 1e-7 to 1e-5 mol/L total dissolved impurity concentration in most polar ice sheets, with higher values closer to the bed). While overall it seems like concentration is not the most important factor, there must be a lower limit where there is no longer an effect on grain growth? There should be some more discussion of how these results might or might not scale to natural ice masses.

The same goes for the choice of KCl and $MgSO_4$. It's clear that different ions have different effects on grain size, so how might the results of this study translate to describing ice with both of these together, along with other impurities as well?

In the Results, some grain size distributions are described as having a 'bimodal component' (lines 172, 185). It's not obvious to me exactly what this means. E.g., the 10-100hr annealed KCl sample in Figure 2(b) does have some higher frequencies of larger grains, but this second 'mode' isn't any larger than one seen in the smaller grain sizes of the starting material in Figure 2(d), which is described as normally distributed. The starting materials in general look to me to have a more skewed distribution, compared to the annealed samples which are more normally distributed. I don't think this is important to the conclusions, but I would recommend either quantifying the skewness and bimodality of the distributions, or removing these descriptions.

Specific comments

line 75: 'Overestimation of the value of n can occur if grain size distribution not in steady state...': are the grain size distributions in this study in steady-state? Could that bias the n value estimates?

line 6: For glaciologists with poor mental maths (like me), it would be good to include what these °K values correspond to in °C.

line 25: ‘Demonstrate weaker mechanical properties’ seems like a roundabout way of saying ‘are mechanically weaker’

line 33: ‘concentration’ is probably more accurate than ’content’

line 76: ‘transition in grain boundary structure’: it’s not clear what this means exactly

line 83: What is the ’prepared solution’, is it the solution from the previous sentence?

line 100: Briefly mention which time periods were chosen up to 100 hrs (i.e. 3.2hrs, 10 hrs, 32 hrs) and why (to capture rapid change in grain size early in the annealing process?)

line 147-149: The starting material grain size distribution in (c) of each of those figures looks shorter and broader than the others. Are they all cut from the same starting sample? I doubt it would make much difference, but it’s worth making a brief comment on how much variation there is between the starting material samples.

line 178: ‘Given an annealing time...’ does this refer to any length of time, or a specific one?

line 195: ‘the growth of grains displays self-similarity’; does this just mean they are similar to one another?

line 223: Isn’t this contradictory? Or there is a difference in grain size between different concentrations, but it’s not statistically significant?

Figure 8: This is a great visualisation. The square symbols are a little hard to interpret, it would help to have the line width the same between all of them (rather than scale the line width with the size of the square). It might even be better to have a separate panel for the $MgSO_4$ values, so that they can be viewed side-by-side.

lines 232-233: ‘could be deemed as’; I think you can just say that it is relatively independent, and therefore you have decided to treat the average value as representative of all of the samples going forward.

line 384: Hammonds and Baker [2016] also found the same with Ca^+-doped ice... maybe worth mentioning.

line 472: There was one case with $n = 1.1$ (10^{-5}mol/L $MgSO_4$ annealed at 258K.) Was this discarded as an outlier?

Appendix B: It would be useful to have the full grain size datasets also included in the figshare repository, so that others don’t have to repeat the Cellpose and ImageJ analysis to use the data.

Typos, etc.

line 25: In **the** grain-size sensitive...

line 41: Replace the semicolon with a full stop

line 47: Highly concentrated NaCl solutions

line 53: ‘including’ makes it sound as though there were other impurities as well. I’d go with ‘soluble impurities (potassium chloride and magnesium sulfate)...’

line 94: ice particles **were** pressed

line 104: **was** done

line 110: within **a** few minutes

line 121: missing full stop

line 129: and **the** standard deviation?

line 143: remove 'is'

line 167: microstructures

line 168: temperature

line 183: 'for' rather than 'to' 100 hours

line 187: 'increase' is repeated

line 212: microstructures

line 229: **is** illustrated

line 256: remove 'obviously'

line 391: separately

line 428: impurities

line 481: soluble **impurities**

line 525: illustrated

line 539: to directly correlate

References

K. M. Cuffey and W. S. B. Paterson. *The physics of glaciers*. Butterworth-Heinemann, Burlington, MA, 2010. ISBN 978-0-12-369461-4. doi: 10.1016/0016-7185(71)90086-8. arXiv: 1011.1669v3 ISSN: 00167185.

K. Hammonds and I. Baker. The effects of Ca++ on the strength of polycrystalline ice. *Journal of Glaciology*, 62(235):954–962, 2016. ISSN 00221430. doi: 10.1017/jog.2016.84. URL `http://www.journals.cambridge.org/abstract_S0022143016000848`.