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The Cryosphere
Discussions

# *Interactive comment on* "The temperature change shortcut: effects of mid-experiment temperature changes on the deformation of polycrystalline ice" *by* Lisa Craw et al.

**Lisa Craw et al.**

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We would like to thank the anonymous reviewer for their insightful comments and questions. We have responded to each comment in turn below, and describe changes we have made to the manuscript to address the issues raised.



**Reviewer 2**

1. **In the Mechanical results section (Section 3.1), the authors state that the tertiary strain rates achieved in the constant-temperature and changing-temperature experiments within each Set are "within the level of variation between the duplicate experiments". From Figure 3 and Table 1, it appears that very similar tertiary strain rates were achieved in all of the -2C and -7C scenarios, but in the -10C scenario it appears that the changing-temperature experiment achieved a lower tertiary strain rate compared to the constant-temperature experiment. However, the authors state in the Discussion that the "Tertiary strain rates at both -7C and -10C from the changing-temperature experiments agree with those from their equivalent constant-temperature experiments to within the same level of variability..." Please give further justification for this result description and subsequent discussion of the -10C scenario.**

   This is a good point which needed clarifying in the text. You are right that the changing-temperature experiments at -10 °C have a lower tertiary strain rate, and we believe this is due to a limitation with the experiments rather than a real effect. The experiments which ran to strains greater than $\sim 0.08$ show a steady drop-off in strain rate after that point, which we believe is because our assumption that cross-sectional area is increasing consistently down the length of the sample becomes less valid (see our response to 2, below). Because the constant-temperature $-10\,^{\circ}\mathrm{C}$ experiments (LC021 and LC023) took such a long time, we were only able to run them to the very beginning of tertiary creep, while the other experiments could run to higher strains. As a result, they never experienced the drop-off in strain rates, while their changing-temperature counterpart experiments reached higher strains and so did begin to decrease in strain rate. As we describe in section 2.2, representative tertiary strain rate values for the experiments were taken from earlier in the experiment, at the beginning of tertiary creep, where the data are more robust. In figure 1 (attached), we have projected the curves for LC021 and LC023 forward with the same curvature as would be expected based on results from the other experiments. As highlighted by the shaded rectangles, the difference in final tertiary strain rates between the changing-temperature and constant-temperature experiments at both -7 °C and -10 °C is very similar. In both cases in fact strain rates are lower in the changing-temperature experiments, but this difference is small and does not exceed the level of variability expected in these kinds of experiments ($\pm 20\%$), so we are not able to attribute it to any real mechanism.

We have clarified this in the results section of the manuscript (now pg. 9, L26-29).

2. **How were the times and amount of added weight chosen to "periodically increase the loads"?**

   We aim to approximate a constant compressive stress, using weights loaded on top of the rigs. As the samples are compressed, they increase in cross-sectional area, and so we add an amount of weight which will increase the stress back to the target stress, assuming that volume is conserved and that the sample is expanding horizontally at the same rate everywhere (this assumption becomes less valid as strain increases, as the middle of the sample is in fact expanding at a higher rate than the top and bottom). Loads were increased every 2-5 days depending on the strain rate (higher strain rates mean it is a shorter time before the increase in cross-sectional area is significant). This is frequently enough to minimise drops in stress due to sample expansion, but infrequently enough to minimise disturbances to the experiments. We have clarified this slightly in the methods (now pg. 7, L14).

3. **Why were the samples kept in the rig setup after the experiments ended? Perhaps to not disturb the other experiments going on. Can you give some clarification on why lowering the temperatures to -18C and leaving the sam-**



**ples for days does not impact any final microstructure measurements.**

Extracting the samples from the rigs involves multiple people, as the rigs must be lifted fully out of the freezers and brought quickly into a cold room for the sample to be detached and cut. It was easiest to wait for more than one experiment to finish and extract those samples at the same time, so some were left after the experiment was over until it was convenient to remove them. They were left with the weights still on to avoid any relaxation affecting the microstructure, only the temperature was changed. Essentially this temperature drop simply slowed the experiment down to the point that any further increase in strain was insignificant.

To give a rough idea, if we interpolate between the strain rate data for different applied shear stresses at -15 °C and -20 °C in Budd and Jacka (1989), with a shear stress of 0.25MPa at -18 °C we would expect to see a strain rate on the order of 2.5e-09s$^{-1}$. Over a full seven days (the maximum time we would leave an experiment before extraction), that would result in $\sim 0.0015$ of additional accumulated strain, which is insignificant compared with the $\sim 0.1$ already accumulated. We have added a brief explanation into the methods section (now pg. 8, L3-4).

4. **Why do the authors think that the resulting grain size (gs_med) is so different for the two -7C samples (LC004 and LC005), and the two -10C samples (LC021 and LC023)? Similarly, why did the two temperature-change experiment samples in Set 1 (LC006 and LC007) have such a large discrepancy in the resulting grain size? In the Discussion, the authors describe these sets of samples as having indistinguishable microstructure. Therefore, what range of grain size (gs_med) values is considered "indistinguishable", or similar enough? This information will be helpful to the reader while interpreting Figures 4 and 5, and Table 1.**

   This important point was also raised by Reviewer 1, comment #12. You are right that there is a significant difference in grain sizes between samples deformed under the same conditions. This is most likely a sampling effect, as our thin sections are small in area and the width of the samples prohibits the taking of multiple sections, so the grain size indicated by one one-dimensional section is not necessarily representative of the entire sample. Whilst the grain sizes seen in the $-10\,^{\circ}$C samples do appear to be tending smaller than the higher temperature samples, the ranges of grain sizes seen in each temperature set overlap with one another, and so it is not possible to actually distinguish the sample groups based on grain size data from such a small number of experiments. This is what we mean by "...it is not possible to distinguish between changing-temperature and constant-temperature experiments in Set 1 on the basis of microstructure".

We have clarified this at the end of the results section: "Because thin section measurements of grain size sample only a small number of grains, and there is a large range of grain sizes measured in samples deformed under the same conditions, we are unable to draw any conclusions based on grain size differences between sets."

5. **Section 1.2, Line 56: unclear what "...this can be delayed significantly beyond the establishment of a quasi-constant strain rate" means. Perhaps consider making this a separate sentence, such as "However, the formation of this steady-state microstructure can occur significantly after the establishment of a quasi-constant strain rate."**

   Good suggestion. We have changed this to: "However, the formation of this steady-state microstructure can occur much later, after the establishment of a quasi-constant strain rate. While tertiary creep..."

6. **Section 1.4, Lines 29-33: awkward, long sentence. Consider rewording, especially the transition "...through to tertiary strain, if it is deformed..."**

   This unwieldy sentence has been replaced with two:

   "Studies in both natural ice (Russell-Head and Budd, 1979; Gao and Jacka, 1987) and laboratory ice (Treverrow et al., 2012) have deformed samples through to



tertiary strain, and then deformed them again at a later stage under the same conditions. In these cases, the second deformation phase of the experiments progresses straight from the initial elastic deformation stage to resume deformation at the same constant tertiary strain rate, with no significant change in CPO, allowing tertiary creep to be reached within strains of $2-3\%$. However, if the stress configuration is changed in the second stage of the experiment, characteristics of the original CPO can persist to higher strains (Budd and Jacka, 1989)"

7. **Section 1.4, Lines 44-45: change the sentence to use either the prepositions "with" or "to" after "compare" (...to compare X with/to Y...)**

   Changed to "to" as suggested.

8. **Section 2.1, Line 56: change "...frozen into..." to "frozen onto"; also, do you mean aluminum plates instead of "platens"?**

   "Platen' is a word for a mounting plate for materials being pressed or deformed, more commonly used in engineering and manufacturing. It's not in common usage, so we've replaced it with "mount" to avoid confusion. The platen/mount contains a large depression which the ice is actually frozen into. We have clarified this.

9. **Section 3.2, Lines 34-35: It would be nice to see this result visually, instead of taking the authors' word for it.**

   We have added these data in Appendix B.

10. **Appendix A, Line 51: Do the authors mean "G50" here instead of "G60"?**

    Our meaning was that FAME can be used with G60 data, but the method described here can be used with G50 data. This was poorly worded, so we've removed it.

11. **Figure 1 caption: move “(a)" and “(b)" labels to before the panel descriptions.**

    Changed as suggested.

12. **Figure A1 caption: period at the end of the caption needed.**

    Changed as suggested.