Comment on tc-2022-250

Anonymous Referee #2

Referee comment on "Chemical and visual characterisation of EGRIP glacial ice and cloudy bands within" by Nicolas Stoll et al., The Cryosphere Discuss., https://doi.org/10.5194/tc-2022-250-RC2, 2023

R2: Stoll et al. provide an interesting insight into the physical and chemical characterization of cloudy bands in glacial ice. The authors use a combination of visual stratigraphy line scanner, fabric analyser, microstructure mapping, Raman spectroscopy, and laser ablation inductively coupled plasma mass spectrometry 2D impurity imaging to classify the cloudy bands from the EGRIP ice core and also studied the localization and mineralogy of several micro-inclusions at different depths. Cloudy bands have been studied from the early days of ice cores research, but insights into their formation mechanism were severely lacking, which is addressed in this work. This study provides a great starting point for a better understanding of the different structural features of glacial ice.

The manuscript presents a sizable amount of valuable data. The methodology used in the study is robust and provides a high level of detail on the chemical and visual characteristics of the ice and cloudy bands. The figures and tables are well-presented and provide clear visual representations of the results. The authors also provide a detailed analysis of the results. However, I feel some results are presented but not well-discussed in the manuscript (see specific comments). While I agree it's impossible to discuss everything in one manuscript, it also doesn't make sense to present data and not discuss it sufficiently. The overall idea of the work and the data present are unique and relevant to The Cryosphere and the glaciological community. Therefore, the manuscript will be ready for publishing after a revision addressing the major issues.

A: We thank the reviewer for constructive feedback, which certainly improves the quality of the manuscript. We implement the suggestions and worked on the discussion, especially on section 4.3 describing the data integration and interpretation.

Specific comments:

R2: Line 2: "Glacial period" would be more apt term here.
A: Changed to "glacial periods".

R2: Line 6: Replace "almost" with "approximately". Approximately works better when you mention numbers.
A: Changed as suggested.

R2: Line 8: Replace "found minerals" with "minerals found".
A: Changed as suggested.

R2: Line 9: If I understand correctly, these minerals are observed rarely, but one might confuse the phrase "rare minerals" with "rare earth minerals". This can be better written as "Rutile, anatase, epidote, titanite, and grossular are rarely observed/found".
A: Changed as suggested.

R2: Line 10: Replace "with" with "at". Add "present" or "occur" with "mainly"; otherwise, the sentence sounds a little incomplete.

A: Changed as suggested.

R2: Line 10-11: Maybe rephrase this as "Whereas, dust-related analytes, such as Al, Fe, and Ti are located in the grain interior, forming clusters of insoluble impurities". Then you could continue with your next statement and say that the cloudy bands are distinguishable.
A: Changed as suggested.

R2: Line 23: What do you mean by “grain size”? Insoluble particle grain size or ice crystal size? Please clarify this.
A: Changed to “Considering different polar ice cores, most of the physical and chemical properties of ice and its impurities vary, depending on several parameters that are different at each drilling site.”. We further clarify grain size later in the text.

R2: Line 34: What does "typical" mean? Do you mean a characteristic description of a cloudy band? If so, then write clearly. Why not just write "cloudy band have been discussed for a variety of reasons, ranging from climatic to deformation aspects".
A: Changed to: “Cloudy bands vary in thickness, brightness, and shape and are thus hard to constrain (Winstrup et al., 2012), but they were discussed for a variety of reasons, ranging from climatic to deformation aspects.

R2: Line 36-38: This part is a bit hard to read. Maybe this can better written as " Svensson et al (2005) compared the brightness intensity values derived from visual stratigraphy with different records from continuous flow analysis (CFA) and showed that the brightness variations in cloudy bands mostly match the seasonal cycles of others tracers.
A: Changed to: “. Svensson et al. (2005) show that, in most cases, the brightness variations of visual stratigraphy and cloudy bands match the seasonal cycles of tracers, especially of dust, derived by continuous flow analysis (CFA) (Fig. 5 in Svensson et al., 2005)”.

R2: Line 61: Replace “and the chemistry” with “, chemistry,”.
A: Changed as suggested.

R2: Line 64-65: Do you means “few tens of microns”?
A: Yes, changed as suggested.

R2: Line 78: Detele “again”
A: Changed as suggested.

R2: Line 89: Since you study both micro-inclusions and ice fabric, its best to clarify what you mean by “grain size”. Maybe use separate terms for both, like particle size (micro- inclusions) and crystal size(ice crystals) and avoid using the terms interchangeably.
A: We clarify this by adding “(in this study grain size refers to the ice crystal)”.

R2: Line 90: Is there a specific reason why the samples are 55cm long?
A: The length of 55 cm has historical/logistical reasons, i.e. the Danish ice cores boxes are 55 cm long. DEP, ECM, and the line scanner are the only techniques analysing the (uncut) 165 cm sections. However, they still separate the data in three 55 cm sections for easier comparison with other data sets.

R2: Line 101: Remove all “e.g.”
A: Changed as suggested.

R2: Line 104: In the dark-field setup, the camera records the light that is "scattered" by the micro-inclusions and not "reflected" (Svensson et al., 2005). The only reflected light recorded is from the ice core periphery. Please correct it throughout the manuscript.
A: Changed to “Slabs of ice were polished from both sides and illuminated from below (“dark field” imaging). The light is scattered by solid impurities, fractures, and bubbles and directed back into the camera making them visible. In glacials, the main scattering objects are cloudy bands and fractures.”

R2: Line 118-119: Why not show examples of what you group as "unknown"? From what I understand, if the images are too dark or layers are too thin, you cannot be sure that the features are cloudy bands. Then why consider them. Moreover, in line 110 you say that you don't investigate deformed bands, so why do you consider them "unknown"? If the bands are classified, that would mean that they are investigated! If that’s not the case, then clarify the same in the text.
A: We explain this in detail in an answer to the first review report and an include examples in the Appendix (Fig. A2).

R2: Line 120: Just because the bands are present in three ice cores, is it prudent to say that the band types are representative of Greenland? I’m not at all against a claim like this, so it’s up to the authors to decide.
A: We discussed this wording before submission and recognized the difficulty in generalizing. Unfortunately, there is not much continuous visual stratigraphy data available and such a claim is thus tricky to discuss, but it is important to state that our results are transferable to other ice cores. We add “probably” to make the statement less absolute.

R2: Line 123: Cloudy bands can be a few milimeters thick too (you too mention this in line 31). So, it’s better to write this as "mm to cm-scale" instead of "cm-scale". Change “analyze” to “analyse”. You mostly use the British variant, so stick to one through the manuscript.
A: Changed as suggested.

R2: Line 146: Replace “before” with “earlier”.
A: Changed as suggested.

R2: Line 152-153: What is the grain size variability within a sample (mean +- std)? Would it be possible to show this in figure 1 with a patch in the background representing the range? That would give a better insight into the range of variability in grain sizes with depth.
A: How to handle, i.e. measure, display and evaluate grain size data in the best way remains difficult, and so far, no standard procedure has been established in glaciology. Our method enables precise measurement of the entire (2D) grain area by evaluating single pixels, which is much more robust than classical diameter measurements. The variability can be large, especially when cloudy bands with fine grains and much larger grains occur in the same sample. Due to the high numbers of grains and thus good statistics, displaying the sample means remains our preferred option while preserving readability. Ongoing work investigates the EGRIP microstructure in more detail, including the shape preferred orientation (SPO) of ice grains and how grain size varies on the small scale, i.e. within samples. We thus prefer to avoid additional data (and discussion) in this manuscript (since it is already packed), which will be the scope of a specific manuscript.

R2: Line 157-158: I believe this is your observation from the EGRIP grayscale data. Why do you then cite Rasmussen et al., 2006?
A: This is indeed confusing, we here refer to the timing of the stadials and interstadials as described in Rasmussen et al., 2006. We delete it to avoid confusion.

R2: Line 158-160: I don't understand the points of writing all this here? What's the relevance? Why don't you better describe your grayscale data here, explaining the overall grayscale variability and its co-variability with other causal factors. If you feel there's isn't much to describe here or you don't want to go in-depth on the factors affecting grayscale variability, remove this part.
A: We agree and shortened this part and combined it with the subsection below. Grayscale is used to classify cloudy bands, which we now mention. Furthermore, grayscale/brightness and grain area are often anti-correlated indicating the impact of solid particles on grain growth. This is displayed in Fig. 1 and now mentioned in the grain size discussion.

R2: Line 166: Is there a specific reason to choose 55 cm sections? The line scans were done for ~1.65 m section (figure A1) then why 55 cm sections are used?
A: See answer above. To enable intercomarability between different techniques it is standard to work with 55 cm sections.

R2: Line 172: No need to capitalize stadials and interstadials. Change them to sentence case throughout.
A: Changed as suggested.

R2: Line 180: "Carbonaceous particles" is a very vague term when you are identifying minerals. Its rather confusing to me. Could you explain this a bit more clearly what these carbonaceous particle are?
A: Changed to: "t further distinguished particles bearing carbon (from here on carbonaceous particles)".

R2: Line 193: I suggest replacing "number of different" with "diversity of".
A: Changed to "Shallow samples (S1-S6) have a diversity of 9 to 14 minerals, while deeper samples (S7-S13) show a variety of 6 to 10 minerals per sample.".

R2: Line 195: Use the term "rare mineral" carefully. It can mislead the readers.
A: Changed to "rarely observed mineral".

R2: Line 216: Delete "especially", "the ".
A: Changed as suggested.

R2: Line 217: "rarely" would be a better word than "infrequently"
A: Changed as suggested.

R2: Line 238: Can you expand this line, so that it is understandable to everyone as to what all factors are different between EGRIP and NEEM site, and how they change the grain size evolution?
A: Changed to: "The grain size evolution at EGRIP is similar to the NEEM ice core (Montagnat et al., 2014) (Fig. 7), but slightly shifted upwards. This could be related to the different boundary conditions (temperature, elevation) at the drill sites, the impact of extensional deformation and high strain inside NEGIS and the hard shearing in flow direction (Westhoff et al., 2021; Stoll et al., 2021b; Gerber et al., 2022), and the strong dynamic recrystallisation observed at EGRIP (Stoll et al., 2021b). However, the grain size evolution within both cores is still comparable, and the fast-flowing ice within NEGIS does not (yet) intensely affect the grain size in the upper 2121 m (~80% of ice sheet thickness)."

R2: Line 243-245: Is it really required? This is more like a concluding remark!
A: Deleted.

R2: Line 319: Add “and” before “widen”. Sounds incomplete without it.
A: We changed the entire paragraph, see new manuscript.

R2: Line 348: Why do you suddenly shift to third person? Replace "The authors" with "We".
A: This refers to the study by Svensson et al. (2005) mentioned in the previous sentence. We change “the authors” to “Svensson et al. (2005)”.

R2: Line 355-357: It’s a very confusing sentence. Maybe replace with "Wet deposition would lead to increasing layer thickness and thus resulting in a thick cloudy band".
A: Changed as suggested.

General questions:

R2: You use terms like “bright layer”, “dark layer”, “medium bright layer”, and “moderately bright layer” in the manuscript. How do you differentiate between them? Is there a quantifiable value for these layers? If so, can you please explain how you came to define these layers as such?
A: The terms refer to grayscale pixel values ranging from 0 to 255, creating the following boundary conditions for the grouping: Below 100-dark, 100 to 150-medium dark, around 150-medium, 150 to 200-medium bright, 200 to 255-bright. We add this information in section 3.2, which now combines grayscale and cloudy band types.
The boundaries are not fixed, as the brightnesses are relative. A medium bright layer can be significant inside a thick cloudy band, although it does not satisfy the definition of exceeding a pixel value of 200.

R2: Do you need to use gridlines in the plots? Some figures are very hard to understand because of the closely packed gridlines.
A: Gridlines help identify absolute values. We checked the five figures with gridlines and do not think they make them harder to read. With them, it is easier to get quantitative data, which is the central message of these plots. We think gridlines are set at reasonable distances (e.g. per sample/every 5 ka/every 12.5%). We leave this decision to the editor and are happy to reduce the gridlines of specified plots if requested.

Reference

Svensson, A., Nielsen, S. W., Kipfstuhl, S., Johnsen, S. J., Steffensen, J. P., Bigler, M., Ruth, U., and Röthlisberger, R.: Visual stratigraphy of the North Greenland Ice Core Project (NorthGRIP) ice core during the last glacial period, Journal of Geophysical Research, 110, NA-NA, 2005.