Review 1

General comments:

This is a great review paper on melt features in cores and should be published with some very minor changes. The authors do a great job in summarizing the importance of melt features and their effect on e.g. the climatic integrity of ice cores, which is of great importance to the ice core community.

I am missing a short explanation of the effect of melt in alpine and polar ice cores at the beginning of the manuscript. Similar to lines 577 to 581. This would be useful to distinguish when the authors refer to alpine or polar cores and to make it clear to the reader if the current section is valid for the full spectrum of melt events, i.e. massive melt events on coastal cores or tiny mm-melt events on the central Greenland ice sheet.

There are also some inconsistencies using the dash separating, e.g. “line scanning” and “line-scanning” throughout the manuscript.

For a better overview of the manuscript, I would suggest changing the list from (1)-(8) in lines 91 to 94 to the corresponding section numbers in the manuscript.

Dear anonymous reviewer,

Thanks a lot for taking the time to critique this review article manuscript and for your positive feedback.

Your suggestion for the content outline at the end of the introduction is very much appreciated and has been re-emphasized by the second reviewer. We have changed the numbering in line 111-115, so that they match the section numbers: “We provide a detailed literature review regarding external drivers of melt events (Sect. 2.1); physics of melt layer formation and behaviour during snow metamorphism (Sect. 2.2); identification and quantification of melt (Sect. 2.3); structural characteristics of melt features (Sect. 3.1); effects of melting on records of chemical impurities, i.e. major ions, trace elements, black carbon (BC), and organic species (Sect. 3.2), stable water isotopic signatures (Sect. 3.3), and gas record (Sect. 3.4); applications of melt layers as environmental proxies (Sect. 3.5).”

A brief introduction to the varying effects of melt in alpine and polar ice cores has been added in revised line 49-52: “While melting is rare and related alterations of climate indicators are yet of little concern to some researchers working on ice cores from central Antarctica, key climate proxy records like $\delta^{18}O$ have already been obliterated through melting in numerous low-latitude high-altitude glaciers (Thompson et al., 2021) and are gradually deteriorating at (sub-)polar sites like Svalbard (Spolaor et al., 2023).”

Inconsistencies in spelling of line scanning have been streamlined to “line scanning” throughout the manuscript, including revised line 24 and 743. Line 288 remains the only exception because of line scan is used as attribute in “line-scan derived”. In a similar way, the authors have re-read the manuscript for other spelling inconsistencies and corrected them where necessary.

Specific comments:

Figure 1: I would prefer to see the scale explanation at the beginning of the caption.

Thanks for this comment. We follow your suggestion to clearly explain the scale and orientation of each panel right from the start, and we have amended the figure caption as follows: “Figure 1: Examples of melt layers reported in snow and ice profiles from around the world using various *techniques; the grey scale bar at the bottom right of each panel equals 1 cm, and the top of each snow/firn/ice section is at the top of each panel: a) two melt layers, 4–6 mm thick, …"*

Figure 2: the map of Antarctica (1) is misleading for the figure, as the largest part of Antarctica is the plateau, which is not the main message of the figure.

In the originally submitted version of figure 2, Antarctica is included as an example of a polar region, in which the climate and melt formation conditions are (among other factors) influenced by teleconnections and synoptic-scale atmospheric circulation as described in (revised) line 141-142 & 155-156. While the authors agree that central Antarctica is not the main area of melting, the intended message of this part of the figure is to symbolize the importance of large-scale meteorological patterns for melt formation, e.g. in coastal Antarctica. We therefore have added arrows to this map (see illustration below), which symbolize large-scale circulation in a simple way without going into the details provided in the text body.

Line 132: "4 mm of melt" please specify if this is related to snow, firn, ice, or water equivalent.

Thank you for this question. The estimate is in mm w.eq. and taken from Van den Broeke (2005), where they state: "A maximum melt rate of 4 mm per day occurs for flow from the NW, which represents a combination of warm air advection and a föhn effect caused by the mountains of the AP." For clarification, we have added "w.eq." to the estimate in line 140 of the revised manuscript.

For further explanation, which is beyond the scope of the manuscript text body, their estimate is methodically based on automatic weather station (AWS) temperature data from the Larsen Ice AWS, which Van den Broeke (2005) used to calculated melt hours (taking the temporal distribution of melt hours over the day and season into account). In combination with a simple expression for the magnitude of the energy fluxes at the atmosphere-ice shelf interface, from which they derive a meltwater flux per hour (0.53 mm per hour), they calculate the maximum estimate of 4 mm w.eq. cited above.

Line 136-139: "Atmospheric rivers, especially during winter". Neff 2018 describes atmospheric rivers during summer and Wille et al 2019 both summer and winter. Please rephrase the sentence "especially during winter".

From your comment, it seems like there may have been a misunderstanding about the statement made in former line 136-139. The authors absolutely agree that atmospheric rivers are not necessarily seasonally biased in occurrence. However, melt production appears strongly correlated with the occurrence of atmospheric rivers, and in Antarctica, this is especially the case during winter.

For example, Wille et al. (2019) state: "Atmospheric rivers are associated with around 40% of the total summer meltwater generated across the Ross Ice Shelf to nearly 100% in the higher elevation Marie Byrd Land and 40–80% of the total winter meltwater generated on the Wilkins, Bach, George IV and Larsen B and C ice shelves." Going into greater detail beyond the scope of our review article here, they state: "During these winter months (March–October), ARs and their residual moisture accounted for

40–60% of the melt days on the Larsen B and Larsen C ice shelves along the central portion of the eastern AP and represent 20–40% of the melt magnitude, according to MAR (Supplementary Figs. 2b and 3c). Further south along the outlet glaciers on the Wilkins Coast, 90–100% of winter melt days and melt magnitude are linked with AR activity."

Focussing on Greenland, Neff (2018) also "revealed that from 2000 to 2012, atmospheric rivers played an increasing role in driving summertime (June, July, August) melt and accumulation. This connection was particularly evident over the western GIS, where increased accumulation (snowfall) at higher elevations was unable to balance mass loss at the lower elevations through melting."

To emphasize the common result of Neff (2018) and Wille et al. (2019) that melt production is often associated with atmospheric rivers, we have rephrased the sentences in line 144-147 as follows: "Linear-shaped air intrusions are often referred to as 'atmospheric rivers' and correlate highly with melt production in both Greenland and Antarctica (Neff, 2018; Wille et al., 2019). The association is especially strong in Antarctica during winter (Wille et al., 2019), and for example, an atmospheric river is considered responsible for the observed extensive melt in West Antarctica in 2016 (Wille et al., 2019)."

Line 184: please specify if coastal or central Antarctica.

Apologies for the typo, the article by Laska et al. (2016) cited in line 191-192 of the revised manuscript deals with Svalbard melt conditions. More specifically, the estimate is based on AWS data from Hansbreen at an elevation of 179 m above sea level, and the conditions described are expected to resemble those at some coastal low-elevation sites in Antarctica and the Sub-Antarctic. The sentence has been corrected as follows: "This duration threshold is reached within a few hours to less than a day, as has been recorded for Hansbreen in Svalbard by Laska et al. (2016)."

Line 198 and 230: "Infiltration beyond the current year is a source of uncertainty" implies that most melt is in the current year's snow layer. Line 230 states that melt does not tend to form at the surface but 50-100 cm deep, i.e. below the current year's snow layer. The two sentences seem to contradict each other, please clarify.

Thank you for pointing out the need for further clarification in this section. The sentences in revised line 204-208 now read: "Meltwater infiltration into deeper, older snow makes percolation a secondary process leading to mixed snow compositions and climatic signatures, e.g. of summer melt in winter snow (Moore et al., 2005). For similar reason, infiltration beyond the current annual layer is an issue when interpreting ice-core proxy and melt layer records, so that using multi-year averages of melt indices has been recommended previously (Graeter et al., 2018)."

We have also added context for the information "50-100 cm deep" in revised lines 241-243 for clarification: "They [dye experiments] also highlight where melt layers don't form directly at the surface but at greater depth. At Neumayer Station in Dronning Maud Land, meltwater has been documented to refreeze 50–100 cm below the snow surface during summer (Kaczmarska et al., 2006)."

Line 315 and 316: here it is not entirely clear if you refer to the snowpack or polar firn for the introduction of this section. Also, do you not analyze melt in deep ice because it does not penetrate that deep, or do you not analyze the effects of these old melt events? Please clarify.

We have changed the wording in the first sentences of Sect. 3.1 to clarify both the focus of this section (physical and structural imprint of melting where it happens) and that melt features will still be present and detectable (though not visually) in deeper, clathrated sections of polar ice cores. Melt features do not decay so the impact of time since formation (age) is not a critical factor. However, differences in *concentration may diffuse to surrounding layers over time and smaller melt events may not be detectable anymore due to thinning. Revised lines 330-334 now read:*

"Melting near the snow surface leaves a physical imprint on the stratigraphy of the glacier. Here, we discuss the appearance of melt features in snow, firn and bubbly ice, where structural differences are visible (Fig. 1). As these melt features are buried under new layers of snow, they participate in the snow/firn densification process as well as ice thinning at greater depth. Melt features in deep ice, where high hydrostatic pressure forces air bubbles into clathrates and bubble-free melt sections are practically impossible to detect visually, are addressed in Sect. 2.3.1 and Sect. 3.4."

Table 1: there is a dash and a word missing at the very bottom left of page 14.

The dimensions of the cell at the bottom left of page 15 in Table 1 have been corrected so that its full content is visible: "Measurements of snow and/or meltwater"

Figure 5: a, b, and c are missing in the figure.

Thanks for pointing this out. The figure panels are now labelled (a), (b), and (c).

Line 499: is this "pre-melting" term the same as used, e.g., in line 181, or should it mean before/prior to melting?

Here in revised line 522, "pre-melting" doesn't refer to the specific process discussed in former line 181 (equals revised line 188), so that we amended the phrase to "prior to melting" as you suggested. To avoid misinterpretations, we also checked the entire manuscript for the term "pre-melting" and made the same corrections in revised lines 461 and 749.

Line 527: does "preserved" refer to a spatial sense in the snowpack? Please specify.

Yes. We mean that the vertical profile of ammonium and other ions is better preserved than that of Ca^{2+}, SO_4^{2-}. To clarify this spatial dimension of the proxy records, we have added the words "vertical concentration profiles" to the sentence in revised line 550-551: "Among major ions, vertical concentration profiles of NH_4^+, F^- and Cl^- are generally better preserved than those of Ca^{2+}, SO_4^{2-} (Table 1)."

Line 663: do we not know exactly how many? Why is the number smaller or equal to 5?

The authors agree that a more precise number would be favourable. However, the estimate "≤5 melt layers" in revised line 690 stems from Etheridge et al. (1996), who state: "At most five melt layers, less than 1 cm thick, were identified in each of the DE08 cores and even fewer in DSS." An exact number can therefore not be given here.

Line 668: "frequently" makes it sound like a quasi-annual phenomenon, which is not the case. Please change the wording.

Following your suggestion, we have rephrased the sentence in revised line 695 to: "Though melt layers are less rare in Greenland…

Line 670: "higher-altitude", higher than in central Greenland? Please specify.

To clarify that we are referring to high-altitude ice cores from central Greenland here, we have added the word "such" to the sentence in revised line 697-699: "In such high-altitude ice cores, the occurrence of melt features is likely limited to the Holocene and Last Interglacial warm periods, and records covering the Last Glacial are affected to a lesser extent."

Line 712” with larger intensity, and at higher elevation further inland.” Change to: ”… with larger intensity, at higher elevation, and further inland”.

Thanks for this suggestion. We have changed the wording in revised line 737-739 accordingly: “Global temperature is rising and melting will affect a growing number of alpine to polar ice-core drilling locations, more frequently, at higher elevation, and further inland.”