Response to Anonymous Referee #1

Manuscript Title: Temperature Dependence of Ice Crystal Size in Tibetan Ice Cores

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Dear Reviewer,

We sincerely appreciate your careful, detailed, and constructive review of our manuscript, as well as the valuable suggestions and professional comments you have provided. We have clarified ambiguities, strengthened methodological descriptions, standardized terminology, supplemented key references and background context, and improved the clarity of our interpretations as advised.

All comments and suggestions are addressed point by point below. Reviewer comments are shown in black, our response is in blue, and the revised manuscript text is in gray.

Sincerely,

He Zhengqiang

This manuscript is an important contribution to the study of ice microstructure in mountain glaciers. Microstructural investigations in these environments remain relatively scarce compared with polar regions (Greenland and Antarctic ice sheets), despite their considerable potential to improve our understanding of glacier dynamics and regional environmental changes. These types of studies are particularly valuable given the rapid retreat and ongoing degradation affecting many mountain glaciers worldwide due to global warming. In addition, due to their remoteness and difficult accessibility, obtaining ice cores from mountain glaciers often requires significant logistical effort, which further highlights the value of datasets derived from these archives.

The geographic setting of this study also adds considerable relevance. High Mountain Asia represents one of the most important cryospheric regions on Earth, often referred to as the “Third Pole”, and plays a critical role in regional hydrology and water resources. Investigations focusing on glacier records from this region therefore have clear scientific importance. The authors present microstructural observations that have the potential to provide meaningful insights into the evolution of glacier ice.

In order to further strengthen the manuscript and improve its clarity and scientific framing, I have several comments and suggestions that I hope the authors will find constructive. These mainly concern aspects of contextualization, methodological description, terminology, and the explanation of some interpretations presented in the text. I summarize these points briefly below before listing the specific

Comments in detail.

From a methodological perspective, several analytical procedures and aspects of the sampling strategy are not described in sufficient detail. In addition, some of the terminology and layer classifications used throughout the manuscript do not fully align with the more commonly adopted terminology in ice microstructure studies, which may create unnecessary ambiguity. Adopting more standard expressions could help enhance clarity. Finally, certain interpretations, particularly those linking microstructural patterns to temperature or climatic conditions, would benefit from clearer explanation and supporting information.

Introduction

Comment (lines 18–22):

The statement presented in this section is conceptually sound; however, the introduction feels somewhat abrupt and would benefit from clearer contextual framing supported by relevant references. A brief overview of ice-core research would help situate the study within the broader field. Ice cores have provided long environmental and climatic reconstructions in polar regions such as Antarctica and Greenland, where this type of research is well established. Introducing this broader context before transitioning to mountain glacier ice cores would provide a smoother narrative. Although mountain records are generally shorter and more discontinuous, they offer regionally specific and highly sensitive environmental archives. Including representative references to previous studies on mountain glaciers would help highlight the significance and distinctive value of such records.

Response:

We revised the introduction according to your comments and added relevant references on microstructural studies of polar and mountain ice cores.

Pioneering work on ice microstructure was first carried out by Perutz & Seligman (1939) on the Great Aletsch Glacier. Since then, systematic studies have been conducted on mountain glacier surface ice and deep polar ice cores (Rigsby, 1951, 1960; Kamb, 1959; Gow, 1969; Gow et al., 1997; Faria et al., 2014a). These studies show that Ice crystal size can reflect glacial strain processes (Gow and Williamson, 1976; Alley et al., 1986a, b; Hellmann et al., 2020) and retain signals of climate change. Specifically, ice crystal size is smaller in ice layers dating to cold periods and larger in those from warm periods (Svensson et al., 2003; Durand et al., 2007; Fitzpatrick et al., 2014).

Comment (lines 20–22):

The link between ice-crystal characteristics, glacier dynamics, and potential implications for climate change is reasonable and would be clear to readers specialized in microstructural studies. However, in the introduction this connection remains somewhat implicit. It would strengthen the manuscript to briefly provide a concrete example illustrating how changes in crystal size or fabric can be related to climate variability or change.

Response:

We added the following description to the introduction:

Ice crystal size is smaller in ice layers dating to cold periods and larger in those from warm periods.

Comment (line 23):

Change: “After decades of research, the polar ice core ‘three-stage model’ is widely adopted to characterize ice…” for “After decades of research, the polar ice core “three-stage model” has been widely adopted to describe ice…”.

Response:

We revised the sentence as suggested.

Comment (lines 28–29):

The statement that ice crystal evolution is more complex in mountain glaciers effectively highlights the relevance of such studies. However, the explanation provided requires clarification. In particular, the reference to faster flow velocities and higher accumulation rates as inherent characteristics of warmer environments appears overly generalized. Warmer conditions alone do not necessarily imply faster glacier flow or higher accumulation, as these relationships depend on several other factors (e.g., impurities, slope, anisotropy, etc.) and may vary regionally. A brief clarification or justification of these links would improve the accuracy of the introduction.

Response:

We reworded this paragraph to eliminate ambiguity and supplement the relevant references.

Our intention here is to convey that mountain glaciers typically exhibit higher temperatures, higher accumulation rates, and faster flow velocities compared to polar ice cores, rather than to emphasize the relationships among these three variables.

Compared with polar glaciers, ice crystal evolution is far more complex in mountain glaciers, which typically feature higher temperatures, greater accumulation rates, and faster flow velocities (Clavette, 2020; Hellmann et al., 2020; Jennings & Hambrey, 2021; Li et al., 2026). These characteristics drive rapid changes in crystal size and fabric, and even induce significant centimeter-scale fluctuations in ice microstructures (Tison & Hubbard, 2000; Kerch, 2016; Hellmann et al., 2020; Hruby et al., 2020; Monz et al., 2021; González-Santacruz et al., 2023).

Comment (line 31):

The term “typical mid-latitude glaciers” is used without a clear definition. It would be helpful to specify what is meant by mid-latitude in this context, at least by providing an approximate latitudinal range. In addition, including information on the typical elevation of these glaciers would strengthen the regional characterization.

The Tibetan Plateau is introduced without sufficient regional context. Given that the broader geographical framework of this study is High Mountain Asia (HMA), it would be important to clearly situate the Tibetan Plateau within this setting. HMA (often referred to as the “Third Pole” due to the extent of its glacierized area) represents a climatically and hydrologically critical region. Therefore, briefly clarifying that the Tibetan Plateau forms part of the third pole, and outlining its relevance, would improve clarity and help emphasize the broader significance of the study.

Response:

The term “mid-latitude glaciers” is commonly applied to glaciers in regions such as the European Alps, the Tibetan Plateau, and the Tianshan Mountains; however, its precise definition is not widely accepted. Therefore, we removed “mid-latitude” to facilitate comparison between our study and other mountain glacier ice cores.

Following your suggestion, we added the terms “High Mountain Asia (HMA)” and “Third Pole” and cited relevant references to support these descriptions.

The Tibetan Plateau constitutes the core of High Mountain Asia (HMA), widely recognized as the Third Pole, and hosts numerous typical mountain glaciers. These glaciers are particularly sensitive to climate change (Bolch et al., 2012; Yao et al., 2012; Sakai & Fujita, 2017). Diverse climatic and topographic conditions across the plateau (Nie et al., 2021) lead to distinct ice formation processes and different microstructural characteristics (Zhang et al., 1993; Li et al., 2017, 2026). However, systematic investigations of ice crystal evolution, recrystallization, and their responses to thermal conditions remain very limited in this region.

Comment (line 32):

The statement referring to "regional climatic and topographic heterogeneities" remains too general. It would be helpful to briefly specify which climatic and topographic factors are being considered (e.g., precipitation gradients, temperature variability, monsoonal/westerlies influence, relief, slope, etc.)

Response:

We added relevant references regarding regional climatic and topographic differences (Sakai et al., 2017; Bolch et al., 2012; Nie et al., 2021).

Comment (line 33):

The term "divergent microstructural characteristics" is unclear in this context. It is not evident with respect to what these characteristics are considered divergent. If the authors intend to emphasize truly divergent behavior, this distinction should be clearly explained and supported. Otherwise, a more neutral term such as "different" may be more appropriate, as the current wording suggests a stronger contrast than what is clearly justified in the text.

Response:

We appreciate your suggestion. We used "different" instead of "divergent" to avoid ambiguity.

Comment (line 34):

It is necessary a more complete review of previous work on mountain glacier ice cores. Several ice cores have been retrieved from glaciers on the Tibetan Plateau, and these studies should be acknowledged with appropriate references.

In addition, microstructural investigations have also been carried out in other mountain glacier regions, including the Alps, the Pyrenees, and other mountain ranges worldwide. Although such studies remain relatively limited, they do exist and should be considered when framing the present research. Including these references would provide a more balanced overview of the existing literature.

Response:

We added the references you mentioned as well as other relevant references: (Clavette, 2020; Jennings & Hambrey, 2021; Tison & Hubbard, 2000; Kerch, 2016; Hellmann et al., 2020; Hruby et al., 2020; Monz et al., 2021; González-Santacruz et al., 2023;Li et al., 2026)

Comment (line 36):

The use of a Microstructure Mapping system should be accompanied by appropriate references to the original developers or key methodological studies establishing this approach.

Response:

We inserted the original methodological references: (Kipfstuhl, 2006; Fegyveresi et al., 2015).

Comment (line 37):

The manuscript states that longitudinal microstructure images span from the firn to the base of the ice cores. It would be useful to clarify how the firn section was accessed. Was the firn exposed at the glacier surface, or was it reached by excavating down to the firn–ice transition before drilling? If excavation was required, a brief description of the procedure would improve methodological clarity.

Response:

We included additional details in the Samples and Methods section. Ice core drilling was initiated after excavating a shallow snow pit, at depths of 1.3 m (ANMQ) and 1.5 m (BJGR).

Samples and Methods

Comment (line 50):

The drilling sites should be specified more clearly. It would be important to indicate whether the cores were retrieved from the accumulation or ablation zone, as the term “summit” does not necessarily imply a persistent accumulation area under current climatic conditions. The season of drilling should also be indicated to provide climatic context. If available, referencing previous studies on the glacier’s mass balance state (e.g., retreating, thinning, or stable) would further support the interpretation of the cores.

Response:

We added these details in the Samples and Methods section: both glaciers were drilled in their accumulation zones in November (autumn). Over the recent decade, local air temperature and precipitation have been increasing, and both glaciers are currently in retreat.

Comment (line 51):

Report the approximate snowline or equilibrium line altitude (ELA) for each glacier.

Response:

We added the ELA data. (ANMQ: 4900–5190 m a.s.l., BJGR: 5300–5400 m a.s.l.)

Comment (line 53):

Basic methodological details should be provided, including the type of drilling system used for core retrieval and the instruments used for temperature measurements.

Response:

We added the required details as follows:

The ice cores were drilled using an electromechanical drill. Borehole temperatures were measured with a 152 m-long cable (Cable No. 16BX-XBQ-1A) equipped with 15 platinum RTD sensors at 1 m intervals. The measurement accuracy was ±0.02 ℃. At each depth, sensors were stabilized for at least 30 minutes to allow thermal equilibrium between air in the borehole and the surrounding ice. Temperatures below 150 m in the ANMQ ice core were not measured. Based on the positive linear temperature trend from 130 m (−6.56 ℃) to 152 m (−6.23 ℃) ($R^2 = 0.93$), we estimate the basal temperature at 170 m depth to be approximately −5.94 ℃.

Comment (line 56):

The description of the sampling interval requires clarification. The statement that “560 slices were obtained from 22.30 m to the base of the BJGR core” is ambiguous. It should be specified whether sampling starts at 22.30 m and continues downward to the base, and if so, why the upper section of the core was not included in the microstructural analysis. In addition, the meaning of “sampling rate” expressed as a percentage is unclear. It would be helpful to explain how this value is calculated and what it represents.

Response:

We revised as follows:

Sampling starts at 22.30 m and continues downward to the base.

The upper section of the core was not sampled because the firn is too unconsolidated to obtain usable ice slices.

The term “sampling rate” is defined as the percentage of the total ice core length that is successfully sampled.

We prepared vertical ice slices following standard microtoming procedures (Fig. 2a). First, continuous ice slabs were cut longitudinally along the ice core using a band saw. These slabs were then cut into smaller pieces 6–10 cm in length, ~4.5 cm in width, and ~7 mm in thickness. For the BJGR ice core, sampling started at 22.30 m and continued downward to the base, yielding a total of 560 slices (covering 71% of the total length). For the ANMQ ice core, sampling started at 14.94 m and continued downward to the base, yielding 1890 slices (covering 91% of the total length). The upper firn section of both ice cores was not sampled, as they were too porous and unconsolidated to prepare intact thin sections.The slices were then frozen onto microtome glass plates using a ~1% ethanol solution, and were microtomed to produce a flat surface with a Leica SM2000R microtome. Finally, the slices were placed in a lidded foam box and sublimated at −20 ℃ for approximately 15 hours until their surfaces were smooth and grain boundaries were clearly visible.

Comment (line 57):

The manuscript states that the sample “was trimmed flat using a Leica…”. While the term trimmed is sometimes used, it is not entirely clear which preparation method is being referred to. Based on the overall methodological description, it seems possible that the surface was prepared using a microtome. If this is the case, it may be more precise to state that the sample was microtomed to obtain a flat surface. Please, clarify the preparation method to improve the methodological description.

Response:

A microtome (Leica SM2000R) was employed in this study. We revised the description to explicitly state that the sample was microtomed to produce a flat surface, with corresponding experimental details added accordingly.

We used a Microstructure Mapping system to acquire microstructural images, following protocols described in previous studies (Fig. 2b; Kipfstuhl, 2006; Fegyveresi, 2015). The system comprises an imaging module (a Canon EOS 5D Mark IV camera with an 180 mm macro lens), an illumination module (a vertical coaxial light and controller), and a manual X-axis translation stage. Photographic parameters, autofocus, and image capture were controlled using Canon Camera Connect software. Each ice slice was placed on a black sponge background and illuminated under vertical coaxial light. Under this lighting, air bubbles and grain boundaries appear dark, while subgrain boundaries appear gray.

Comment (line 58):

It would be helpful to indicate in which facilities this process was carried out, as this would clarify the environmental conditions under which the sample preparation was performed.

Response:

We added the relevant laboratory information.

We prepared vertical ice slices following standard microtoming procedures (Fig. 2a). First, continuous ice slabs were cut longitudinally along the ice core using a band saw. These slabs were then cut into smaller pieces 6–10 cm in length, ~4.5 cm in width, and ~7 mm in thickness. For the BJGR ice core, sampling started at 22.30 m and continued downward to the base, yielding a total of 560 slices (covering 71% of the total length). For the ANMQ ice core, sampling started at 14.94 m and continued downward to the base, yielding 1890 slices (covering 91% of the total length). The upper firn section of both ice cores was not sampled, as they were too porous and unconsolidated to prepare intact thin sections.The slices were then frozen onto microtome glass plates using a ~1% ethanol solution, and were microtomed to produce a flat surface with a Leica SM2000R microtome. Finally, the slices were placed in a lidded foam box and sublimated at −20 ℃ for approximately 15 hours until their surfaces were smooth and grain boundaries were clearly visible.

Results and Discussion

Comment (line 76):

The expression “firn layer (<35 m)” is somewhat ambiguous. If the authors intend to refer to the firn interval extending from the surface down to approximately 35 m, it would be clearer to specify this as “0–35 m”.

Response:

We revised accordingly. (ANMQ: 0–35 m; BJGR: 0–35 m)

Comment (line 78):

The manuscript states that both ice cores reached the critical density of 0.830 g/cm³ . If density measurements were performed on the cores, the methodology used to obtain these measurements should be described in the Methods section.

Response:

We added the density measurement methods in the Samples and Methods section.

The density of each ice core tube was calculated from its measured length, diameter, and mass in the laboratory.

The density of each ice slice was deduced using the formula: Density = (1 − porosity) × 0.917 g/cm³ (Kerch, 2016)

Comment (line 79):

The description of the grain area as “small” appears somewhat redundant, since the manuscript already provides the quantitative range (ANMQ: 2–5 mm2; BJGR: 1–3 mm2). Given that the values are explicitly reported, the qualitative descriptor may be unnecessary and could be omitted.

Response:

We removed the redundant description.

Comment (line 80):

It should be clarified whether these grain-size proportions refer to both ice cores or to a single core. As currently written, it is not clear whether the reported distributions apply to ANMQ, BJGR, or both.

Response:

We revised as follows.

The average grain area of both ice cores is less than 2 mm² and increases slowly with depth (ANMQ: 2–5 mm²; BJGR: 1–3 mm²). Grains >1 mm² and those ≤1 mm² each account for approximately 50% of the total, while grains >5 mm² account for ~10% (Fig. 4) of both ice cores.

Comment (line 81):

The subdivision into “3.1.1 Firn layer (<35 m)” and “3.1.2 Growth layer (35–45 m)” may require reconsideration. Grain growth appears to occur within the firn layer as well, meaning that both sections are characterized by grain-growth processes. As a result, the term “growth layer” may be somewhat misleading, since growth is not exclusive to that interval. It may be worth exploring alternative terminology that more clearly reflects the processes or structural characteristics distinguishing these layers.

Response:

We replaced this with the Firn layer, Firn–ice transition layer, RRX layer, and SIBM layer.

Comment (line 87):

The transition between the general description of polar studies and the discussion of the present results is not clearly marked. In this sentence, the text appears to shift to the specific case of the studied cores, but this change is not explicitly indicated. It would be helpful to clearly signal when the discussion moves from general observations (polar areas) to the results of the present study in order to avoid confusion for the reader.

Response:

We reworded the first sentence to improve the flow and coherence of this section.

Notably, the firn layer and growth layer exhibit consistent evolutionary trends (these two layers are often classified as a single unit in polar ice core studies).

Comment (line 92):

Please clarify whether any post-drilling borehole measurements were performed, such as temperature logging or other physical profiling along the boreholes. Such data could help contextualize the processes discussed here.

Response:

We added the details of the borehole measurement program in the Samples and Methods section. The borehole temperature is displayed in Figure 1b.

The borehole temperatures were measured with a 152 m - long cable (Cable No. 16BX-XBQ-1A) equipped with 15 platinum RTD sensors at 1 m intervals, with a measurement accuracy of ±0.02 ℃. At each depth, sensors were stabilized for at least 30 minutes to ensure thermal equilibrium between borehole air and the surrounding ice. Temperatures below 150 m were not measured in the ANMQ core. Based on the positive linear temperature trend from 130 m (−6.56 ℃) to 152 m (−6.23 ℃) ($R^2 = 0.93$), the basal temperature at 170 m depth is estimated to be approximately −5.94 ℃.

Comment (line 95):

The term “stable layer” is somewhat confusing in this context. The description of this interval indicates ongoing changes, including decreases in average grain area and large-grain proportions, as well as increases in small-grain proportions and total grain number. This suggests that microstructural evolution is still occurring rather than remaining stable. It may therefore be helpful to reconsider the terminology or clarify what is meant by “stable” in this context.

Response:

We replaced this with the Firn layer, Firn-ice transition layer, RRX layer, and SIBM layer.

Comment (line 103):

Minor typographical and formatting inconsistencies are present throughout the manuscript (e.g., missing spaces between words and symbols). A careful review of the document is recommended, as attention to these stylistic details improves readability and overall presentation.

Response:

We carefully checked the entire manuscript and corrected all formatting errors.

Comment (line 105):

The manuscript suggests that higher temperatures enhance grain growth and lead to a larger equilibrium grain area. It would be helpful to indicate whether there is supporting evidence in the literature for this interpretation. If such relationships have been previously documented, including appropriate references would provide better support for the argument.

Response:

We revised the manuscript, and cited supporting references to validate the relationship between temperature, stress, and equilibrium grain size in the RRX layer.

Specifically, we have revised the relevant description as follows:

However, the average grain area in deeper, warmer section of ANMQ remains larger than that in the shallower, colder section of BJGR, even though ANMQ experiences higher vertical stress. This confirms that higher temperatures enhance grain growth, resulting in a larger equilibrium grain area (Gow, 1969; Cuffey and Paterson, 2010; Montagnat et al., 2014). Grain size in the RRX layer thus represents a balance between stress-driven refinement and temperature-driven growth, consistent with polar ice core studies (Alley et al., 1986a, b; Faria et al., 2014a, b; Weikusat et al., 2017).

Comment (line 113, 114, 116):

The manuscript states that SIBM typically occurs when ice temperatures exceed −10 ℃ and that the basal temperatures of the studied ice cores satisfy this condition. However, the basal temperatures of the cores are not reported in the manuscript. It would be helpful to specify the temperature values (measured or estimated).

The term “oversized grains” is qualitative and would benefit from quantitative support. If possible, it would be helpful to indicate the approximate grain size or provide a representative value or range to better substantiate this description.

The statement refers to a temperature transition at ~150 m depth, but the actual temperature values are not reported.

The terms “mutation layer” and “stable layer” are not standard in ice microstructure studies and is inappropriate in this context, as it may lead to confusion. More conventional terminology should be adopted. It may be clearer to define the sections based on depth intervals and dominant processes (e.g., polygonization, RRX, SIBM).

Response:

We added the ice temperature data and measurement details in the Samples and Methods section, and revised the relevant paragraph as follows:

These observations are consistent with rapid grain boundary migration dominated by Strain-Induced Boundary Migration (SIBM), which tends to occur when ice temperatures are above -10 ℃ (Duval and Castelnau, 1995; Faria et al., 2014b). The basal temperatures of both ice cores satisfy this criterion（BJGR: -8.31—-8.17 ℃, ANMQ >-6.38 ℃）. Notably, in the ANMQ ice core, ice temperature reaches its minimum of −6.84 ℃ at 126 m depth, where grain area is also minimized at ~5 mm^2. Below 126 m, the temperature trend reverses from decreasing with depth to increasing, and grain size increases accordingly. Below 150 m (>-6.27 ℃), grains grow rapidly, accompanied by abnormally large grains (>400 mm^2) and a 5 m thick basal bubble- free ice layer.These observations indicate that basal temperature also influences ice crystal size in this SIBM layer.

We apologize for a typo in the depth of the ice temperature transition. This depth has been corrected from 150 m to 126 m in the revised manuscript.

Comment (line 123):

Further explanation is needed. The manuscript states that the BJGR core reflects characteristics of Cold-type Ice Genesis, but the connection between the reported observations (lower temperature, lower firn density, smaller grain size) and this interpretation is not fully developed. It would strengthen the argument to more clearly explain how these observations support the classification as cold-type ice formation.

Response:

We added more detailed descriptions of the firn characteristics in the BJGR ice core, and explicitly noted that melt-refrozen layers are rarely observed throughout the firn (only sporadic and minimal). These features collectively demonstrate that the BJGR core represents typical Cold- type Ice Genesis. We have also supplemented key references to support this classification.

Comment (line 134):

The comparison presented here appears somewhat limited. It would be helpful to verify whether additional mountain glacier ice cores (particularly from High Mountain Asia) are available for comparison. If other records exist in the region, including them would strengthen the contextual interpretation.

In addition, comparisons with well-documented mountain glacier cores from other ranges (e.g., the Alps or other high-altitude regions) could also provide useful context. Expanding the set of reference sites would help place the reported firn temperatures in a broader framework.

Response:

We have revised this section by adding comparisons with Urumqi Glacier No. 1 and Tsanfleuron Glacier, supplemented detailed information for these glaciers, and presented the data in Table 1.

We compared the two ice cores with four additional ice cores from mountain glaciers in the eastern Tibetan Plateau, Tianshan Mountains, and European Alps (Table 1; Zhang et al., 1993; Tison & Hubbard, 2000; Kerch, 2016; Li et al., 2017). At a depth of ~35 m, we observed the following ice temperature ranking: Tsanfleuron > Urumqi Glacier No. 1 > ANMQ > BJGR > KCC > Guliya. This ranking is broadly consistent with the grain area ranking at the same depth: Urumqi Glacier No. 1 > ANMQ > BJGR > KCC. These comparisons further confirm that temperature is the dominant factor controlling grain growth in these mountain glaciers.Note that the grain areas of the Tsanfleuron and Guliya ice cores were measured using the linear intercept method (Pickering, 1976), which tends to overestimate the average grain area.

Table 1. Ice temperature and grain size at 35 m depth in different mountain glaciers

Ice Core	Location	Elevation (m a.s.l.)	Length (m)	Firn Thickness (m)	Temperature (℃)	Grain Area(mm^2) / Diameter (mm)
Tsanfleuron	Western Alps	2800	39.86	36	~0	> 78 / > 10
Urumqi Glacier No. 1	Middle Tianshan Mountains	4050	90.24	3	-1	7–12 / 1.5–2
ANMQ	Eastern Tibetan Plateau	5750	169.45	35	-2	5–10
BJGR	Eastern Tibetan Plateau	6180	77.6	35	-6.2	3–5
KCC (Colle Gnifetti)	Western Alps	4484	72	36	-13	2–4
Guliya	Western Tibetan Plateau	6200	308.6	1	-14.8	> 50 / > 8

Comment (lines 139, 140):

The description of cloudy band thickness requires clarification. It is unclear whether the statement means that the combined thickness of all cloudy bands within one meter of core is <20 cm, or whether it refers to an average thickness of ~20 cm per band. As currently written, the phrasing is ambiguous and should be explained more clearly.

The description of the cloudy bands in this interval also requires clarification. It is not clear whether the reported total thickness of up to 90 cm refers to the combined thickness of all cloudy bands within the 120–140 m interval, or to the thickness of an individual band.

Response:

We revised the term “cloudy bands” to “impurity layers”

We revised the sentences and clarified that their thickness refers to the cumulative thickness of all impurity layers within one meter of ice. The “total thickness of up to 90 cm” also refers to the cumulative thickness of all impurity layers within one meter.

Comment (line 146):

The discussion linking impurities to grain-size variability is well supported by the cited polar ice-core studies and by the mountain glacier example already included (e.g., Eichler et al.) It may also be worth noting that similar relationships between impurities and ice microstructure have been reported in other mountain glacier settings. For instance, the study by González-Santacruz et al. (Annals of Glaciology) on the Monte Perdido Glacier in the Pyrenees documents comparable interactions between impurities and ice microstructure. Including these type reference could further broaden the contextual framework for interpreting impurity-related grain growth processes in mountain glaciers.

In addition, the manuscript would benefit from a brief overview of previous microstructural studies conducted on mountain glaciers. There is a long-standing body of work examining ice fabrics and microstructural characteristics in non-polar glacier settings that could help contextualize the present study. Early investigations include classic work on glaciers such as Aletsch (Perutz and Seligman, 1939) and Emmons Glacier (Rigsby, 1951), followed by

Comparative studies across several mountain and high-latitude glaciers (e.g., Rigsby, 1960; Kamb, 1959). More recent contributions have examined ice fabrics and microstructural properties in glaciers such as Tsanfleuron, Colle Gnifetti, Storglaciären, Rhône Glacier, sites in the Mont Blanc massif, and Jarvis Glacier, among others. While these studies often focus primarily on ice fabric, they nevertheless provide important background for understanding microstructural evolution in mountain glacier environments. Including a brief acknowledgment of this body of work would help place the present results within the broader historical development of mountain glacier microstructural research.

Response:

Thank you very much for your valuable suggestions. We revised this section and cited the reference (González-Santacruz et al., 2023). In this study, we observed a significant negative correlation between grain area and the total thickness of impurity layers within one meter. This aligns with previous glacier and polar ice core studies, in which impurities have been widely found to restrict grain growth, typically by inhibiting grain boundary migration and pinning grain boundary. In our samples, grain boundary pinning features are visible in the micrographs, but the exact nature of the pinning particles cannot be fully resolved owing to resolution limits. Notably, some studies suggested that impurities would change ice properties by influencing grain internal strain (Eichler et al., 2017, 2019; Stollet al., 2021). However, the deep discussion of these mechanisms is beyond the scope of the present work and may be addressed in future research.

We also cited the other relevant references you mentioned to describe the historical development of microstructural research on mountain glaciers in the introduction section.

Comment (line 149):

“Ice temperature” instead of only “temperature”

Response:

We revised accordingly

Comment (line 162):

The interpretation that low d18O values in the cloudy-band zone reflect colder conditions is reasonable and consistent with the isotopic signal. However, the expression “cold periods” may benefit from further clarification. As currently written, it is not entirely clear whether the authors refer to large-scale climatic phases (e.g., glacial conditions) or to shorter-term colder intervals.

It is understandable that resolving the exact temporal scale may be difficult given the limitations of the chronology. Nevertheless, it may be useful to acknowledge the possible range of temporal scales involved. Previous studies have linked higher dust concentrations in ice cores to glacial conditions through mechanisms such as increased continental aridity and stronger atmospheric circulation. However, it is less clear whether the same mechanisms apply to shorter-term or seasonal cold intervals. Briefly recognizing these different possible scales would help refine the interpretation and avoid ambiguity.

Response:

We added dating data for the two ice cores over the depth interval of 45–51 m (BJGR: 1975–1985; ANMQ: 1957–1969), indicating that grain area may retain the signal of seasonal climate variations.However, no robust age constraints are available for the dense zone of impurity layers at the bottom of the two ice cores, whose time span is inferred to be on the millennial scale.