The manuscript (MS) of Horlings et al. compares the microstructure of two sites from the Allen Hills the snow/firn is/was undergoing extreme metamorphism. The two cores compared show in the uppermost 5 m extreme differences in microstructure and density. Therefore this comparison deserves publication.

In its present form the manuscript is lacking a thorough discussion of the processes which may have caused the differences in microstructure and the related physical properties. Therefore I recommend major revisions.

We sincerely thank the reviewer for providing a detailed as well as comprehensive review. We acknowledge that the addition of a more comprehensive discussion as well as adding quantitative information will strengthen the original manuscript. The comments have helped us revise, expand upon, and restructure to address these concerns. Overall, the edits we performed in response to the reviewer's comments are within the following categories: 1) adding age estimates for each core, 2) analyzing velocities within the region and effect of spatial interpretation, 3) expanding upon the AHMIF microstructure, 4) expanding upon depositional and post-depositional processes, such as wind packing, erosion, and sublimation, 5) expanding upon trends in microstructural parameters, and 6) balancing discussion of alternative hypotheses. We elaborate on these categories below. Note that we use the following abbreviations: line (L), Comment (C), Reviewer 1 (R1), and manuscript (MS).

General comments

The differences in the microstructure of the two core sites (Pico2303 and AHMIF published by Dadic et al. (2015)) are obvious in some figures and 3d reconstructions presented, also in SSA and density but the comparison is limited by the low resolution of the AHMIF core. Below 30 cm the AHMIF core is older than 100 years and may be older than 600 years at the bottom in 5 m depth. No ages are given for the Pico2303 core. The poor age constraints of both cores make it difficult to develop ideas over which time scales the microstructures develop, have developed or which processes have worked on them. It seems obvious that microstructures developed over very different time spans and have been undergoing different processes are compared. The authors hardly discuss this aspect. They do not try to provide age estimates.

Helpful information how the snow patches at these sites developed during the time of activities between 2011 and 2023 are not given or do not exist.

My impression is that the AHMIF core shows a discontinuity or an hiatus at 30 cm depth. The high SSA values at the surface (top ~7 cm) indicate relatively recent deposition above much 'older' firn.

The katabatic winds in this hilly region certainly cause somehow the observed features and properties. A basic question, however, is not discussed: to which densities can wind pack snow grains? What is the highest packing density of snow grains? The high densities (up to more than 600 kg/m3) observed close to the surface in the AHMIF core are exceptional and therefore interesting but if a density of 550 kg/m3 for snow is assumed as the highest packing density (densification stage I) then densities above 550 kg/m3 may not be anymore the result of wind packing. Internal deformation is commonly invoked in explaining densities above 550 kg/m3 (stage II) observed in the AHMIF core already as shallow as ~30 cm depth. Is it possible that the AHMIF site was/is undergoing significant **erosion or sublimation** or did it slowly move from an accumulation region into an ablation site with higher winds and significantly more erosion/sublimation? Blue ice is indicated not far below the AHMIF position in the satellite picture (Figure 2). The AHMIF site **moves ~16 cm/year** towards a blue ice region where more sublimation/erosion must occur. Where in the AHMIF snow patch is **accumulation predominant and where ablation**. Is this known? May a possibility to **estimate ages**.

Spaulding et al., 2012 in their conclusions:... Blue ice and adjacent firn areas are thinning at an average rate of 1.5±1 cm per year. Elsewhere they write that the snow cover is known to change seasonally and annually and sastrugi up to 1 m height are not rare. The focus on wind packing as the only explanation appears to be a very restricted view and explanation.

We appreciate this feedback. We agree that more clarity is necessary, and address the questions and concerns from the reviewer by breaking them into the following sections and edits.

Impacts on wind crust formation:

First, we add the following paragraph at L69 (Section: Introduction):

"At the atmosphere-snow surface boundary as well as in near-surface firn, the interplay of processes is key. For example, crust formation favors larger grains with lower mobility because smaller grains, which typically form at lower temperatures on the East Antarctic Plateau, are susceptible to wind erosion and redistribution (Endo and Fujiwara, 1973; Weinhart et al., 2021). Additionally, sintering causes grains to stay at the surface and prevents mobilization compared to weakly bonded grains (Weinhart et al., 2021). Thus, the mobility and grain size of surface snow at sites in the interior of Antarctica may not be as optimal to build crusts with both the occurrence of erosion and redistribution (Weinhart et al., 2021). This implies that there is a higher potential for their destruction at the surface of such low accumulation sites. Temperature also influences crust formation where, in colder temperatures, snow at the surface remains soft due to reduced metamorphism and thus mobile even during moderate wind conditions (Weinhart et al., 2021). This tends to prevent longer residence times at the surface and prevent crust formation so that only strong crusts will survive strong firn metamorphism. The influence of these variables was studied by Weinhart et al. (2021) and shows a positive correlation between the logarithmic accumulation rate and crusts per annual layer in surface snow, where they used snow profiles derived from microfocus X-ray computer tomography to analyze the spatial distribution of wind crusts on the East Antarctic Plateau and northern Greenland."

Wind erosion, sublimation, wind packing, & density:

Next, we follow the paragraph above at L69 of the MS (Section: Introduction) with the paragraphs below:

"Wind packing in Antarctica is an important process because of its influence on mass balance, occurring when wind hardens the snow and creates surface wind crusts and slabs (Sommer et al., 2018). The resulting hardness of the snow affects both the threshold wind speed for snow transport as well as the erodibility of the snow (Li and Pomeroy, 1997). It is commonly the reason why snow is permanently deposited without being remobilized and redeposited at another location (Groot Zwaaftink et al., 2013). Wind packing itself may be influenced by a range of factors, including air humidity, wind speed, air temperature, and accumulation rate (Sommer et al., 2018)."

The question about maximum wind-driven surface snow density may not be easy to infer because of the complexity of processes occurring. Thus, we also include the following paragraphs at L69 (Section: Introduction).

"The surface density of wind-packed snow is not as basic as it seems. Hardening occurs after deposition in wind-exposed areas as other processes are occurring simultaneously (Sommer et al., 2017; 2018). For example, wind packing is complicated by the interplay of wind redistribution and scouring. Drifting snow is key for the formation of both wind crusts and slabs while erosion has no hardening effect on fresh snow but erases surface layers (Sommer et al., 2017; 2018). Other integral processes, such as accelerated surface sintering caused by increased ventilation which induces increased vapor flux, may occur without saltation or drifting. Further, mechanical working over time, through fragmentation, creates higher densities (e.g., Weinhart et al., 2021). Finally, sublimation, aided by katabatic winds, is particularly important in BIA regions where mass balance is negative or zero (e.g., Lenaerts et al., 2012, Das et al., 2013; Markov et al., 2019). It depends on a range of variables, including heat, momentum, and moisture exchanges with the surface; turbulent mixing from surface roughness; atmospheric saturation; and wind intensity (Das et al., 2015). In the right conditions, this results in the uppermost surface layer being destroyed and exposing the layer below, which tends to have higher surface density and hardness (Markov et al., 2019). Some studies have found significant ablation of the firn layer from this process. For example, Das et al. (2015) found around 16-18 m of firn, corresponding to around 200 years of accumulation, that had gradually ablated in the wind-scoured environment of Recovery Ice Stream in Antarctica.

In models, surface density and the overall effect of wind packing are defined in a variety of ways. Some models solely parameterize density through wind speed, or through a combination of wind speed and other variables (e.g., temperature) (e.g., Kaspers et al., 2004; Lenaerts et al., 2012; Vionnet et al., 2012; Gallée et al., 2013; Agosta et al., 2019). However, the evolution of denser packing from wind scouring and redistribution through complete burial may be underestimated (Weinhart et al., 2021). Models, such as Crocus and Snowpack, simulate the average effect of wind packing by when wind speed exceeds the threshold for drifting snow (Brun et al., 1997; Groot Zwaaftink et al., 2013). Other models may include additional processes. For example, wind-driven compaction, such as mechanical destruction and subsequent sintering, may be defined for simulating near-surface layers (Wever et al., 2023). Saltation may be initiated when the actual friction velocity exceeds the threshold friction velocity, which is dependent on microstructural properties (Schmidt, 1982a; Lehning and Fierz, 2008). Erosion may be implemented through thresholds based on saltation mass transport and balance. Further, when deeper layers exhibit properties that hinder erosion, such as high density or high bond strength, erosion may be halted. For example, Amory and others (2021) apply a threshold of 450 kg m^{-3}, so that, when a layer exceeds this density, erosion is terminated."

We tie in the information we have from Dadic et al. (2015) at L188 (Section: Discussion):

“For the AHMIF core, Dadic et al. (2015) conclude that there were either erosion events and/or periodically deposited snow with no or very little deposition in between, which would mean that deposition occurred under extreme wind conditions and with high initial densities. With such high surface densities, snow could therefore survive strong erosion events, although the transportation distance beforehand remains unknown (Dadic et al., 2015). At the same time, the lack of Pb-210 below 30 cm is likely a result of erosion (Dadic et al., 2015). Densities are between 510 - 610 kg m^{-3} at 30 cm, potentially a result of older firn becoming more shallow. Thus, exposure of the surface to wind packing and associated surficial redistribution processes in combination with erosion and sublimation likely cause the variations within the near-surface AHMIF core. While we cannot determine exactly which processes dominantly contributed, we note that such high surface densities (up to 480 kg m^{-3}) have been seen before in some regions, such as Adelie Land (where drifting-snow compaction and summer melting occur). Although no melting occurs at AHMIF, these are close to the averaged near-surface density from AHMIF core (around 460 kg m^{-3}). High densities of over 400 kg m^{-3} are also seen in the near-surface layers at other locations on the East Antarctic Plateau (e.g., Figure 2, Weinhart et al., 2021).”

Additionally, we expand our description of the Allan Hills BIA area (see below) in the Introduction at L98 by creating a general subsection called “1.1 Allan Hills BIA” that absorbs 1.1 Core Location and 1.2 Climate at Allan Hills BIA. The headings below are references to the topic addressed, pertinent to R1’s comments, while the text is the response that is included in the MS.

<u>Velocity in the Allan Hills BIA area</u>

“Spaulding et al. (2012) state that the estimated thinning is likely balanced by the thickening of the snow plains within the Allan Hills MIF. They suggest that estimated horizontal velocities indicate two distinct flow regimes: 1) very slow flow (<10 cm yr^{-1}), and 2) faster-moving outlet channels between MIF and the neighboring NWIF. The first is characteristic of BIAs and dictated by shallow bedrock ridges, which contribute to enhanced ablation rates causing steeper surface slopes and enhanced katabatic winds. The AHMIF core is located close to point P10, where horizontal velocities are around 0.16 m yr^{-1} (Spaulding et al., 2012). While there are no points at site PICO2303, P18 and P19 exist close by in the snow plains around 25 m lower in elevation, where GPS-based measured mean velocities of around 0.45 and 0.48 m yr^{-1}.”

<u>Variability of accumulation from katabatics:</u>

“Spaulding et al. (2012) state that the accumulation rate in the snow plains is highly variable because of the presence and migration of large sastrugi formed by katabatic winds. The strength and direction of surface winds has seasonal and annual variability which generates short-term fluctuations in these accumulation rates. This may be influenced by the erosion, sublimation, redistribution, and other deposition and post-depositional wind-driven processes to create the structure observed in the AHMIF core.

<u>Measured accumulation rates:</u>

“Dadic et al. (2015) used Pb-210 analysis to estimate the mean accumulation rate at AHMIF to be 0.0075 m weq yr^{-1}. There are no robust measurements of surface mass balance near the

PICO2303 core site. Vertical velocity derived from GPS stake measurements here are within its uncertainty bounds. Surface-elevation changes derived from variations in stake height are unreliable given the migration of sastrugi, and/or wind scour and deposition. Further, recent model fits to ApRES data cannot give an accurate estimate of accumulation rates due to, for example, a lack of an absolute reference datum.

I am wondering if the **Herron-Langway firn mode**l can't be used to derive some estimates of the ages of the cores. Firnification stage I does not depend on accumulation but the densification rate does depend on the accumulation rate. Densities of ~600 kg/m3 are generally observed below 15 m depth in firn for annual mean temperatures of -30°C. A **question** then is if wind is able to erode firn of densities above 550 kg/m3 or if it is predominantly sublimation. Katabatic winds are always dry winds. If thinning (1.5±1 cm/a) means sublimation then 1 m of firn is removed in about 100 years at the AHMIF site. If such a scenario is plausible then the two exceptional microstructures may not be so exceptional anymore to describe the differences in the observed evolution of the microstructure, density, SSA and grain growth.

We agree with the feedback that approximate age constraints would substantially strengthen the interpretations within the MS. The Herron and Langway (1980) model is a benchmark firn-densification model and is highly regarded for its simple, computationally efficient formulation. It may be limited at sites with very low accumulation rates, rapid changes in microstructure, and other non-steady state variables. However, correctly determining age through modeling efforts is prevented by the lack of data at the sites (e.g., accumulation rate at PICO2303) and is beyond the scope of this research. Thus, we use the model to provide a first-order approximation of the age of firn. Our response follows the response to R1's Comment 5.

We run the Herron and Langway (1980) firn-densification model to provide estimations of age. From Dadic et al. (2015), the accumulation rate at AHMIF is calculated as 0.0075 m weq yr^{-1}. However, no accumulation rate estimation exists at PICO2303. In general, the accumulation rate may be highly variable in the Allan Hills BIA region and so we show age estimations using the accumulation rate calculated from a rate of 0.0075 m weq yr^{-1} at AHMIF to a rate of an order of magnitude higher, 0.075 m weq yr^{-1} (see Figure 10). To show the sensitivity of the estimations to surface density, we show estimations using both surface densities. We add the following to the analysis outlined above after L175 (Section: Results):

"We estimate firn age in the upper 5 meters of the firn layer by using the Herron and Langway (1980) model. The model is considered to be a benchmark firn-densification model, as many firn-densification models developed after are based on similar assumptions (e.g., Stevens et al., 2020). To derive their densification-rate equation, Herron and Langway(1980) used depth-density data from 17 cores and Sorge's law, a steady-state assumption stating that, under constant temperature and accumulation, the relation between density and depth is invariant over time. Firn age is defined as

$$Age(\rho) = [1/(k_0 \dot{b}^{a})] ln[(\rho_i - \rho_0)/(\rho_i - \rho)], \quad \rho \leq 550 \text{ kg m}^{-3}$$

and

$Age(\rho) = [1/(k_1 \dot{b}^b)] ln[(\rho_i - \rho_{550})/(\rho_i - \rho)] + Age(550), \quad \rho > 550 \text{ kg m}^{-3}$,

where *a* and *b* are site-specific constants, *Age*(550) is the firn age at the boundary of the second stage of densification, ρ_i is ice density, ρ_0 is surface density, ρ_{550} is the density at the boundary of the second stage, $\dot{b}$ is the accumulation rate, and *k* is a coefficient that incorporates an Arrhenius rate law that depends on temperature and the firn-densification zone (Herron and Langway, 1980; Lundin et al., 2017). We run the model using the accumulation rate calculated from Dadic et al. (2015), 0.0075 m weq yr^{-1}. Because the accumulation rate is unknown at PICO2303, we also run the model at 0.0135 m weq yr^{-1} intervals until an order of magnitude greater. To understand the model's age estimation sensitivity to surface density, we show these approximations using both the surface densities at AHMIF and PICO2303. "

We also add the below figure as Figure 10.

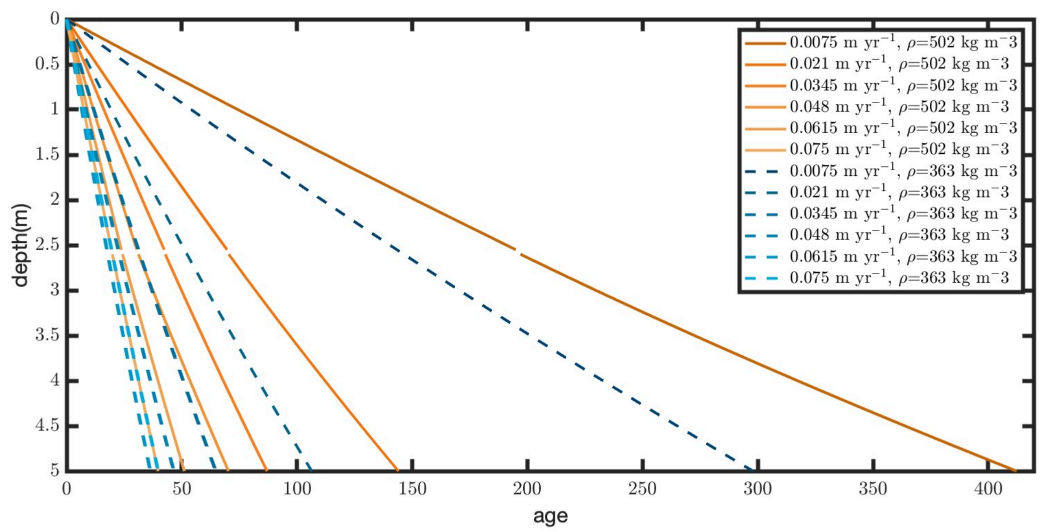

Figure 10. Age estimation of the upper 5 meters are modeled from $\dot{b}$=0.0075 m weq yr^{-1} until 0.075 m weq yr^{-1} using surface densities at AHMIF (orange) and PICO2303 (blue) from the Herron and Langway (1980) firn-densification model.

We then include the following after L188 (Section: Discussion):

"From Figure 10, the Herron and Langway (1980) model estimates age at the bottom of the AHMIF core to be 412 years. Because the PICO2303 core is taken from a location most likely with higher accumulation, we assume that the age must be anywhere from 30 years to over 100 years. From Pb-210 data, Dadic et al. (2015) estimate that the bottom of the AHMIF core (z = 5 m) is around 660 years old using a constant accumulation rate of 0.0075 m weq yr^{-1}, which is several hundred years older than the estimate and suggests the influence of model assumptions (e.g., constant accumulation rate, no erasure of layers, etc).

We suggest that the near-surface firn of the AHMIF core must have been exposed to the surface longer than the PICO2303 core, potentially several hundreds of years. However, microstructure that is indicative of a strong, consistent TGM, such as large, faceted depth hoar, is not present.

Thus, this must indicate that either 1) the accumulation rate has changed over time over the development of the AHMIF core, 2) there is the development of different microstructure (i.e. solid-type grains of a hard cohesive depth hoar) from high surface densities, and/or 3) there is an erasure of layers (e.g., wind erosion and snow redistribution) near the surface due to very low or negative accumulation. Further, Dadic et al. (2015) suggest that snow redistribution processes may be partially responsible for the Pb-210 data that suggest an abrupt age increase below 0.3 m. They conclude that areas that experience katabatic winds, such as the AHMIF region, are acknowledged to have irregular Pb-210 profiles because of the post-depositional snow migration. Overall, the modeled estimation provides a first-order approximation but includes uncertainties, and future measurements are needed to constrain the depth-age scale at PICO2303."

Helpful for the reader would be if the information about the core sites would not be so widely distributed and a short summary of the Spaulding et al. paper would be nice to read somewhere in the introduction section of the MS. The maps in the Spaulding- paper seem clearer to me to explain and better understand the differences of the two sites.

We agree with the reviewer that providing more information from Spaulding et al. (2012) would be helpful, and have already addressed this under the section "Velocity in the Allan Hills BIA area" above.

Spaulding et al., 2012 in their conclusions:... Blue ice and adjacent firn areas are thinning at an average rate of 1.5±1 cm per year. Elsewhere they write that the snow cover is known to change seasonally and annually and sastrugi up to 1 m height are not rare. The focus on wind packing as the only explanation appears to be a very restricted view and explanation.

We appreciate the feedback, and aim to provide a more balanced discussion. This is addressed in the response to R1's Comments 3 and 6. We place the text at L188 (Section: Discussion) of the MS and before the Discussion paragraph from the "Wind erosion, sublimation, wind packing, & density" (see above). Overall, we deconstruct the complexity of the variables in the Allan Hills BIA area of PICO2303 and AHMIF as follows:

"Several factors must be considered as possible contributors to the observed stratigraphy and microstructure in the PICO2303 and AHMIF cores."

Regional velocity (C6)

Note that velocities are described in more detail under the paragraph that is added in the Introduction at L98 under the header "Velocity in the Allan Hills BIA area" above. However, we add the discussion paragraph below at L188.

"From horizontal velocity data of Spaulding et al. (2012), Dadic et al. (2015) estimate that the bottom of the AHMIF core was 160 m upstream 1000 yrs ago, and that the core remained within the topographic depression and accumulation area it was extracted from. Similarly, if we assume the velocity at PICO2303 is around those estimated at P18 and P19, the PICO2303 core remained in the region of the snow plains during its formation."

Variability in accumulation rate and other processes (C3)

"Despite residing in their respective regions during their formation, the cores have likely been influenced by variability in accumulation rate. Spaulding et al. (2012) state that the accumulation rate in the snow plains is highly variable because of the presence and migration of large sastrugi (up to 1 m) formed by katabatic winds. The strength and direction of the surface winds have seasonal and annual variability, which generates short-term fluctuations in the local accumulation rate. In opposition, wind erosion implies that shallow firn is exposed longer to near-surface processes. Thus, short-term fluctuations in surface winds and deposition lead to differences in the surface density layer and observed microstructure (e.g., type of depth hoar) (Pfeffer et al., 2002). For example, Dadic et al. (2015) suggest from Pb-210 activity that post-depositional migration of the snow is partly responsible for the AHMIF core's profile where the upper 0.3 m shows distinctive layering indicative of wind erosion. This implies that any accumulation at AHMIF must have survived erosion if it was deposited at high wind speed and close to the initial density of the random close packing (Dadic et al., 2015)."

Age difference (C3)

"The long exposure time of the firn in both cores is validated by our age estimates. For the AHMIF core, our estimate using the Herron and Langway (1980) model predicts an age of 412 years at the bottom of the core (z = 5 m), which is over two hundred years younger than the age predicted by Dadic et al. (2015). Dadic et al. (2015) based their calculations on those from Crozaz and others (1964), and calculated the bottom of the core to be around 660 years old using the same accumulation rate of 0.0075 m weq yr^{-1}. For the PICO2303 core, our estimations using the Herron and Langway (1980) model range anywhere from 30 years to over 100 years at z = 5 m. This indicates a predicted age difference between the two cores of several hundred years at this depth, which may be much smaller than in reality as our modeled estimates do not include wind erosion and its potential removal of layers. Further, Dadic et al. (2015) suggest snow below 0.3 m in the AHMIF core is older than 100 years, making our age estimates underestimations even at that depth."

Other post-depositional processes (C3)

"Other post-depositional processes may be at play as well. The density data show that 1) the mean density increase is not significant in the near surface of either core, which is likely from the lack of sufficient overburden pressure needed to instigate structural compaction; and 2) the observed decreases in density in both cores are likely from a decrease in mass loss from the temperature gradient. For example, upward vapor flux instigated from the temperature gradient in shallow firn may not be condensed but instead lost to the atmosphere. (e.g., Inoue et al., 2024)."

Horizontal strain

"Additionally, horizontal strain affects layer depths and metamorphism. More specifically, horizontal strain from ice-flow stresses impacts firn compaction in two ways: thinning due to dilatation and "strain softening" which arises due to the acceleration of time-dependent microphysical densification processes (Horlings et al., 2021; Oraschewski et al., 2022). For example, firn-air content may be 4-6% less from horizontal strain rates of 10^{-3} per year as a result of layer thinning alone, given typical West Antarctic climate conditions (Horlings et al., 2021). On a microphysical scale, power-law creep is enhanced by horizontal stresses because it scales with the square of the effective stress and can lower viscosity, mainly impacting stage 2 densification (Alley and Bentley, 1988). Due to the lack of sufficient overburden pressure to instigate high initial rates of creep, we assume the overall contribution of horizontal strain is negligible."

Specific comments

Abstract

L3: Some of the oldest ice cores are located in blue-ice areas ...

May be instead: Some of the ice cores with the oldest ice are located in blue-ice areas.

We agree with this edit and fix it within the manuscript.

L6: .. impact of very low-accumulation rates (A= O(10−3 −10−2 m a-1))

is estimated or measured?

This is an approximate accumulation rate range that follows Courville et al. (2010), where they state that the accumulation rate has a first-order effect on firn properties, including microstructure, at polar sites with accumulation rates less than approximately 40 mm weq yr^{-1}.

Easier to read would be: 1 mm to 1 cm per year or so, ice or water equivalent or snow

We would like to keep the units in base units. However, we agree that the inclusion of ice or water equivalent is critical. These are in water equivalent and we have added this into the manuscript.

L12ff

Differences between parameters of the two cores alone are not very helpful if their averages are not given.

We agree that more quantitative information is necessary. However, averages amongst a complete parameter set obscures gradients or thresholds, which may be misleading. Thus, we add the statistical analysis shown in the response to R1's Comment 1 and 2.

-------------1.1 Core Location

Figure 2: units in km would be easier to read

We rewrite both axes in Figure 2 to be in kilometers. We also included the AWS location on the map.

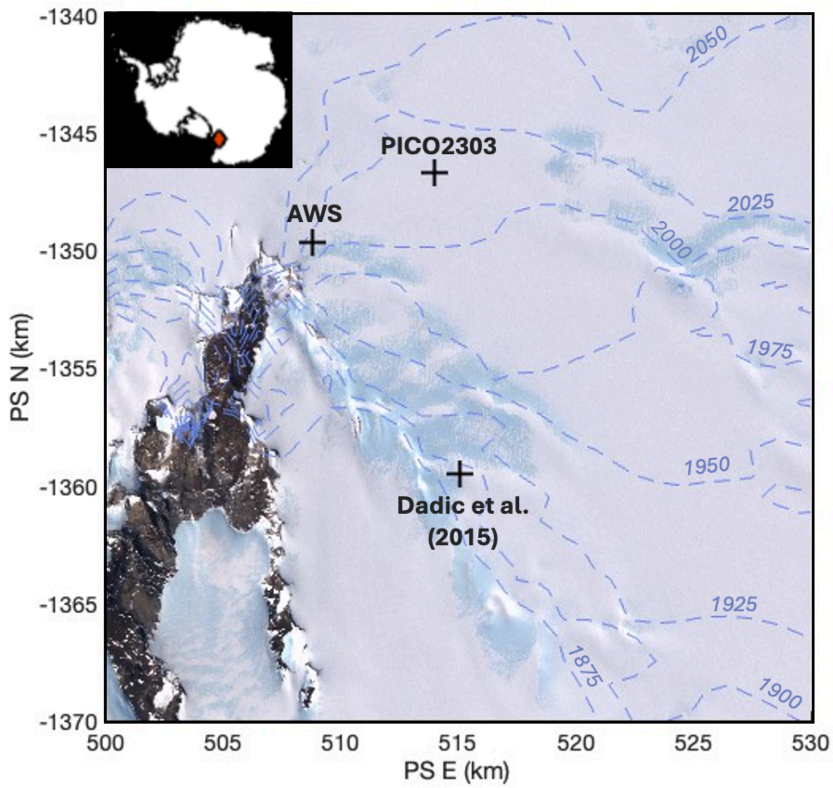

Figure 2. A map showing location of the two firn cores discussed in this paper at Allan Hills BIA, Antarctica: PICO2303 firn core (dark blue circle) and the firn core collected by Dadic et al. (2015) (light blue circle). Elevation contours (in m) from REMA (Howat and others, 2019) are superimposed on Natural-Color, Pan-Sharpened imagery that combines Landsat ETM+ bands 3,2,1 (red, green, and blue of the electromagnetic spectrum) from the Landsat Image Mosaic of Antarctica (LIMA) Projection. Blue shaded color on the map represents the wind-swept glacial blue ice that outcrops at the surface. The map inset shows location of figure domain in Antarctica. The projection is polar stereographic (EPSG: 3031).

L91 and L94/95: -76.667°S, 159.25°E, ... missing is °S/E

We add degree symbols to the longitude/latitude.

Somewhere within in the introduction section I am missing useful site information about this blue ice region given by Spaulding et al., 2012.

See above replies that address site information given by Spaulding et al. (2012).

-------- 1.2 Climate at Allan Hills BIA

Missing here is the annual mean temperature or a 10 m firn temperature and summer mean and not only daily variations.

While we agree that having a 10-m firn temperature would be beneficial, there is no firn temperature recorded at the Allan Hills, to our knowledge.

We calculate the mean and standard deviation of the automated weather-station data (wind speed, wind direction, temperature) shown in Table A1 below and included in the Appendix.

Table A1. Automated weather-station data recorded on a PPMK impermanent weather station for the field campaign years for variable time periods (Figure 4). Mean temperature, wind speed, and wind direction as well as associated standard deviations are listed. Note that no temperature data was recorded in 2015.

Year	$\bar{T}$, σ_T **(°C)**	$\bar{u}$, σ_u **(knots)**	$\bar{\theta}_u$, σ_θ**(°)**
2010	-14.63, 3.06	6.21, 5.04	179.71, 85.47
2011	-20.71, 1.57	8.84, 0.86	195.29, 8.74
2015	NaN	10.55, 5.55	47.14, 61.45
2016	-19.88, 3.61	6.07, 3.33	143.33, 99.55
2019	-15.81, 4.79	7.23, 3.34	213.49, 68.19
2020	-15.82, 0.95	11.00, 0.89	210.35, 38.56
2022	-19.84, 3.96	8.26, 3.87	204.16, 39.21
2023	-20.06, 3.61	8.87, 3.78	193.80, 70.56
2024	-18.69, 3.44	5.57, 2.75	206.49, 24.55

Additionally, we reflect the changes in the adaptation of Figure 4, below.

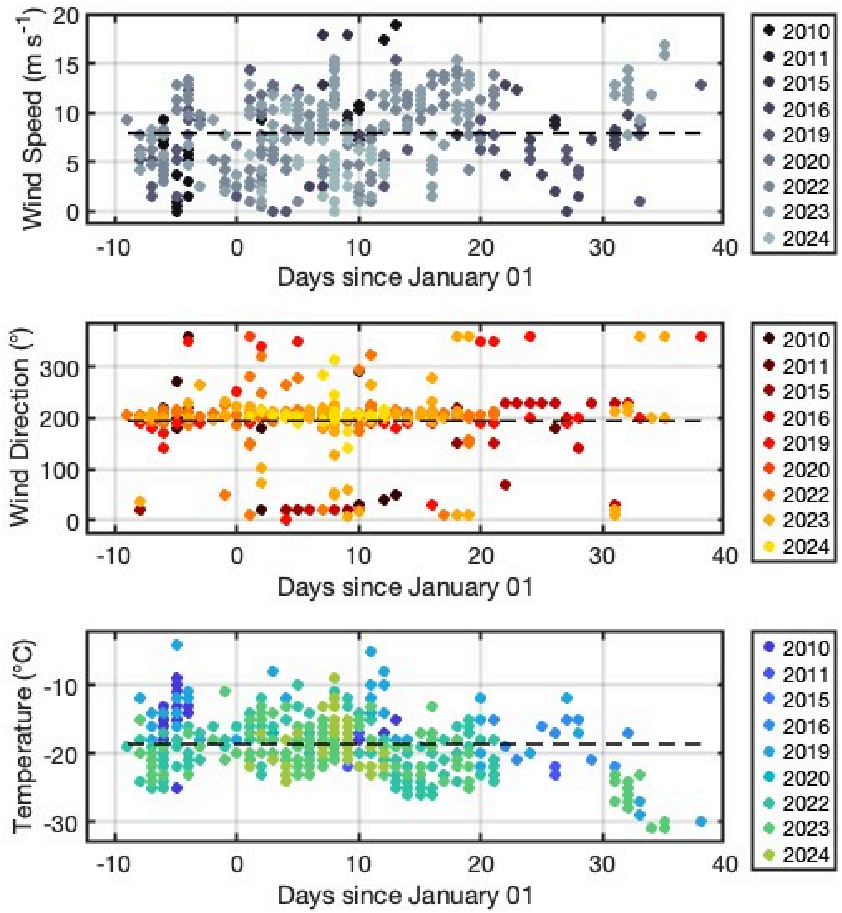

Figure 4. Wind speed relative to grid north (a), wind direction (b), and temperature (c) data from the weather station from summer of 2010, 2016, 2019, and 2022 (Naval Information Warfare Center Atlantic, Polar Programs Integrated Product Team (NPP), 2024). Black dashed lines are the averages across all data. Automated weather station data was recorded in 2010, 2011, 2015, 2016, 2019, 2020, 2022, 2023, and 2024 at -76.742 degrees, -159.345 degrees at the Allan Hills.

- Position of the AWS? how close was it to the Pico23 site? Please mark it in Fig. 2

The latitude is -76.742 degrees and longitude 159.345 degrees. We mark the AWS in Figure 2.

- which data are presented? hourly or daily averages ?

Data were sampled at 10-minute intervals by the AWS.

- wind was measured at which height?

Wind was measured with an anemometer positioned at 2 - 3 m in height on the automatic weather station (AWS) (Isabella Onsi, personal communication, June 2026). The AWS was constructed during each field campaign and thus the height of the instruments, including the anemometer, varied between field seasons.

- is/was it a permanent AWS and if yes then please also present annual data

This was an impermanent AWS deployed during four field campaigns, occurring over various intervals during the austral summer. Consequently, we do not have annual data from the site.

- please define grid north - is it identical to true north?

Polar stereographic coordinate systems are commonly used for Antarctica because of issues that arise while using lat/long the further south one is. For example, all meridians converge at the south pole, and therefore "true north" varies depending on your location. However, grid north, in the polar stereographic coordinate system, is a fixed direction and designated arbitrarily along the prime meridian. In Figure 2, grid north is designated towards the positive *x* axis.

- there are obviously no accumulation sticks at this site although revisited over 4 field seasons

While there are current efforts to estimate accumulation rates near the PICO2303 core, there are currently no measured accumulation rates that we can report.

-------- 1.3 Micro-computed tomography (micro-CT)

L119:

rho = (m3/m3)/kg/m3 = m3/kg ??? change "/" to "*"

We agree with this comment and apologize for the error. We correct the equation from '/' to '*'.

L120

DA = 1− (λmin/λmax)

this definition does not allow to infer if the preferred alignment of a structure is vertical or horizontal

We agree that this is indeed confusing given the definition, so we edit the language to the following (L120): "Degree of anisotropy (DA) is a parameter to assess how much the structure varies from total isotopy (DA=0), to total anisotropy, (DA=1)." We have also clarified that this is the definition of DA that CTAn, the proprietary software packaged used for processing micro-CT data, uses (L121). "It is calculated from CTAn using the minimum and maximum eigenvalues…"

Please write somewhere how many µCT samples did you take or what resolution you have chosen?

The resolution is referenced on L108 as 39.49 micrometers. There were 61 samples and 187 scans of the PICO2303 core from 0 to 11.3 m. This is edited at L108 (Section: Introduction, subsection 1.3): “Imaging of the firn core is performed on 61 samples through 187 scans…”

-------- 1.4 Comparison of cores

Figure 5:

most likely shown are vertical projection?

These are cross-sectional images. We add this information in the figure caption of Figure 5 and 6.

Helpful if noted: scale bar is 2 mm

We add this information within the figure caption.

--------- 2 Results

L170:

There is some trend in DA obvious despite the high scatter

We agree with this comment that there is some trend although it is unclear and with high scatter. We edit the text at L170 (Section: Results) to: “Additionally, degree of anisotropy (DA) shows a trend towards more isotropic values (see Figure 7) although it is characterized by large fluctuations…”

Wind crusts:

They take a lot of space in the MS in particular as their formation is not at all fully understood. They are nice visible features to have. The wind crusts I have seen did not show large grains (L196: large-grained WC) and not much is known about their spatial distribution. They are always restricted to a very limited area (dimension of a snow patch, order of 10 m by 10-50 m or so). So it might also be statistical problem to observe or not observe a wind crust.

We address this in the above section on wind crusts on page 2 on this document.

------- 3.1 Operating processes

Figure 7:

In Fig. 7e,f Structure thickness and SSA show a change in their gradients below about 4 m depth. Changes of the slope are not observed in DA and density. This is not discussed.

We appreciate the reviewers comment and add the following after the first paragraph of Subsection 3.1 at L188 above the text outlined on pg 7-9 of this document:

"We observe that the gradients in structure thickness and SSA have a marked change at around 3.5 m in depth. Generally, SSA decrease corresponding to grain growth during temperature-gradient metamorphism (TGM) has been observed in the first few meters of firn in interior Antarctica (e.g., Gallet et al., 2011; Calonne et al., 2017) as well as in the laboratory (e.g, Marbouty, 1980; Calonne et al., 2014). Further, previous studies have noted that two depth ranges appear for the trends in SSA: 1) 0 - 0.5 m, and 2) 0.5 - 3 m). The first, at the very near-surface, higher SSA and density is formed from wind packing due to strong winds and subsequent redistribution through fragmentation into fine grains (Domine et al., 2009). Second, the change in gradient in SSA observed at around 3 m depth has been observed at other sites (e.g., Dome Fuji) and is a result of the decrease in the temperature gradient (Inoue et al., 2024). Accumulation rate may also influence SSA. For example, Inoue et al. (2024) showed that lower SSA occurs at lower accumulation rate sites, which suggested to be a result of a stronger TGM from longer residence times. Accumulation rate in part determines the residence time of a layer in the top few meters where the temperature gradient is strong (Inoue et al., 2024). Thus, lower accumulation rates will create longer residence times (e.g., Courville et al., 2007; Hörhold et al., 2009). Other factors, such as the depositional environment, influence SSA values as well (e.g., Inoue et al., 2024). For example, lower topographic slopes may cause wind-driven preferential deposition of fragmented snow (Domine et al., 2009). Further, post-depositional changes from TGM have been suggested to not fully replace the initial SSA variations from the original surficial depositional environment (Inoue et al., 2024). Our comparisons show that 1) from 0 - 0.3 m, SSA at AHMIF shows higher values, and 2) from 0.3 m - 5m, SSA at PICO2303 is higher. This suggests validation of previous studies, where higher winds cause larger effects of wind-packing and subsequent redistribution, while longer residence times result in lower SSA (Inoue et al., 2024)."

Figure 8:

- The best-fit of the structure thickness in Fig. 8a seems to be the best fit of the two data sets. Is this meaningful and why?

We include the text below to address this comment following the response to the previous comment on SSA at L188 (Section: Discussion): "The impact of accumulation rate and depositional environment versus post-depositional changes through TGM manifest in the evolution of microstructure. In the upper 5 m, the best-fit curve for structure thickness of PICO2303 resembles that of AHMIF. However, because the curves are similar in both slope and intercept, our results indicate that structure thickness may not be a good indication parameter because it does not allow for the separation of effects at sites with different conditions." Further, we have decided to include best-fit curves for each dataset of Figure 8. This is expanded in the response to R1 Comment 1.

- You shift the best-fit in SSA of the AHMIF core into the Pico2303 core SSA. This is not discussed why.

We agree that this discussion is lacking, and include the following at L188 (Section: Discussion) in between the responses to the previous two comments: “If we assume either that (1) wind erosion occurred at AHMIF or (2) differences in SSA from initial deposition are not fully replaced by post-depositional processes, then the shift either indicates (1) potential depth of erosion if all other variables stay constant or (2) the representation of differences in surface initial depositional processes.” However, to address R1’s comments as well, we have replaced the shifted best-fit curve with the dataset’s own best fit curve to highlight differences more readily.

Snow patches in blue ice regions belong probably to the regions with the most dynamic snow surfaces in any respect - in particular Sastrugi up 1 m height are reported by Spaulding et al., 2012. I am not wondering why wind crusts are inclined or horizontal and why temperature gradient metamorphism above densities of 350 kg/m3 should not be possible. TGM is commonly observed in areas with "normal" accumulation rates within limited boundaries in the controlling parameters. Snow on blue ice is not a standard case.

We are unsure of the specific meaning of the reviewer’s comment. We assumed that the reviewer is unsure if the TGM is commonly observed in snowpatches in blue ice regions. TGM is prevalent in the near-surface firn as much of the literature expands upon (e.g., Colbeck, 1983; Pinzer et al. 2012; Inoue et al, 2024). More specifically, diurnal and seasonal variations in insolation produce variable surface heating which cause a vertical temperature gradient in the upper few meters, inducing TGM via vertical vapor transport (Inoue et al., 2024). The data from the AHMIF core is from the upper 5 meters, and so has been exposed to consequences of diurnal and seasonal variations, namely, TGM, regardless of the complexity of those effects.

If we misunderstood the reviewer’s comment, we would be eager for clarification during the next round of reviews.

L190

why is higher SSA indicating high winds in the top most centimeters but shows the opposite relationship found in greater depth where SSA decreases with increasing density? How do you explain?

At the surface, wind-packed layers are formed with higher SSA and density from strong winds. At depth, a longer exposure under a temperature gradient may cause vertically elongated microstructure and lower SSA (Inoue et al., 2024). As we stated in the above response on the comment on SSA with added MS text at L188 (Section: Discussion), our comparisons show that 1) from 0 - 0.3 m, SSA at AHMIF shows higher values, and 2) from 0.3 m - 5m, SSA at PICO2303 is higher. This suggests validation of previous studies, where higher winds cause larger effects of wind-packing and subsequent redistribution, while longer residence times result in lower SSA (Inoue et al., 2024).

Instead of showing as inset the SSA versus depth profile I suggest to show a scatter plot SSA vs. density. I assume that all data are derived from the same samples. Therefore it would be interesting to see scatter plots of the different parameters if they provide additional information.

We did analyze figures using density in replacement of depth during previous rounds of revision of the MS and decided to not keep those figures in the final draft as we did not believe they added additional information to the MS.

L192:

Lack of wind crusts below ~30 cm is probably not surprising as the firn is old and the metamorphism phase of the AHMIF core is unknown. Do wind crusts survive heavy metamorphism?

Weinhart et al. (2020) assume that only strong crusts will survive strong firn metamorphism. Further, they state that there is also a higher potential for destruction at the surface from other processes which, at low accumulation sites, may be from high snow grain mobility.

This is addressed within the response section labeled "Impacts on wind crust formation" on page 2 of this document.

L200±

Air/vapour movement in porous firn is an interesting aspect for the interpretation of isotope profiles but challenging in a blue ice region when the age is not well constrained. So here more a side aspect here.

We thank the reviewer for this comment and add the following to edit the text on L250 (Section: Discussion):

"The Allan Hills Blue Ice Area is the source of a multitude of ancient ice cores, including the oldest ice on Earth (up to 6 million years old) (Shackleton et al., 2025). Ice that currently flows into the Allan Hills Blue Ice Area is sourced from the low-snowfall accumulation area ~20km upstream (Faure et al., 1992; Spaulding et al.). Quantifying post-depositional processes targeting where the Allan Hills ice cores originated is key to understanding alteration of the water-isotope record used for temperature reconstructions derived from these old ice cores at the Allan Hills Blue Ice Area (e.g., Hu et al., 2022).

The combination of high permeability and high winds increases water-vapor exchange between the atmosphere and the subsurface through snow and firn ventilation which promotes advection. In general, surface and subsurface processes in the snow and firn can drive kinetic fractionation. This process involves the exchange of molecules between the solid and vapor phases, modifying the stable water-isotope ratios from those originally established during snow precipitation. In just the surface snow alone, the atmospheric vapor-snow exchange may explain 36% of summertime day-to-day $\delta 18O$ variability between precipitation events (Wahl et al., 2022); subsurface post-depositional impacts are less well-constrained and are therefore subject of many relatively recent studies (e.g., Town et al., 2008; Wahl et al., 2021; Wahl et al., 2022)."

L212: Effect of wind

see my comments about wind packing density above

We address this above where these comments were first posed.

L247

"... while higher wind speeds generate high-impact deposition, and thus the higher density cap and higher SSA near the surface."

I do not understand.

We edit the manuscript for clarity: "...while higher wind speeds at AHMIF might generate high-impact deposition…"

Recommendation

The MS presents another interesting new data of microstructure and physical properties from a blue ice region studied not much yet. However, the discussion and the interpretation appears too focussed to a single explanation: wind packing. Other interpretations appear possible. Therefore, I recommend major revision.

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