Detailed responses to the comments from reviewer #1

The authors present an extended total air content record for EPICA Dome C (EDC) as well as investigate other previously published TAC datasets to understand different climate parameters' influence on TAC. The authors indicate that the records can be used for orbital tuning but only after considering local climatic influences on the TAC record. Overall, very well written and thorough manuscript that does an excellent job summarizing not only the current state of understanding of TAC but also explores new ways to consider TAC in different climate instances. I recommend the manuscript be published after considering the following minor comments:

We thank the referee for their thorough reading of our manuscript. Their comments have helped us improve both the analysis and the presentation of the results. Below, we provide detailed point-by-point responses (in blue) and changes in the text (in bold blue) to each comment (in black). The changes will also be visible in the track-change version of the manuscript.

Page 4, line 96: "...(Clausius-Clapeyron)" is a reference that makes sense here, but should be written out. A quick sentence about how the CC relationship relates here or even adding the relationship would add to the manuscript.

We added a short clarifying sentence in the revised manuscript. We opted not to include the full equation to avoid adding technical complexity to an already dense manuscript.

(103) **"Temperature affects atmospheric moisture capacity through the Clausius-Clapeyron relationship, which describes the exponential increase in saturation vapour pressure with temperature**"

Pg 4, ln 99: Use of parenthesis back to back made the sentence difficult to read. Recommend rewording it.

This sentence is reworded in a rewritten paragraph (see second review):

(131) **"Accumulation rates fundamentally control the timeline of firn densification, with higher rates reducing the time available for grain growth near the surface and the age difference (Δ-age) between ice and trapped gas (Alley et al., 1982; Schwander and Stauffer, 1984; Edwards and Epifanio, 2025)."**

Pg 8, ln 160 and pg 20 ln 399: Typo - Remove period inside parenthesis of "(Equation 1.).". Actually, lots of extra periods inside parenthesis when referring to figures and tables.

We thank the referee for pointing this out. We have removed the extra periods inside parentheses throughout the manuscript when referring to equations, figures, and tables (e.g., "(Equation 1.)" = "(Equation 1)")

Pg 11, ln 253: Remove quotes from “Densification age scale”. Quotations are unnecessary. Also related, on page 12, ln 273, you then refer to the same concept as a ‘densification integrated’ age-scale. Recommend to pick one label for the concept. However, I’m glad to see an in depth discussion of this issue, and appreciate the need for a densification age scale to be developed.

We agree that using two different labels for the same concept was confusing. We have removed the quotation marks around "Densification age scale" (page 11, line 253) and have harmonised the terminology throughout the manuscript, consistently referring to this concept as the **densification age scale**.

Page 14, figure 2 – The newly measured TAC in figure 2a seems to be much higher resolution than older data. In section 3.1 you compare the resolution of the Bern and IGE datasets. What is the resolution comparison between the older and newer IGE datasets? I don’t suspect it does, but does this change the analysis in any way?

We indeed checked the temporal resolution of the two IGE sub-periods separately: the recent interval (0-440 ka, Raynaud et al., 2007, n=213) has a mean resolution of 2.05 ka (median 2.12 ka), while the new extension (440-800 ka, this study, n=179) has a mean resolution of 2.02 ka (median 1.83 ka). These values are very similar, confirming that this does not change the analysis in any way.

Pg 16, figure 4b – the ‘HYSI+1 and HYSI +2’ labels are a bit confusing. I spent a while thinking that the HYSI +2 was a multiple regression using HYSI, temperature AND accumulation, while I see now that it is HYSI and accumulation. Consider different labels, or being more clear in the caption.

We agree this cross-referencing between panels was not sufficiently clear. We have relabelled the columns in Fig. 4b as "HYSI+acc." and "HYSI+temp." to remove any ambiguity, and we have also clarified this in the figure caption.

Pg 16, figure 4b – why is there no data for DF HYSI +2? There is data in the single regression for both temperature and accumulation, so I would expect the mulitple regression to have some solution.

We acknowledge this apparent inconsistency. There is no missing data: multiple regression results for DF are present in Fig. 4b. The apparent inconsistency comes from sites that were sorted independently in each panel. We have now used a consistent ordering across both panels to avoid this confusion.

Pg 18, ln 378: No need for a new paragraph after first sentence here.

We have implemented this change.

Pg 18, paragraph 3: This paragraph places an emphasis on the multiple regressions of HYSI + temperature. However, I also see in figure 4b you did multiple regressions with both temperature and accumulation (though not in the same regression). Did you do multiple regressions with both temperature and accumulation? If not, why? Also, some discussion on how accumulation changes the strength of the regressions would be helpful.

We thank the referee for this question. We did not perform a triple multiple regression combining HYSI, temperature, and accumulation together, as we consider the pairs HYSI+temperature and HYSI+accumulation separately (Fig. 4b). This choice was made because temperature and accumulation are not independent parameters at most sites (see Section 4.1 and the discussion of the Clausius-Clapeyron relationship, Fig. 8a), so combining all three predictors in a single regression would introduce strong multicollinearity, making the individual regression coefficients difficult to interpret physically.

"While both accumulation and temperature improve the HYSI regression at most sites (Fig. 4b), these parameters are themselves correlated (Fig. 6a), which limits our ability to attribute the improvement to one parameter individually."

Page 21, Figure 7 caption: confusing wording after "**b.** Vc values **and** Present-day temperature **c.** Present-day accumulation". Maybe move the reference to Vc before the '**b."** Since it makes the following insets (c-e) seem like they are not compared to anything. I had to read the caption a couple times to understand it.

We have implemented this change.

Page 22, line 428: "In line with the observations from Fig 7.e…" was a bit confusing because you then go on to describe how there is not correlation at the EAIS sites between HYSI and Vcr, when fig 7e definitely shows a correlation (though its between HYSI and Vc). Maybe something like "different from the observations in Fig 7.e" would be more clear.

We have implemented this change.

Page 23, figure 8: A bit of confusion on labels with this figure.

Change the WAIS ice cores to a different shape to more easily see them, like you used squares for Greenland ice cores. The use of different shades of greens for three ice cores on two different regional correlations makes it difficult to see which ice core is which.

We have updated Fig. 6 to use distinct marker shapes (circles for EAIS, triangles for WAIS, squares for Greenland) and a unified color scheme by region (blue, green, red respectively).

Fig. 8 will be replaced by the following figure:

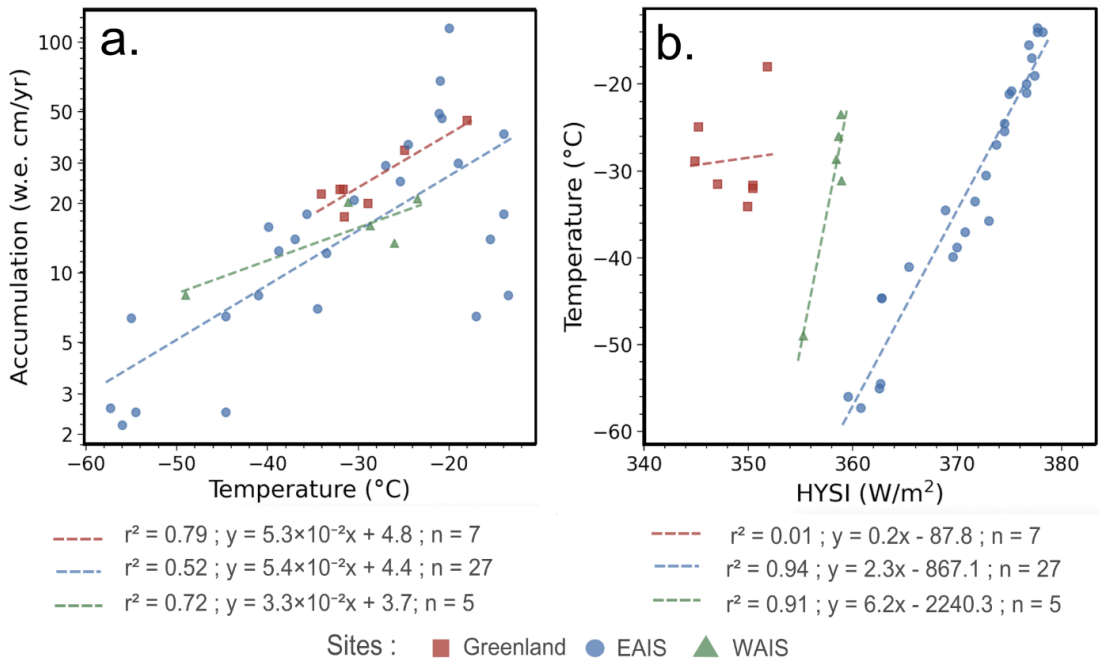


Figure 8. Temperature relationships across polar ice core sites. Scatter plots showing a. present-day accumulation rates versus mean annual temperature and b. mean annual temperature versus Half Year Summer Insolation (HYSI) for compiled ice core sites (Table 1). Linear regression lines highlighting different climatic regimes for EAIS sites (blue circles; DF, EDC, TALDICE, Vostok, BHF, BHJ, BHP, BHB, BHQ, D-10, DE08, BHD, Mizuho, D-57, KM-60, KM-73, KM-105, KM-140, KM-200, KM-260, KM-325, KM-369, KM-400, D-47, B34, B37 and BEOI), WAIS sites (green triangles; WD, SP, SK, RICE and Byrd) and Greenland sites (red squares; GRIP, NEEM, GISP2, NGRIP, RECAP, Camp Century and EUROCORE).

On a different note, the WAIS ice core should be called WD (to avoid confusion with the West Antarctic Ice Sheet).

We changed this throughout the manuscript. WD is now referring to WAIS Divide ice core and WAIS refers to the West Antarctic Ice Sheet.

What are the dark grey diamond shapes? They don't seem to appear in figure 8a, but do appear in figure 8b.

The dark grey diamonds corresponded to the KM traverse sites (Martinerie et al., 1994), which lacked published temperature and accumulation data and therefore did not appear in panel a. In the revised figure, all sites including the KM traverse are now uniformly color- and shape-coded by regional group.

Related to Figure 8 - Did you look at a correlation between accumulation and HYSI? It may also highlight the regional difference in TAC behavior. The R2 for temperature/HYSI in Greenland cores is 0.00, but

might be different for accumulation, further strengthening your conclusion that climate-regime needs to be considered when parameterizing TAC.

We investigated the correlation between accumulation and HYSI across sites (Fig. R1). Consistent with the temperature/HYSI relationship shown in Fig. 8b, Greenland sites show no significant correlation between accumulation and HYSI (R^2=0.06), while EAIS sites show a moderate correlation (R^2=0.62). We note that any accumulation/HYSI correlation is physically mediated through temperature via the Clausius-Clapeyron relationship and therefore does not provide independent information beyond Fig. 8a and 8b. For this reason, we present this figure in the response here only and do not include it in the revised manuscript.

We stress that although we observe that Greenland surface climate is not clearly coupled to local insolation at the spatial scale, the small number of sites (n=7) and their limited insolation range prevent formulating firm conclusions. We note that at the temporal scale, Greenland TAC records do correlate with local insolation (Fig. 4), suggesting such a link exists but cannot be resolved with the current spatial dataset.

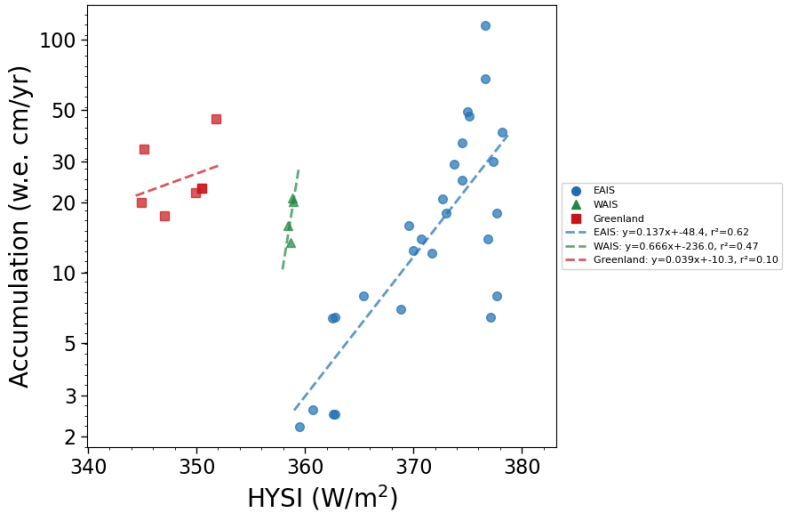


Fig. R1: Scatter plots showing a. present-day accumulation rates versus HYSI

Pg 26, line 518: Don't use 'both' and then describe three parameters. Use the word 'all' or restructure the sentence.

We have implemented this change.

Finally, please also note that, compared to the original manuscript, NEEM and GISP2 have been added to the spatial and temporal analyses (holocene analysis). This addition may result in minor differences in

some regression values reported in the revised manuscript relative to those cited in our responses below. Additionally, a minor error in the insolation index computation was corrected, which affects absolute HYSI values and some linear regression (not significantly) but does not alter any of the conclusions drawn in the manuscript.

The manuscript has also undergone substantial structural revisions in response to Reviewer #2's comments, including a reorganisation into separate spatial- and temporal-scale sections and a revised interpretation of the spatial Vc–HYSI relationship; we refer Reviewer 1 to our detailed responses to Reviewer #2 to see the implemented changes.

Bibliography

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