Review "*Greenland climate simulations show high Eemian surface melt"* by Plach et al.

The authors compare modeled and measured Eemian (130-115 ka) total air content (TAC) extracted from seven ice cores drilled in Greenland and the Canadian Arctic. TAC is a proxy commonly used to infer past changes in surface elevation since the density of air trapped in the ice declines with altitude. The authors show that low TAC values observed in Greenland Eemian ice are affected by high melt rates and subsequent refreezing that reduce TAC through the formation of ice layers (referred to as melt layers). Therefore, high Eemian melt rates could explain the low measured TAC in ice cores, a process that should be considered when estimating surface elevation changes in past warm periods.

The paper is well-written and provides important insights on the impact of Eemian high melt rates on measured TAC that should be accounted for to accurately estimate surface elevation changes in past warm periods. The paper would benefit from additional clarifications/details regarding the methods, model evaluation and study limitations. The reviewer deems that **minor revisions** are required before publication in *Climate of the Past*. The reviewer's comments are summarized hereunder.

General comments

1. The authors use the climate model MAR to dynamically downscale two Eemian time slices from the Earth System Model NorESM1-F (125 and 115 ka) as well as a pre-industrial control run. Modeled melt, refreezing and temperature are the core of the study as these are used to estimate modeled TAC that are compared with Eemian ice cores observations. The description of the MAR model is however not sufficient. The authors should mention which model version is used, and at what spatial resolution (i.e. 25 km in **L67** appears too late in the text). The authors should also briefly describe in Section 2 how surface melt (SEB-derived) and subsequent refreezing are calculated in MAR.
2. The authors prescribe a fixed contemporary Greenland ice sheet geometry in MAR to simulate the surface mass balance (SMB) components over the warmer than present Eemian period. This is acceptable given the lack of an accurate estimate of Eemian ice sheet geometry and the high computational costs of an offline coupling with an ice dynamics model (e.g. Le clec'h et al., 2019). However, the authors should discuss the limitations and uncertainties introduced by the use of a fixed modern ice sheet geometry. For instance, Van de Berg et al. (2011) and references therein suggest a 30-60% ice sheet volume reduction in the Eemian relative to present-day. Consequently, simulating melt and SMB on a more extensive, modern ice sheet may artificially cause high melt rates over larger ablation zones than expected if using a more accurate Eemian ice sheet geometry. Could the authors elaborate on this matter? Figure 1 could also show MAR melt rates averaged for the Eemian period 125 ka as a background.
3. The Eemian period is characterized by a climate significantly warmer than today, however in Fig. 2, annual mean near-surface temperature from the pre-industrial, 125 ka and 115 ka Eemian periods are almost systematically colder than or roughly equal to present-day observations. This is confusing especially since summer temperatures in the Eemian shown in Fig. 3 are considerably higher than present-day (3-4 K). Is this the result of a more pronounced seasonality of the Eemian climate, i.e. with colder winters and warmer summers, making the average annual temperature comparable to present-day but with markedly warmer summers? Could the authors further comment on this?

Point comments

L6: The reviewer suggests reformulating as: "Therefore, simulating high Eemian melt rates and associated melt layers is beneficial to improve the representation of past surface elevation."
L23: The authors could reformulate as: "However, refrozen melt has the potential to form impermeable ice layers (melt layers henceforth) that alter the diffusion of ice core signals."
L33-35: With respect to which period are these temperature anomalies estimated?
L39: The site GISP2 is not shown in Fig. 1 nor referred to elsewhere in the manuscript. The authors could remove "(used synonymous … proximity)."
L40: The authors could mention that Agassiz ice cap is situated in the northern Canadian Arctic.
L42: "evaluated" instead of "validated", same comment in **L50.** The authors should stress that present-day measurements are used as a reference for comparison with a warmer Eemian and colder

pre-industrial climate rather than for model "evaluation". Strictly speaking, present-day observations cannot be used to "validate" nor "evaluate" Eemian or pre-industrial climate.

L47: The reviewer suggests: "based on **two** Eemian time slice simulations … conditions and one pre-industrial (PI; **YYYY-YYYY**) control simulation." Later on in the text (**L52**) "four" Eemian experiments are mentioned while only two (125 and 115 ka) are described in the text. Please, mention the period spanned by the pre-industrial control run (e.g. 1850-1949?) as well as the 125 and 115 ka runs (i.e. number of thin lines in e.g. Fig. 2).

L51: Maybe "All climate simulations use a fixed, modern ice sheet geometry, in lack …" See also general comment #2, i.e. a too large ice sheet extent are likely to artificially increase surface melt.

L54: To clarify, the reviewer strongly suggests to replace "SEB-derived SMB" by "MAR SMB" across the manuscript.

L56: The authors could reformulate as: "Additionally, while providing the most complete representation of physical surface processes in the pool of investigated models, MAR shows lower Eemian melt rates (**XX**%) than intermediate complexity SMB models.".

L62: "Eemian ice sheet volume equivalent to ~0.5 m …"

L71: "SMB simulations are compared to present-day satellite …", see also comment in **L42**.

L76: The authors could reformulate as: "covers the whole MAR grid at 25 km from May to September for most years between 1979-2010".

L93-100: This paragraph describing the data sets presented in Figs. 6 and 7 should be moved to **P9** under Subsection *Total air content (TAC).*

L119: In Eq. 6 "$C_{a,O2}$" instead of "$C_{a,N2}$".

L124-126: To the reviewer's knowledge, average pre-industrial temperatures should be colder than present-day observations. Could the authors elaborate on this?

L128-129: "The lower borehole … than near-surface temperature". The sentence is unclear, could the authors reformulate?

L131-133: This is confusing as temperature in the Eemian should be warmer and pre-indutrial temperature colder than present-day. For instance, how should readers interpret the fact that near-surface temperatures at NGRIP are systematically warmer in the pre-industrial period than in present-day? See also general comment #2

L132: "(Fig. 2; blue and orange)", there is no red data in Fig. 2.

L134-135: How come that the 3-4 K warming only appears in summer temperature, see also general comment #2.

L138: What do the authors mean by "precipitation-weighted temperatures"? How is this calculated? Why do annual precipitation-weighted temperatures show a warming similar to that of summer temperatures? What is the difference with the annual data shown in Fig. 2?

L161: The reviewer suggests: "~3,200 m elevation, refreezing surpasses 25% of the annual accumulation under 125 ka conditions. […] where refreezing percentages can reach 80-90%." It is much clearer to mention period averages (thick lines in Fig. 5) rather than single year values (thin lines).

L167-168: The authors should consider mentioning period averages as: "… 45-70 ml kg^{-1} on average, whereas … between 75-100 ml kg^{-1}. At Dye-3 … is about 25 ml kg^{-1} on average for the warm …"

L173: The authors should consider removing Dye-3 data in Fig. 7 as the ice core does not include Eemian ice.

L196: The reviewer suggests "the lowering and retreat of the Eemian ice sheet", see also general comment #2.

L204-206: This is unclear, could the authors reformulate?

L214: What do the authors mean by "100% melt"?

L260-261: Eemian melt derived from the regional climate model RACMO2 should be available from Van de Berg et al. (2011).

L264-267: Such analysis has been conducted in e.g. Fettweis et al. (2013) or Tedesco et al. (2020).

L272: The reviewer suggests: "The simulated air pressure … are used to estimate Eemian total air content (TAC). Simulated high melt rates could explain the low corresponding ice core TAC observations."

Style

L3: The reviewer suggests "affect" instead of "influence". Same in **L21** and **L44.**

L5: Do the authors mean "high surface melt" or "enhanced surface melt relative to present-day"?

L9-10: Replace “elevated levels of surface melt” by “high melt rates”.
L10: “when interpreting measured Greenland TAC fluctuations as surface elevation changes.”
L19: “favorable for high melt rates across the Greenland ice sheet.”
L20: “alter” instead of “be a problem for”.
L26: Replace “can be applied on” by “can be estimated for”.
L37: “limited” instead of “small”.
L60: “larger” instead of “bigger”.
L201: “that the climate simulations might include a cold bias.”
L244: “air content to estimate ice surface elevation changes”.
L259: “obtain” instead of “accomplish”.

Figures
Fig. 1: The authors could consider showing MAR Eemian melt as a background (125 ka).
Figs. 2, 3, 5, 6 and A1-3: Data should be shown in chronological order: PI (pre-industrial), 115 ka (late Eemian), and then 125 ka (early-Eemian).
Fig. 4: Replace “nan” by e.g. “NA” for “Not Available” and explain the acronym in the caption. NAN commonly means “Not A Number” while the authors certainly mean “unavailable data”. How should readers interpret the fact that the number of melt days is higher in the present-day climate than in the warmer Eemian period at Agassiz site?
Fig. 6 caption: “almost completely overlaps with …”.

References
Le clec’h et al. (2019): https://tc.copernicus.org/articles/13/373/2019/
Van de Berg et al. (2011): https://www.nature.com/articles/ngeo1245#Sec7
Fettweis et al. (2013): https://tc.copernicus.org/articles/7/241/2013/
Tedesco et al. (2020): https://tc.copernicus.org/articles/14/1209/2020/