How dominant is surface mass balance during the Last Deglaciation using iTraCE?

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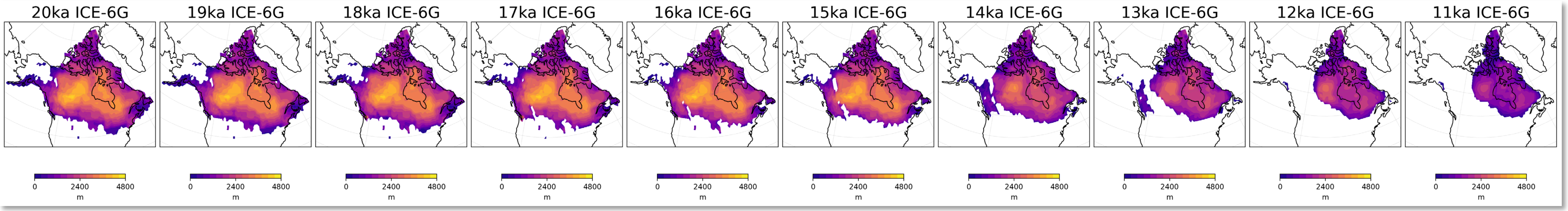
- **Glacial isostatic adjustment** and **sea level indicators** determine the path of the last deglaciation, yet the **primary role of climatic feedbacks** that might aid in this evolution are unknown



- How does the atmosphere/ocean interact with the ice sheet to determine accumulation/ablation patterns? Are **orbital configurations** the determining factor? **CO2**? **Meltwater forcing**?
- **In this work, we attempt to assess these climatic feedbacks using a surface mass balance (SMB) of the Laurentide ice sheet (LIS) of iTraCE.**

- Transient climate simulation of the *last deglaciation* from *20 ka to 11 ka* performed with the isotope-enabled version of CESM 1.3
- Prescribed ice sheet boundary conditions from ICE-6G and nonactive ice sheet
- Four experiments:
    - ICE: only evolving ice sheets and ocean bathymetry
    - ICE+ORB: evolving ice sheet and orbital conditions
    - ICE+GHG+ORB: ice sheet, orbital conditions, and greenhouse gas concentrations
    - ICE+GHG+ORB+WTR (or iTRACE): ice sheet, orbital, greenhouse gas, and melt water forcing (fully forced experiment)

Forcings used in iTraCE

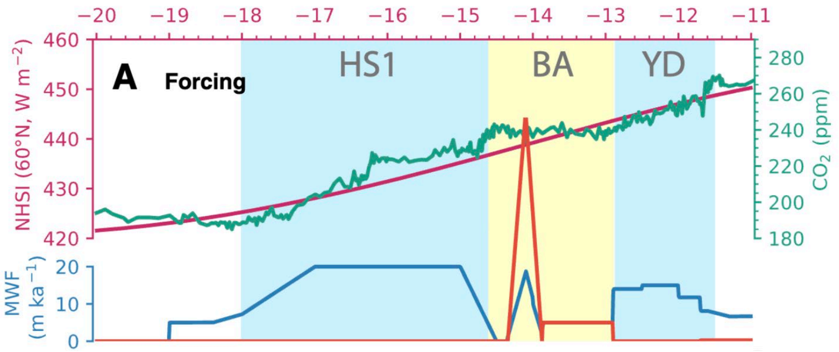


Fig. 1 from He et al., 2013. June insolation at 60N (red), atmospheric CO2 (green), meltwater fluxes in the Northern (blue) and Southern (orange) Hemisphere

Melt Parameterization

- To compute annual melt (m/yr w.e.), we use a surface energy balance given by (Vizcaino et al., 2013):

$$M = \frac{SW_d(1-\alpha) + (LW_d - \epsilon\sigma T_s^4) + SHF + LHF + GF}{L\rho_w}$$

- Where $SW_d(1-\alpha)$ defines net absorbed shortwave radiation, $(LW_d - \epsilon\sigma T_s^4)$ net longwave radiation at the surface, SHF sensible heat flux, LHF latent heat flux, and GF geothermal heat flux
- We take the numerator to be 'FGR' from the land component and divide by $L\rho_w$ to convert to m/yr w.e. where $L = 334 \times 10^3\ J/kg$ and $\rho_w = 1000\ kg/m^3$
- Note that the sign convention for SHF, LHF and $\left(LW_d - \epsilon\sigma T_S^4\right)$ make these quantities negative

Refreeze Parameterization

- To compute the fraction of melt (and liquid/rain accumulation) that is refrozen into the thermally active snow layer, we follow Colleoni et al., 2009:

$$f = 1 - min\left(1, max\left(0, \frac{\frac{M}{P_s} - 0.7}{0.3}\right)\right)$$

- where P_s is snow accumulation (m/yr w.e.). We use the variable SNOW from the land model.
- Melt, M, is calculated from the surface energy balance equation (1) and snow accumulation is a model output which is annually averaged and weighted by seconds in each month

Surface Mass Balance

- Annual SMB (m/yr w.e.) is given by (Colleoni et al., 2009):

$$SMB = P_s + fP_L - E - (1-f)M$$

- Recall that $M = \frac{SW_d(1-\alpha) + (LW_d - \epsilon\sigma T_s^4) + SHF + LHF + GF}{L\rho_w}$ and $f = 1 - min\left(1, max\left(0, \frac{\frac{M}{P_s} - 0.7}{0.3}\right)\right)$
- Where P_L is liquid/rain accumulation and E is sublimation and evaporation

- Note that we assume surface snow redistribution **through snow blowing is negligible** and that the difference between SMB and total ice volume change (of ICE-6G) is attributed to ice flow and calving

Surface Mass Balance Compared to Ice Volume Change of ICE-6G

Increased variability in SMB between 12ka and 11.4ka

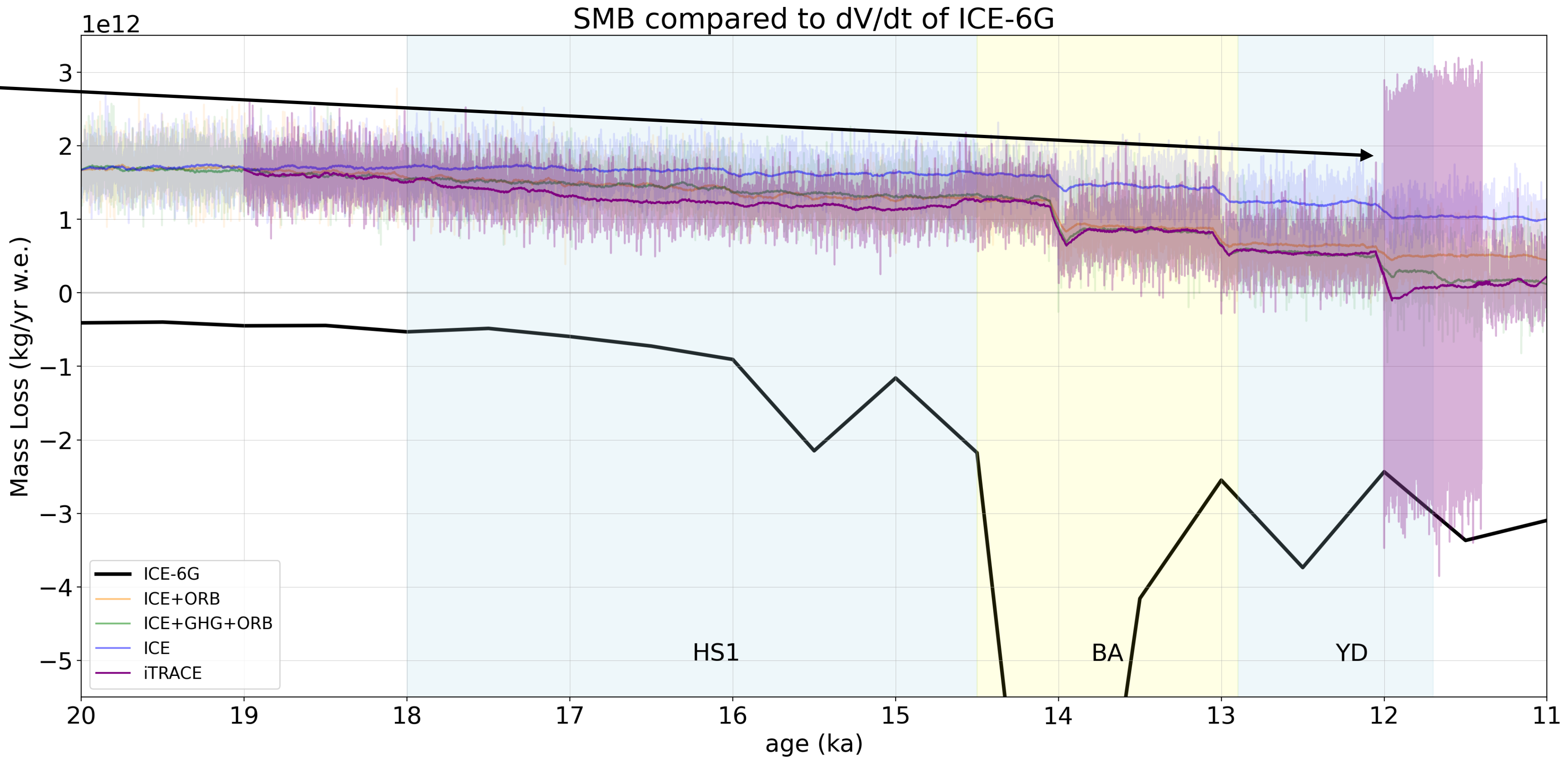


Figure 1: SMB compared to change in ice volume of ICE-6G summed over all gridcells containing ice. Each thicker, colored line represents a different experiment smoothed using the Savitzky-Golay filter with a window length of 100 years and linear fit. The shaded regions are the non-smoothed, yearly SMB. The thick black line is dV/dt of ICE-6G data.

All the experiments drastically underestimate SMB and actually predict positive growth of the ice sheet…Is our assumption that melt is the heat flux divided by latent heat of freezing and density of water incorrect? Does iCESM1.3 predict too much snow accumulation? What happened between 12ka-11.4ka?

Spatial Surface Mass Balance of the iTRACE Experiment

Orographically induced precipitation

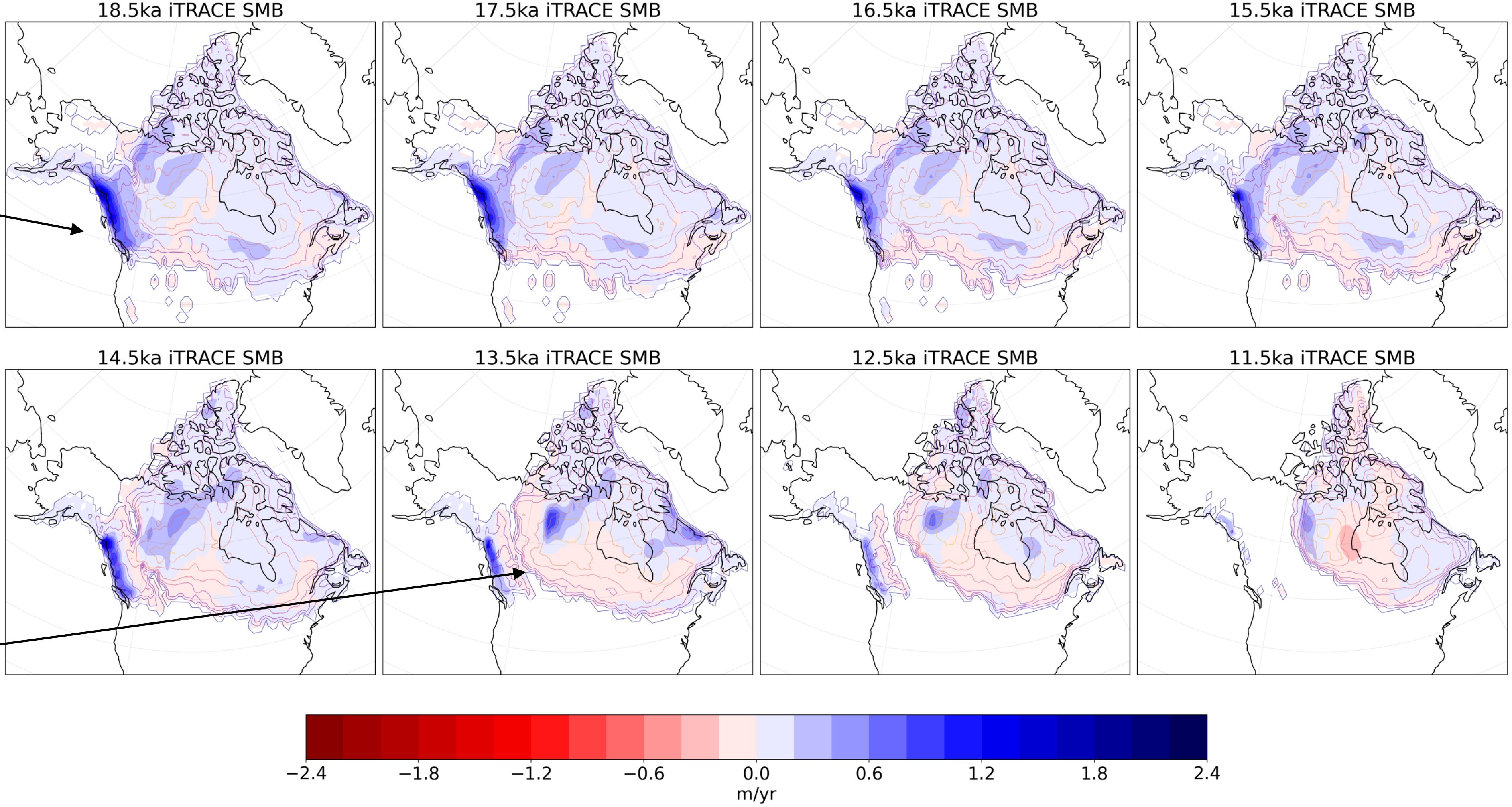


Figure 2: SMB of each gridcell across the Laurentide Ice Sheet (LIS) averaged over 100 years centered at the time slice indicated in the title.

Marginal melting

Overall, we see too much accumulation and not enough melting. The spatial distribution of melt looks right, but maybe not the correct magnitude?

Projected Ice Volume Change Compared to ICE-6G

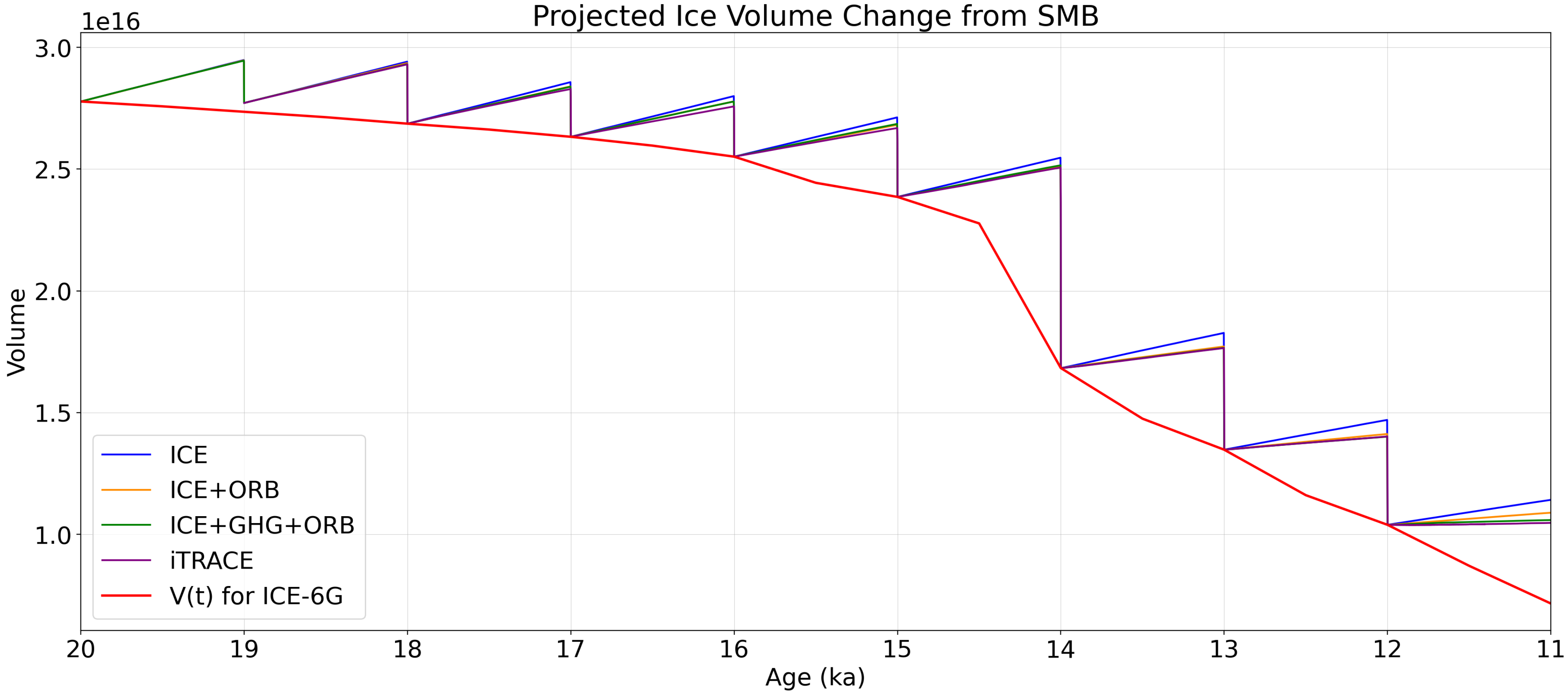


Figure 3: Integrated SMB of each experiment compared to total ice volume change of ICE-6G (red).

The overall growth and not total ice sheet decay as expected during deglaciation is shown clearly here with a slight decrease in rate after 14ka.

Increased Variability between 12ka and 11.4ka

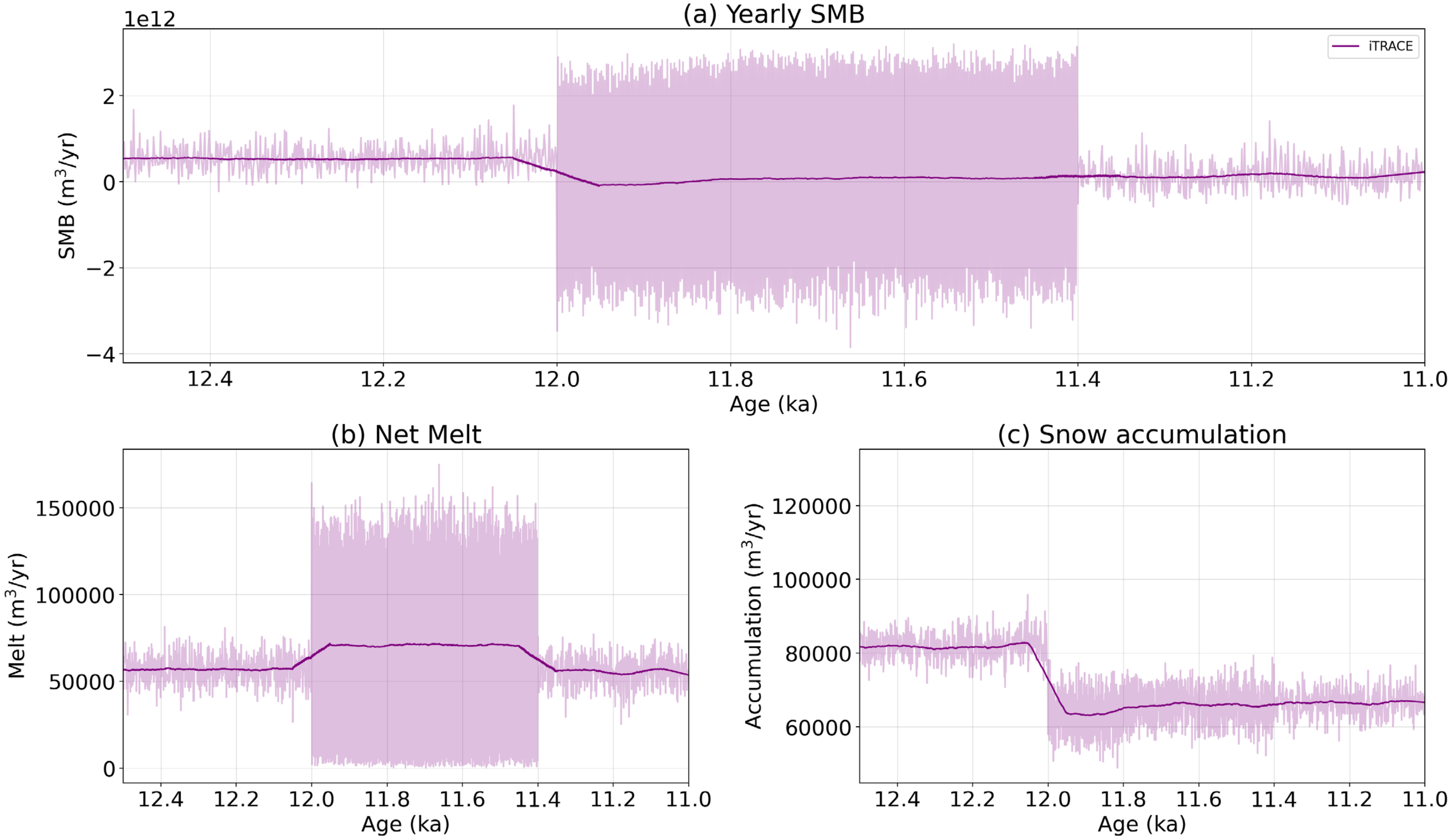


Figure 4: Plot (a) shows the annual SMB in the shaded purple with the smoothed in darker purple. Panel (b) shows the same but for net melt,$(1-f)M$, and (c) snow accumulation, P_S.

Net melt looks appears to contributes the most to the increase in variability in annual SMB, although there is a slight increase in variability in snow accumulation.

Increased Variability between 12ka and 11.4ka

Here, we take the STD of 50 years before the transition and 50 years after and take the difference of each grid cell of SMB, net melt, and snow accumulation.

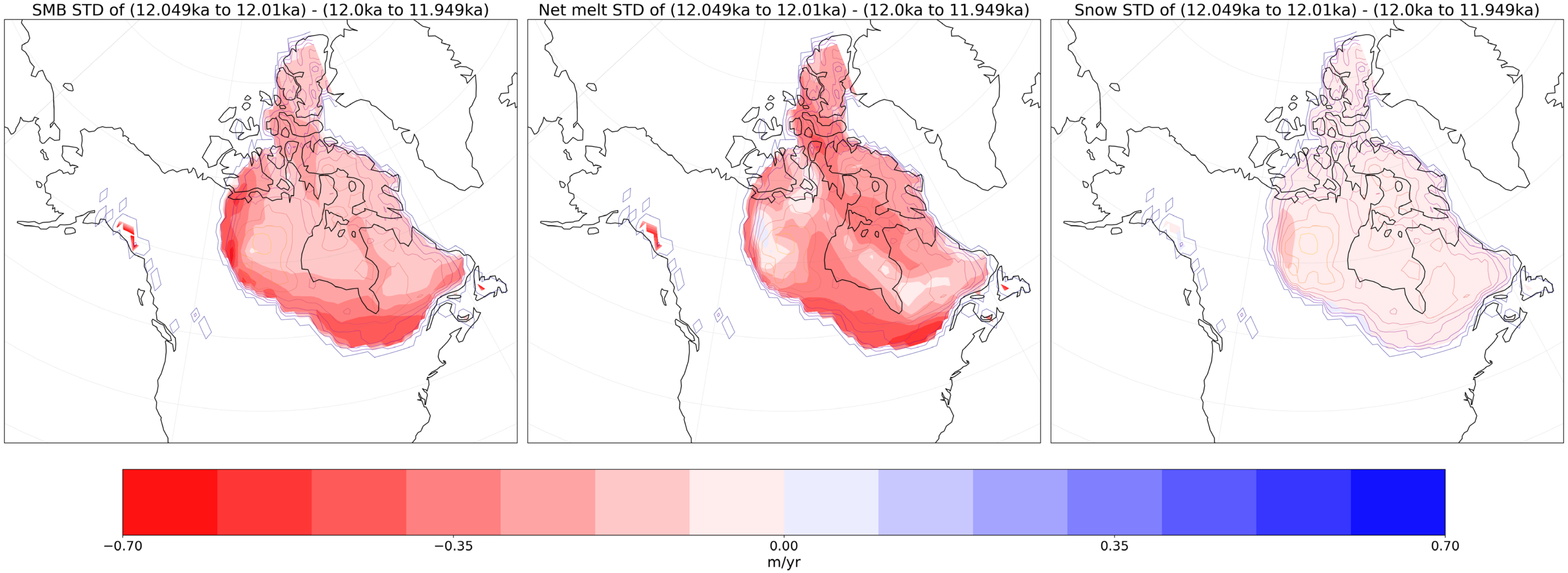


Figure 4: Plot (a) shows the annual SMB in the shaded purple with the smoothed in darker purple. Panel (b) shows the same but for net melt,$(1-f)M$, and (c) snow accumulation, P_S.

Again, net melt clearly contributes the most to the increase in variability in annual SMB, although there is a slight increase in variability in snow accumulation.

Summary

- We used a **SMB parameterization** that includes a **refreeze** term to study **the ice sheet dynamics of the Last Deglaciation** using the iTraCE dataset.
- **SMB overestimates total ice volume** change (of ICE-6G) for all the experiments with a slight slow down in growth rate after 14ka.
- **Increased variability** in annual SMB in the iTRACE experiment between **12ka and 11.4ka due to an increase in variability in net melt**

Future Work

- Investigate if there might be a better way to estimate total melt
  - Where does this variability at 12ka in FGR come from?
- Run our own CESM2 (CAM5) experiments with different ice topographies and other initial conditions to examine this relationship in more depth (thanks to Jiang Zhu)
  - If truly the SMB is not a good indicator of deglaciation vs glaciation, then these experiments will need to be run with an active ice sheet…
- Suggestions? Questions?