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Firn air content changes on Antarctic ice shelves under three future warming scenarios

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Text S1. Layer merging and splitting

In FDM v1.2A, layer merging and splitting are limited to the upper layer. If the upper layer thickness exceeds 0.15 m, the layer is split into two equal parts, and if the layer thickness falls below 0.05 m, this upper layer is merged with the layer below. Subsurface layers that become thinner than 0.05 m, due to snow compaction, are not merged. In case of snowfall, the density of freshly fallen snow is mixed with the upper layer. Accumulation is low (<100 mm w.e. yr^{-1}) in most of the AIS and therefore 0.15 m of snow can consist of snow from multiple years. The mixing of freshly fallen snow with the upper layer has a larger impact on the density evolution in FDM v1.2AD compared to FDM v1.2A, as the densification rate in FDM v1.2AD depends on local overburden pressure and grain size instead of long-term annual average accumulation and temperature. Therefore, the fresh snow in FDM v1.2AD has more distinct characteristics (a low overburden pressure and small grain size). To approximate densification of freshly fallen snow the upper layer thickness in FDM v1.2AD is kept between 0.008 and 0.012 m. We use this small range around 0.01 m to avoid mass needing to be constantly added or removed to the upper layer to keep it exactly at 0.01 m thickness. In case of snowfall in FDM v1.2AD, the age and grain size of the freshly fallen snow is mixed with the upper layer, similarly as done for the density. The splitting approach of the FDM v1.2A upper layer is then applied to the second layer in FDM v1.2AD.

Text S2. Model initialization

For the IMAU-FDM simulations indirectly driven by ERA5 (Table 1), an initial firn layer is obtained by looping over the forcing of the 1979-2020 reference period, since no significant AIS-wide long-term trends in surface climate have been detected during that period (Fig. S1). In contrast, CESM2 does exhibit AIS-wide long-term trends in the modelled historical (1950-2014) surface climate (Fig. S1). We therefore used the 1950-1999 period to initialize IMAU-FDM simulations driven indirectly by CESM2.

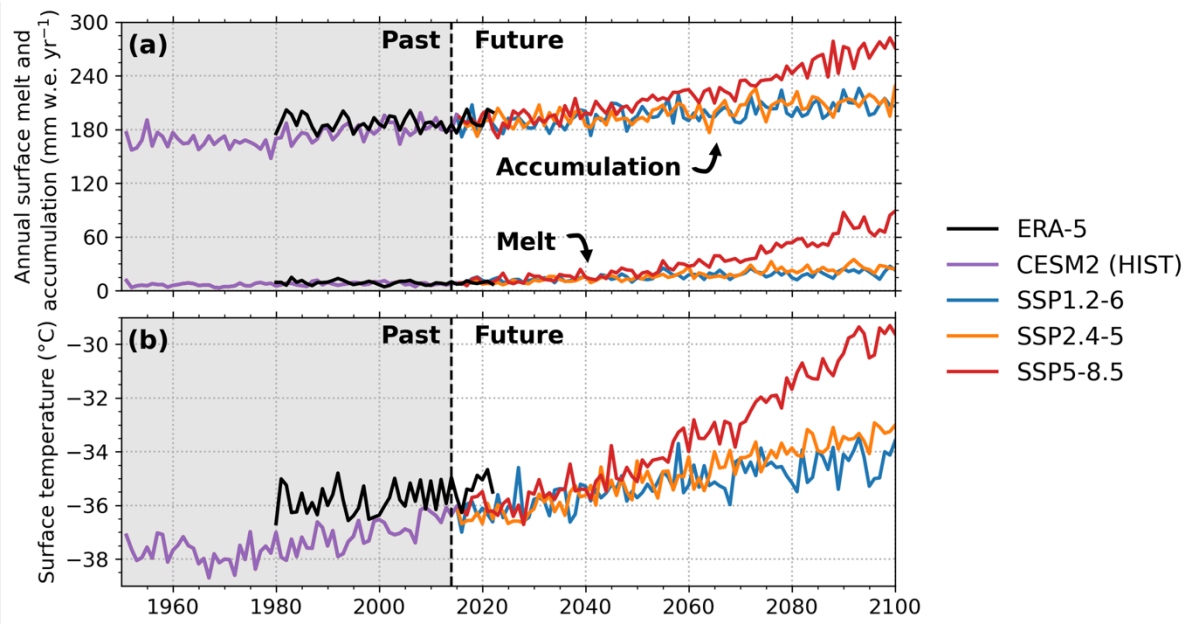

Figure S1. Time series of mean annual **(a)** surface melt, accumulation and **(b)** surface temperature over the AIS from RACMO2.3p2 forced by ERA5 (1979-2021), historical CESM2 (1950-2014) and future CESM2 scenarios SSP1-2.6 (2015-2100), SSP2-4.5 (2015-2100) and SSP5-8.5 (2015-2100).

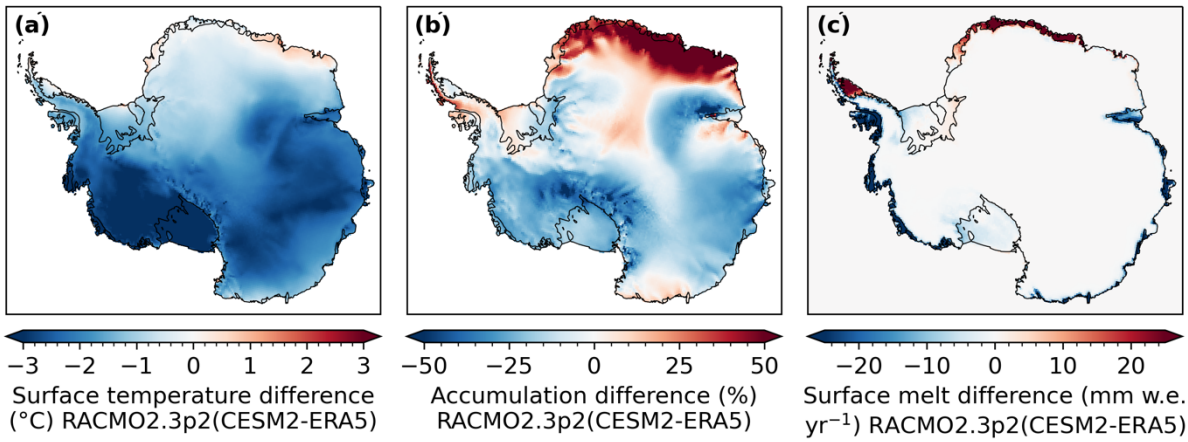

Figure S2. Difference in mean annual **(a)** surface temperature, **(b)** accumulation and **(c)** surface melt, over the period 1979-2014 between RACMO2.3p2-CESM2 and RACMO2.3p2-ERA5 (RACMO2.3p2-CESM minus RACMO2.3p2-ERA5).

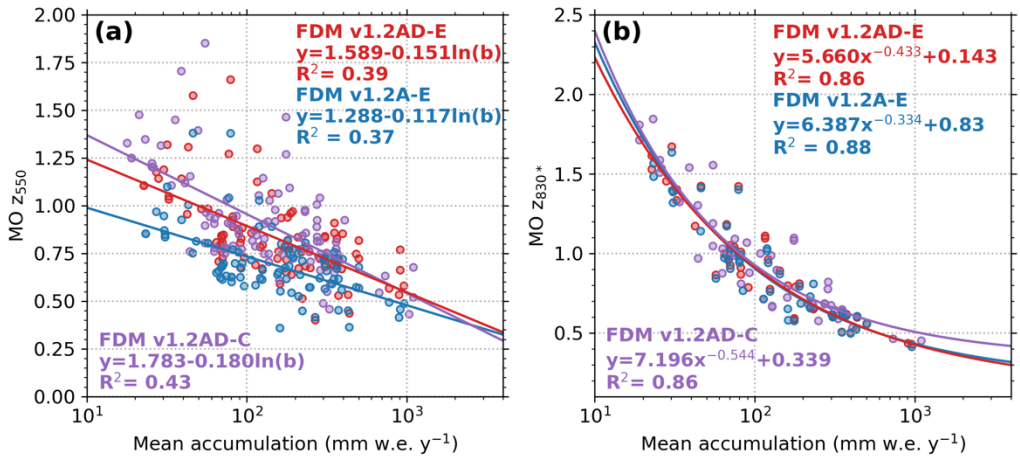

Figure S3. MO ratios and fits for FDM v1.2AD-E, FDM v1.2A-E and FDM v1.2AD-C for **(a)** z_{550} and **(b)** z_{830} as a function of the mean annual accumulation.

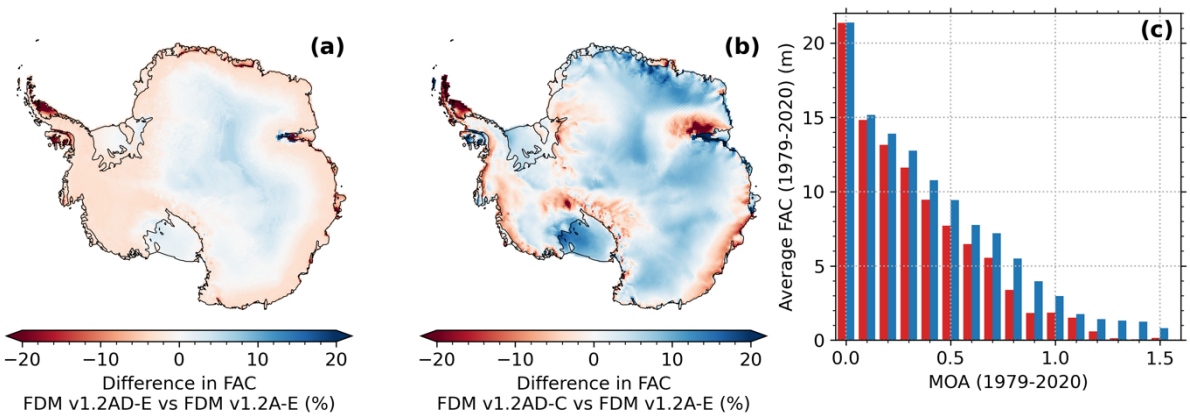

Figure S4. (a) Difference in average firn air content (FAC) between FDM v1.2AD-E and FDM v1.2A-E (FDM v1.2AD-E minus FDM v1.2A-E) for the period 1979-2020. **(b)** Difference in average FAC between FDM v1.2AD-C and FDM v1.2A-E (FDM v1.2AD-C minus FDM v1.2A-E) for the period 1979-2014. **(c)** FAC distribution by melt-over-accumulation ratio (MOA) bins of 0.1 for FDM v1.2AD-E and FDM v1.2A-E averaged for the period 1979-2020.

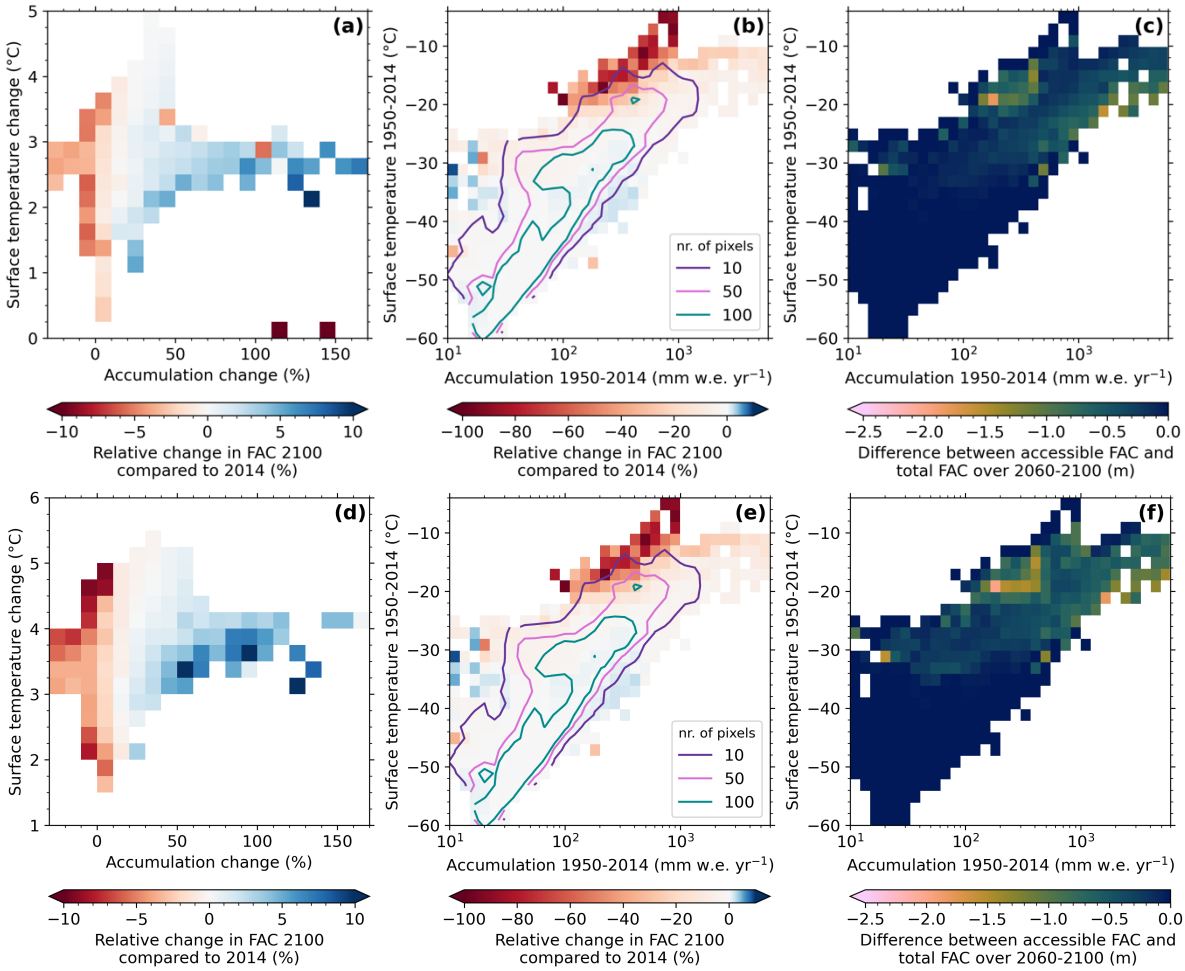

Figure S5. Relative change in total firn air content (FAC) by 2100 for SSP1.2-6 **(a)** and SSP2-4.5 **(d)** compared to 2014 **(a,d)** as a function of temperature change and accumulation change by 2090-2100 compared to 2005-2014 for locations that do not experience melt by the end of the century in SSP5-8.5 and **(b,e)** as a function of annual average accumulation and temperature (1950-2014) for the entire AIS. Average difference between accessible FAC and total FAC (accessible FAC minus total FAC) in 2060-2100 for the entire AIS for SSP1-2.6 **(c)** and SSP2-4.5 **(f)** as a function of annual average accumulation and temperature (1950-2014). Contour lines in **(b,e)** indicate the number of pixels per accumulation/temperature bin. Please note the different scales for decreasing and increasing FAC in panel **(b,e)**.

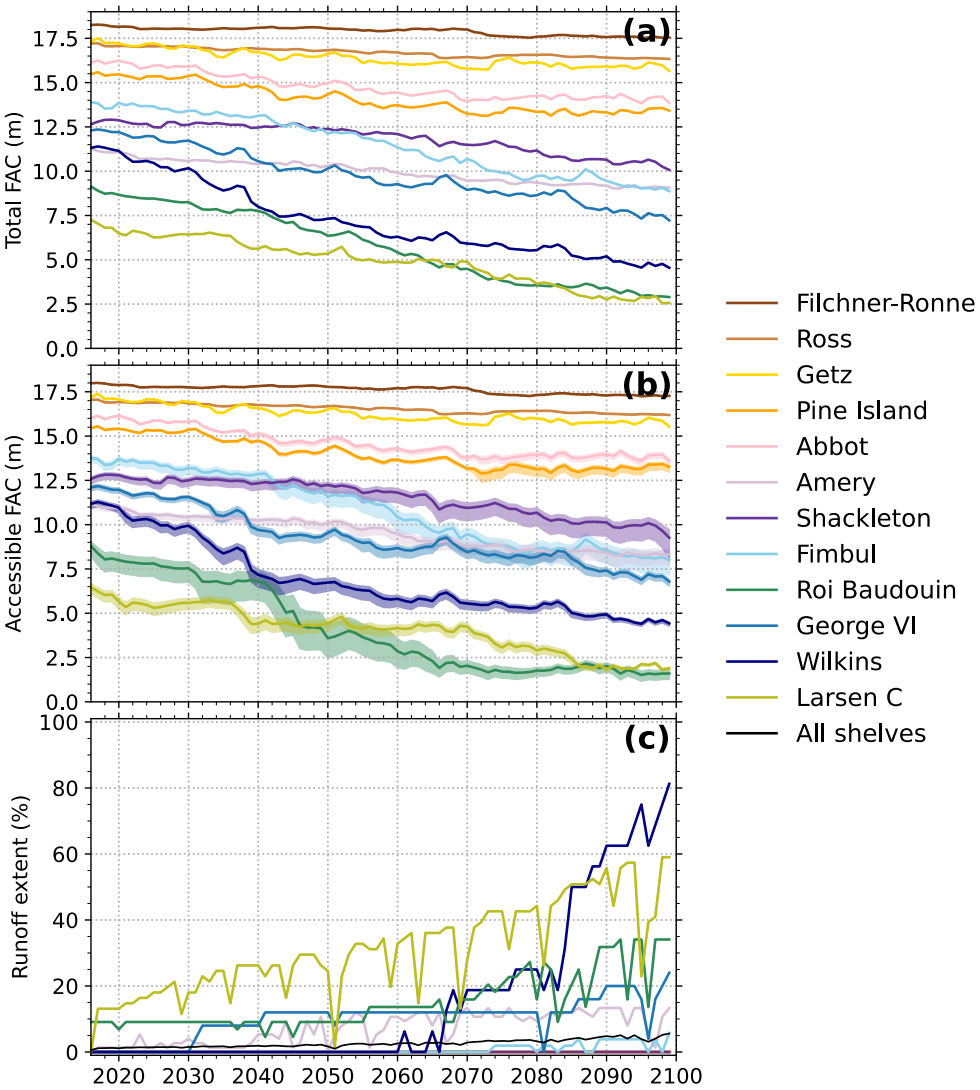

Figure S6. Timeseries of **(a)** total firn air content (FAC), **(b)** accessible FAC and **(c)** runoff extent of twelve ice shelves for SSP1-2.6 for the period 2015-2100. The shaded areas indicate the sensitivity to the relation between ice layer thickness and permeability factor shown in Fig. 3a.

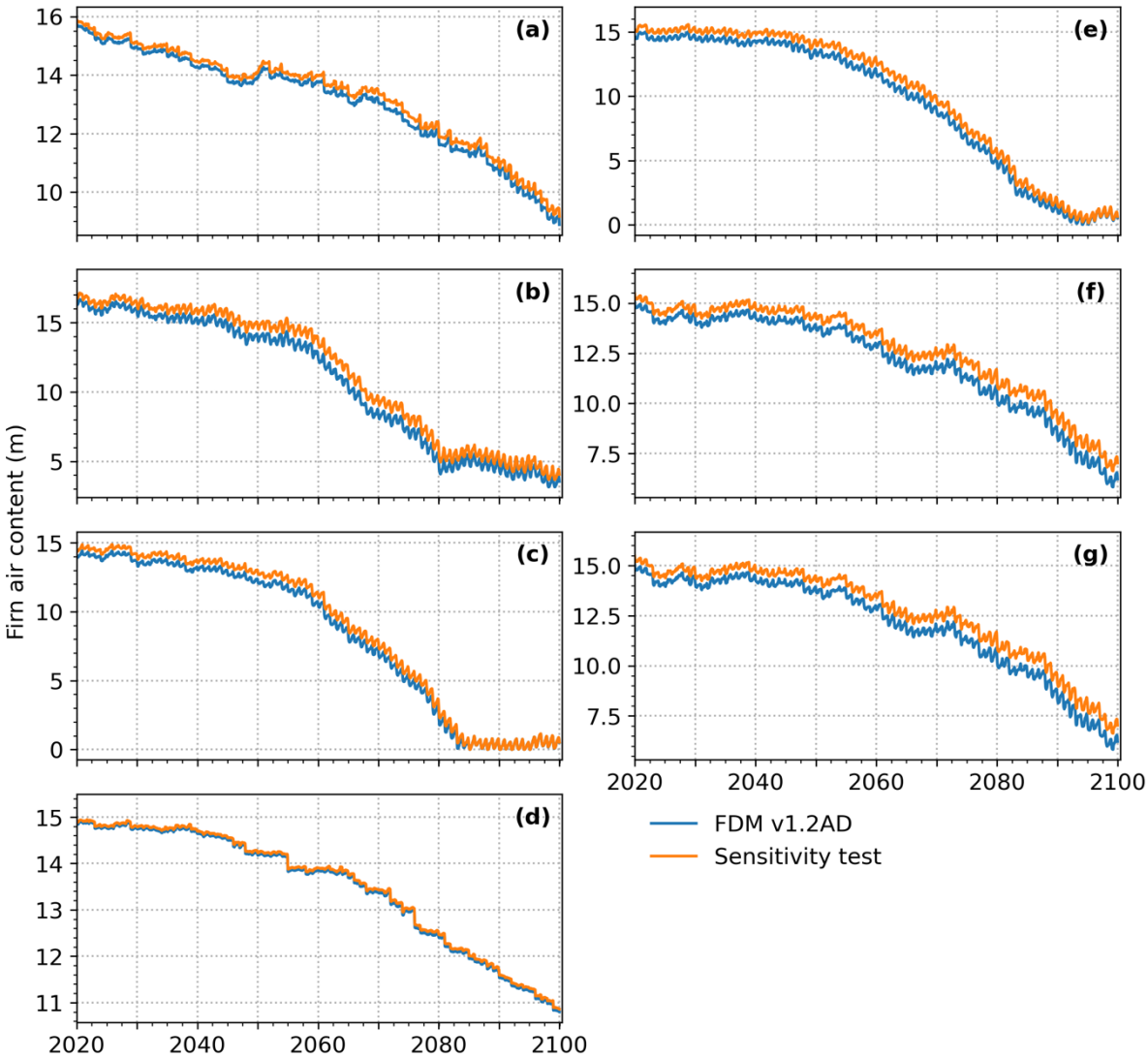

Figure S7. Test with different refreezing grain (0.4 mm) size for several locations. The locations correspond to the locations in Figure 7.