# Supplementary material: A deep learning reconstruction of mass balance series for all glaciers in the French Alps: 1967-2015

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## 1 Influence of area in glacier-wide SMB signal and proof on non overfitting

Due to similarities between the averaged reconstructed glacier-wide surface mass balance (SMB) and the observations during the 1984-2015 period, we decided to include an analysis to isolate the topographical influence in the glacier-wide SMB signal, in order to verify that the model is not overfitting. Since the climate signal is the main common driver of interannual variability of glacier-wide SMB in the region, one needs to find a way to isolate the topographical signal. In Fig. S1, the median reconstructed annual glacier-wide SMB of the 661 glaciers in the French Alps (i.e. the interannual variability, hence a proxy of the climate signal) is subtracted to the mean annual values of the observations and of 4 subsets of glaciers divided by area classes. Therefore, one can observe the residual influence of glacier area on the glacier-wide SMB signal. The influence of area on glaciers with observations is quite similar to glaciers with areas greater than 2 $km^2$, which is reasonable since glaciers with observations have an average of 4 $km^2$ (range: 0.3-31.8 $km^2$ in 2003). Moreover, one can see that even for a relatively short period of 30 years, the differences between the reconstructions for very small glaciers (< 0.5 $km^2$) and observations are quite important, accounting for an average cumulative loss of more than 5 m.w.e. As stated in Sect. 2, this does not necessarily mean that the model has fully captured the topographical influence in the glacier-wide SMB signal in the region, but it does prove that the model is not overfitting since it exhibits consistent variations in SMB when the topographical predictors move away from the training data. Moreover, this is coherent with the importance attributed to topographical predictors (Bolibar et al., 2020).

The same analysis has been performed with the reconstructions from the updated version of Marzeion et al. (2015), shown in Fig. S2. The gradient with respect to glacier surface area appears to be similar, except for the behaviour of glaciers after 2007. Small and middle sized glaciers (0.1 - 2 $km^2$) switch to a positive influence, as opposite to large glaciers (> 2 $km^2$), which transition to a negative influence. Conversely, our results show a more continuous trend, without a change of behaviour in the last years of the analysed period.

## 2 Supplementary figures

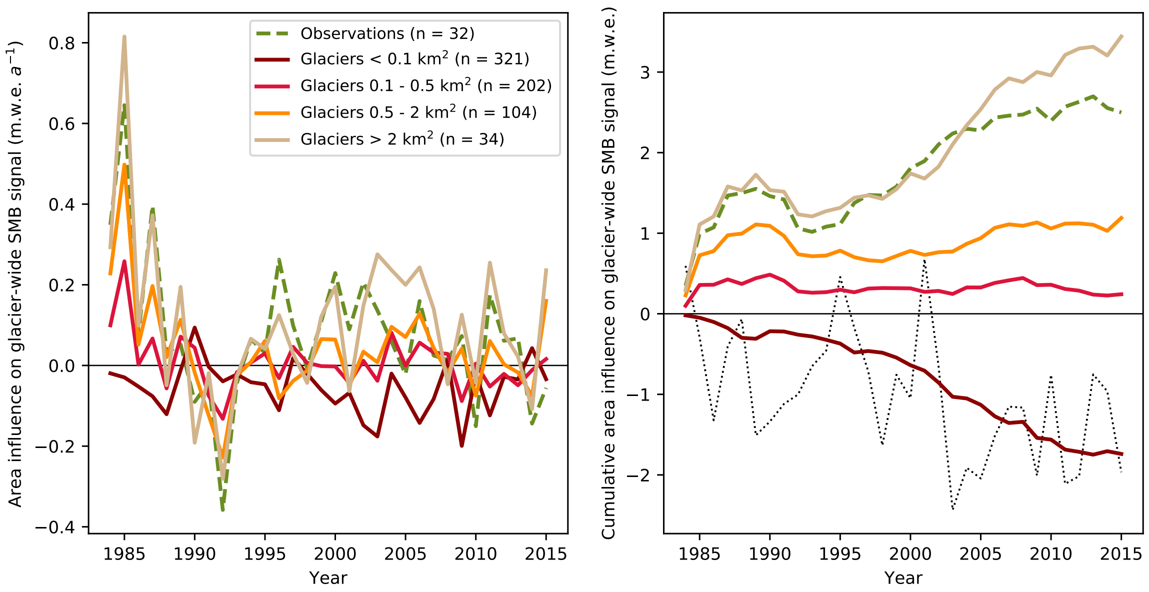


**Figure S1.** Influence of glacier area on the glacier-wide SMB signal. The reconstructed median annual glacier-wide SMB of the 661 glaciers in the French Alps can be seen as a proxy of the climate signal in the region. It is subtracted to the mean annual glacier-wide SMB of the glaciers with observations and to four different subsets of reconstructions divided into glacier area size, showing only the annual differences based on glacier area classes. The dotted line depicts the subtracted signal (non cumulative) in order to give some context.

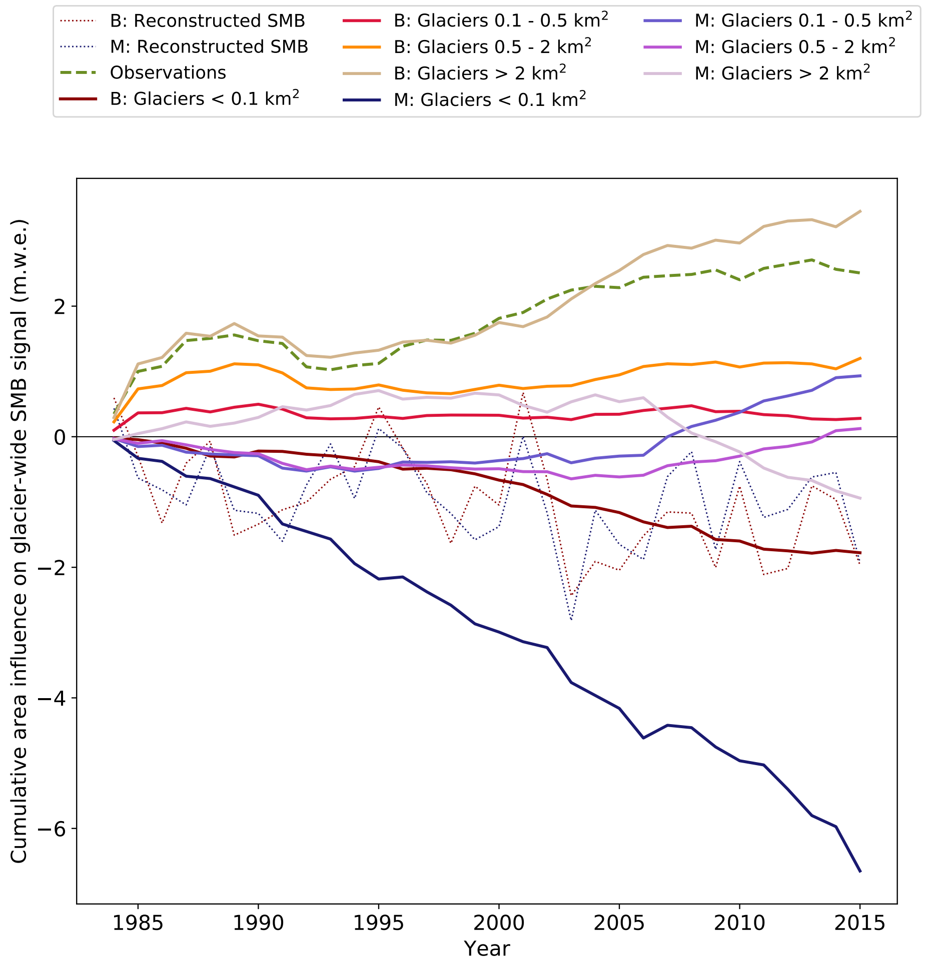


**Figure S2.** Same as S1 but comparing this study to the updated version of Marzeion et al. (2015). In the legend, "B" stands for Bolibar et al. (this study) and "M" for the update of Marzeion et al. (2015). Both models show a relatively similar gradient effect with respect to glacier area, with differences in the amplitude of the effects. The main differences appear from 2007, where small and middle sized glaciers (0.1 - 2 $km^2$) from the update of Marzeion et al. (2015) switch to a positive influence, as opposite to large glaciers (> 2 $km^2$), which transition to a negative influence. The reconstructed SMB dotted lines are not cumulative and they are depicted in order to give some context of the subtracted climate signal.

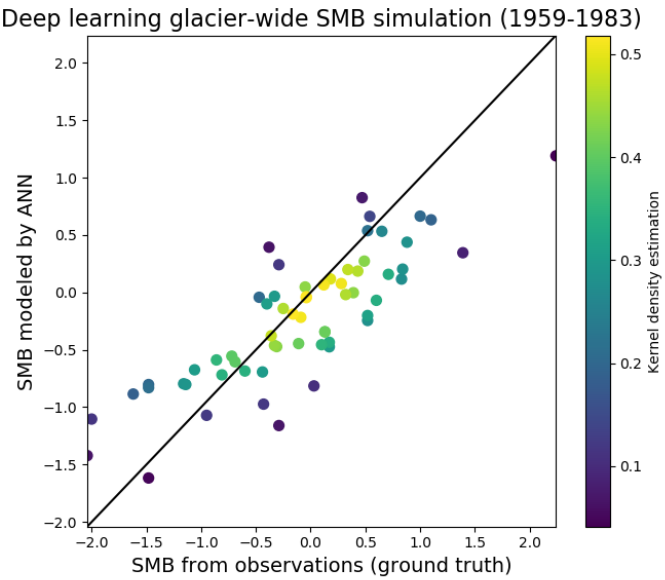


**Figure S3.** Cross-validation for annual glacier-wide SMB values outside the main 1984-2014 training period. The black line indicates the one-to-one reference. Simulations have been done from 1959, the earliest date with observations to validate against the maximum number of values. This serves to confirm that the model is capable of reproducing glacier-wide SMB outside the main observed period.

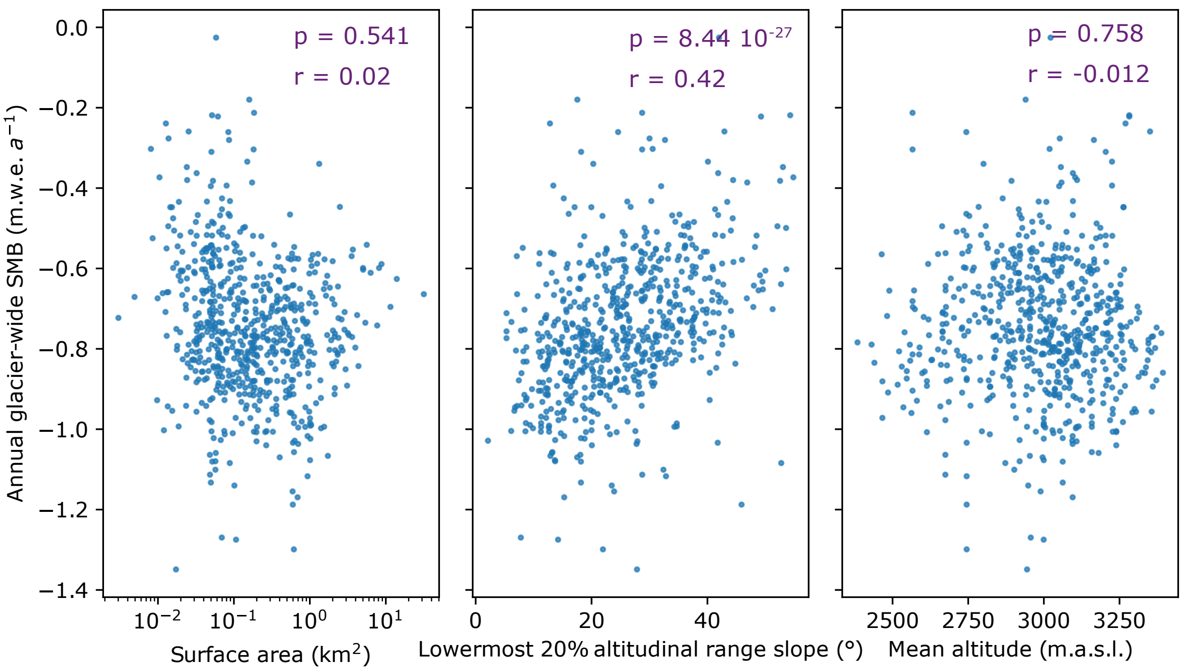


**Figure S4.** Average annual glacier-wide SMB for each glacier over the entire study period with respect to (a) glacier surface area, (b) the lowermost 20% altitudinal range slope and (c) mean glacier altitude. p indicates the p-value and r the correlation between the topographical variables and the average glacier-wide SMB.

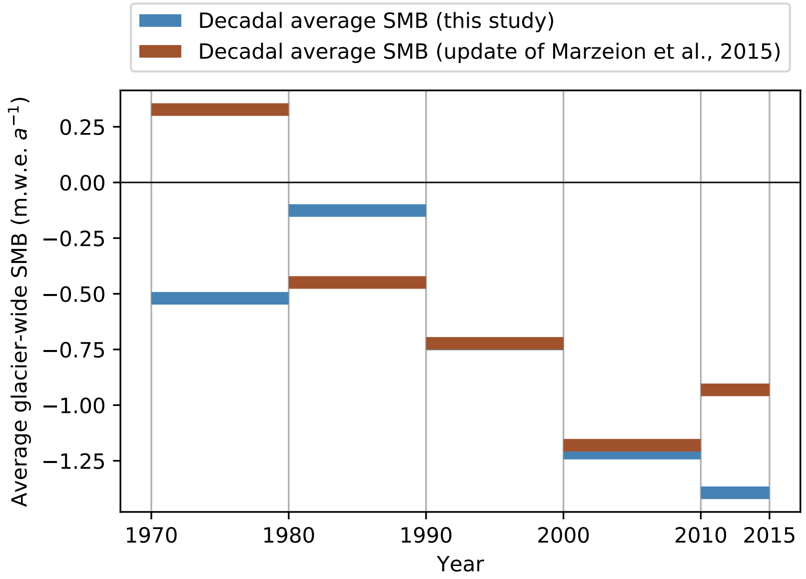


**Figure S5.** Comparison of area-weighted decadal glacier-wide SMB simulations in the French Alps between this study and an update from Marzeion et al. (2015).

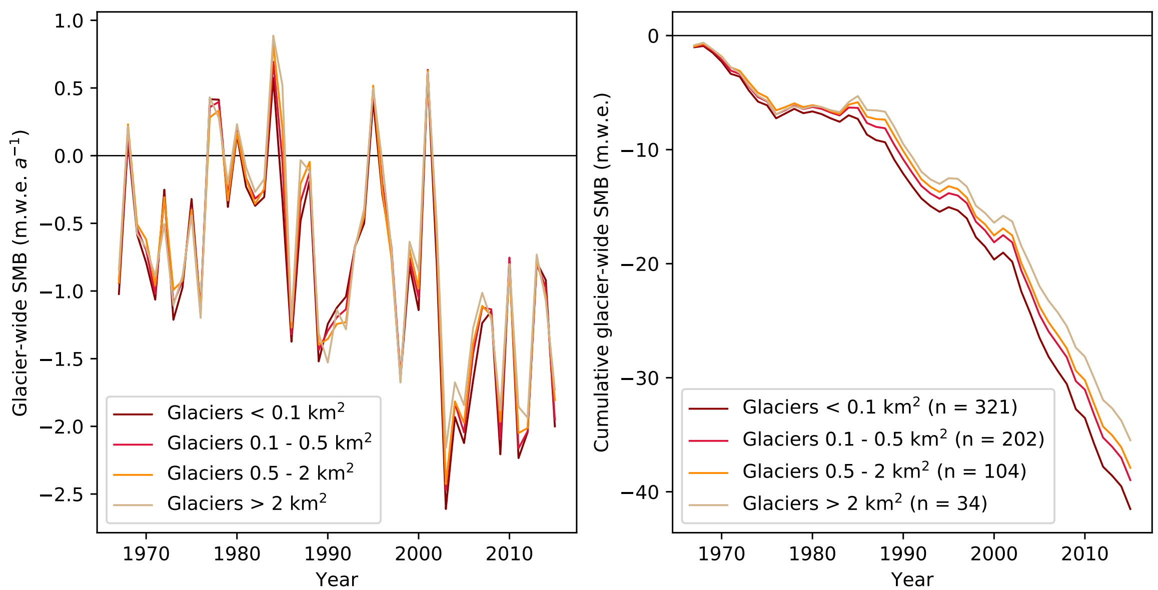


**Figure S6.** Average annual glacier-wide SMB per glacier area classes

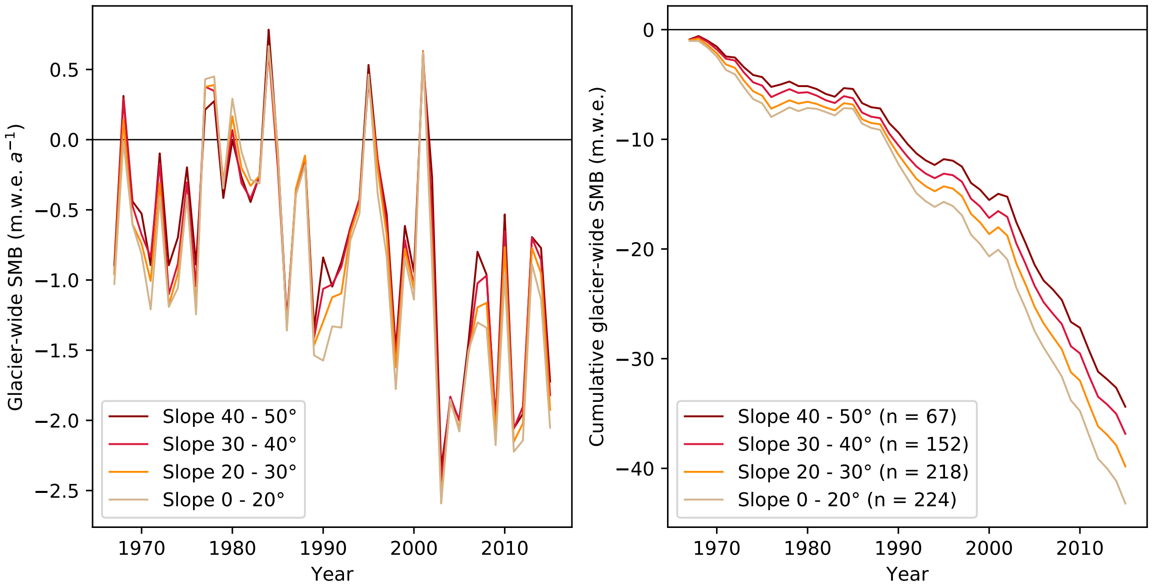


**Figure S7.** Average annual glacier-wide SMB for classes of glacier slope of the lowermost 20% altitudinal range (i.e. a proxy of the glacier's tongue slope)