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# On the influence of changes in glacier extent and surface elevation on modelled glacier mass balance

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Long-term records of direct glacier mass balance measurements are well established indicators of climate change, as changes in glacier extent should result in a zero mass balance after a glacier specific response time. Continuously or increasingly non-zero mass balances indicate a constant or accelerated climatic forcing, respectively. As most mass balance measurements have been initiated for hydrological purposes, the measured values refer to the actual glacier size and the strength of the climate signal is thus reduced. Moreover, long-term measurements are difficult to compare with respect to climatic forcing as the same climate leads to a different mass balance only due to geometric changes. This effect has also to be considered when mass balance is calculated backwards or forward in time from climate data.

A promising tool to investigate the effects of changes in glacier extent or elevation on mass balance are distributed mass balance models in combination with recent and reconstructed DEMs of the glacier surface. In order to calculate a maximum effect of both changes, we compare modelled mass balances for about 50 glaciers in the Aletsch region (Switzerland) using the 1850 and 1973 glacier extent combined with a reconstructed and recent DEM. The used mass balance model is based on the calculation of the energy balance at the glacier surface in daily time steps to fully account for topographic effects (e.g. shading) and utilizes high-resolution gridded data sets of mean annual climatic precipitation to account for its spatial variability in the Alps. In principal, we have performed four experiments: (1) A temperature sensitivity study with the 1850 and 1973 extent, (2) a change of the extent but with the 1850 DEM, (3) a change of the DEM but with the 1850 extent, and (4) changing both the DEM and the extent.

The study reveals a large scatter of the mass balance changes among the individual glaciers. While temperature sensitivity only slightly decreased for the recent extent (experiment 1), mean mass balance values are about 2/3 of the sensitivity more positive due to the change in extent since 1850 (exp. 2). The surface elevation change alone gives a mixed effect, but in the mean, mass balances are getting slightly more negative (exp. 3). This implies that the higher temperatures at lower surface elevations dominate over increased shading. Both effects combined increase mean mass balance by about 1/2 of the sensitivity (exp. 4). Thus, the mean annual mass loss with respect to an unchanged geometry is about a factor of two higher than the measured one. The implications of these results for operational aspects of glacier monitoring require further investigations.