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Extrapolating glacier mass balance to the mountain range scale: The European Alps 1900-2100

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Glacier surface mass balance is directly observed on only a few selected glaciers. However, for quantifying the contribution of glacier mass loss to sea-level rise or mountain hydrology, regional mass balances are required. Extrapolation of single glacier mass balance series to several thousand glaciers within a mountain range is not trivial and involves considerable uncertainties. As mass balances of neighbouring glaciers can differ by a factor of up to four due to different climate sensitivity, surveyed mass balance glaciers might not be representative for larger areas. This fact needs to be accounted for in mountain range scale assessments of glacier mass change.

In this study mass balance and ice volume change series for all glaciers in the European Alps are derived for the period 1900-2011 based on mass balance and glacier inventory data. Further, future mass balances are modelled until 2100 using GCM ensembles based on four IPCC emission scenarios. Uncertainties in the extrapolation of single glacier mass balance series to the entire European Alps are analyzed and the required field data basis for deriving mass balance estimates on the mountain range scale is discussed.

Long-term mass balance series for 50 Swiss glaciers are available from a combination of field data and modelling for the entire 20th century. These series are complemented with data for 25 glaciers in Austria, France and Italy provided by WGMS. Outlines of all glaciers in the European Alps relative to the year 2003 are given by a glacier inventory.

Extrapolation is performed using (1) arithmetic averaging, (2) glacier hypsometry, and (3) multiple regression of mass balance with variables describing glacier geometry (e.g. area, slope etc.). For each individual glacier, area change series are derived, thus allowing the calculation of mountain range annual ice volume changes since 1900. Future mass changes are computed by driving a combined model for mass balance and 3D glacier geometry change with scenario temperature and precipitation. Given the sound field data basis for the European Alps, multiple regression yields the best results and is used for the extrapolation of mass balance in this study.

Mean glacier mass balance in the European Alps 1900-2011 was –0.28 m w.e. a^{-1} corresponding to a total ice volume loss of 92 km^3. The glacier mass budget was balanced or slightly positive in the 1910s and between 1960 to the mid-1980s, and strongly negative in the 1940s and over the last two decades. Until 2050 mean mass balances are expected to decrease to –1.3 m w.e. a^{-1} on average. Modelled glacier area in the European Alps by 2100 corresponds to 4-18% of the glacierized surfaces in 2003 depending on the climate scenario.