



## **Attribution of Past Glacier Mass Loss to Anthropogenic and Natural Climate Forcing**

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Glaciers have contributed to sea-level rise during the 20th century with relatively constant mass loss rates, even though warming accelerated towards the end of the 20th century. The mass loss during the first decades of the 20th century presumably was governed by loss of ice at low altitudes, when glaciers retreated from their 19th century maxima at the end of the little ice age. Since glacier response times are typically decades and longer, the attribution of glacier mass loss to different climate forcings is not trivial.

We use a model of the global glacier evolution that is based on modeling each of the world's glacier's mass balance, including a simple parameterization of ice dynamics leading to glacier hypsometry change. The model was independently validated with both surface mass balance observations and observed, temporally integrated volume changes of hundreds of glaciers, and has been used to reconstruct and project the global glacier mass change from 1850 to 2300 (Marzeion et al., 2012). Using the "historical" experiments from the CMIP5 ensemble, the state of the glaciers in 1850 is reconstructed. From that starting point, the course of global glacier evolution is modeled forward, once using natural forcing (i.e., solar and volcanic) only, and once using all climate forcings (i.e., including anthropogenic greenhouse gases, aerosols, and land use change).

During the past two decades, there is a significant (>95 % confidence) difference between observed and modeled mass balances under natural forcing on the global scale, while the fully forced model results generally agree with the observations. An anthropogenic contribution is therefore detectable with high confidence in the observed mass balances. On a regional scales and/or shorter time scales, stronger intrinsic variability and higher model uncertainty lead to less reliable results.

The fraction of global glacier mass loss attributable to anthropogenic causes has shown an almost linear increase from  $-2\pm 37\%$  during the period 1851-1880 to  $64\pm 21\%$  during 1981-2010.