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Attribution of glacier fluctuations to climate change

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Glacier retreat is a worlwide phenomenon, which started around the middle of the 19th century. During the period 1800-1850 the number of retreating and advancing glaciers was roughly equal (based on 42 records from different continents). During the period 1850-1900 about 92% of all mountain glaciers became shorter (based on 65 records). After this, the percentage of shrinking glaciers has been around 90% until the present time. The glacier signal is rather coherent over the globe, especially when surging and calving glaciers are not considered (for such glaciers the response to climate change is often masked by length changes related to internal dynamics). From theoretical studies as well as extensive meteorological work on glaciers, the processes that control the response of glaciers to climate change are now basically understood. It is useful to make a difference between geometric factors (e.g. slope, altitudinal range, hypsometry) and climatic setting (e.g. seasonal cycle, precipitation). The most sensitive glaciers appear to be flat glaciers in a maritime climate.

Characterizing the dynamic properties of a glacier requires at least two quantities: the climate sensitivity, expressing how the equilibrium glacier state depends on the climatic conditions, and the response time, indicating how fast a glacier approaches a new equilibrium state after a stepwise change in the climatic forcing. These quantities can be estimated from relatively simple theory, showing that differences among glaciers are substantial. For larger glaciers, climate sensitivities (in terms of glacier length) vary from 1 to 8 km per 100 m change in the equilibrium-line altitude. Response times are mainly in the range of 20 to 200 years, with most values between 30 and 80 years.

Changes in the equilibrium-line altitude or net mass balance of a glacier are mainly driven by fluctuations in air temperature, precipitation, and global radiation. Energy-balance modelling for many glaciers shows that, globally speaking, a 1 K temperature increase has the same effect as a ∼25% decrease in precipitation, or a ∼15% increase in global radiation. However, the relative importance of these drivers depends significantly on the climatic setting (notably continentality).

In this contribution I will give a brief survey of glacier fluctuations over the past few centuries, and provide arguments that on the worldwide scale air temperature must have been the main driver of these fluctuations. A history of global mean temperature that explains the observed glacier fluctuations best will be discussed. On smaller spatial (regional) and temporal (decades) scales, changes in precipitation become important. Both with respect to the attribution problem (what caused the glacier fluctuations in the past?) and the projection issue (what will happen in the next 100 years?), it is important that many more glaciers are explicitly studied with numerical models. I will argue that for non-calving glaciers these models can be relatively simple.