Glacier retreat crosses a line
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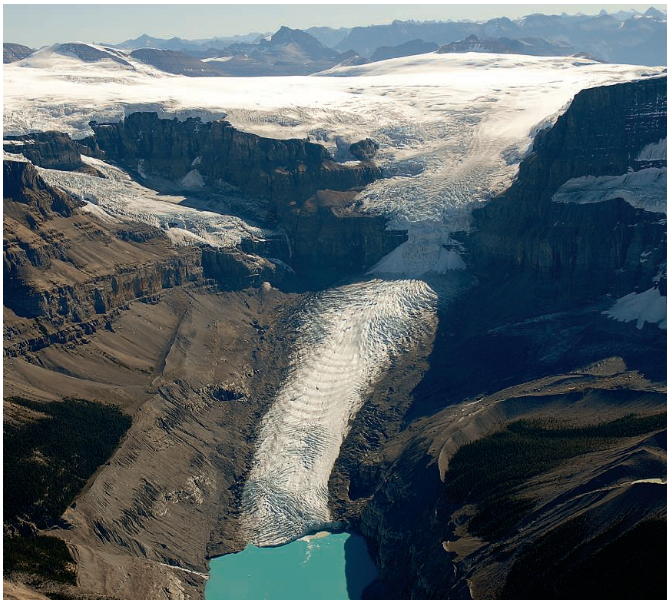
CLIMATE CHANGE

Glacier retreat crosses a line

Mountain glacier loss since the 1970s has mostly been caused by human influences on climate change

By Shawn Marshall

Retreating glaciers, bleached coral reefs, stranded polar bears, parched East African earth, receding tropical shorelines: These are the symbols of climate change in our young century. But how much responsibility do humans bear for these changes? In the case of glaciers, their worldwide retreat began in the 19th century, well before human effects on global climate are believed to have been significant. How much glacier retreat can be attributed to human influences on climate? On page 919 of this issue, Marzeion *et al.* (*1*) use climate models to assess the natural and anthropogenic (caused by humans) contributions to historical glacier mass loss.



Rapid retreat. Mountain glaciers around the world have receded since the 1850s. Marzeion *et al.* show that since the late 1970s, most of this retreat can be attributed to human influences on global climate. The image shows Columbia Glacier in the Canadian Rocky Mountains, photographed in 2010. The abrupt edges of today's vegetation define the late-19th century extent of the glacier.

Their analysis builds on earlier work (*2*) that fed into the 2013 IPCC report (*3*). The authors use an ensemble of global climate models (GCMs) to simulate glacier mass balance, that is, snow accumulation minus snow and ice melt. To do so they must first interpolate from the GCMs, which represent Earth's surface at a resolution of hundreds of kilometers, to the detailed topography and high elevations of mountain glaciers. With these interpolated climate fields, the authors then simulate glacier mass balance for the global suite of almost 200,000 glaciers.

Marzeion *et al.* simulate glacier mass balance from 1851 to 2010 for two scenarios. The first scenario combines natural and human influences on climate, whereas the second is a control run with only natural forcing. The results indicate that most glacier mass loss between 1850 and 1980 and about 75% of the total glacier retreat since 1850 can be attributed to natural climate forcing. However, in the late 1970s, glaciers appear to have crossed an invisible line into a state of decline that can be deemed unnatural. Over the past three decades, the human fingerprint on glacier mass balance emerges clearly, accounting for about 70% of glacier mass loss from 1991 to 2010. Glacier mass loss from 2001 to 2010 exceeded that of any other decade studied.

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The results are subject to many uncertainties; it is a giant leap from GCM climate fields to mountain snowpacks and glacier melt processes. The mass losses that Marzeion *et al.* simulate are consistent with available glacier mass balance observations from the past several decades (*3*, *4*). In contrast, reconstructed glacier mass loss in (*1*) for 1851 to 1950, before worldwide mass balance observations, exceeds earlier estimates that were based on observations of glacier length changes (*5*, *6*). The magnitude of sea-level rise due to glacier attrition from 1851 to 2010 in (*1*) is also high relative to other reconstructions (*5*–*9*). Both naturally and anthropogenically forced glacier mass loss estimates may therefore be on the high side in the study of Marzeion *et al.*

The numbers will gradually come into better focus with improved resolution of mountain regions in climate models, application of more detailed models of snow and ice melt (*9*), and observational innovations (*8*). The main conclusions of Marzeion *et al.* with respect to attribution are unlikely to change, however; if there is a tendency to too much melting in the simulations, modeled glacier mass losses will be equally oversensitive to both natural and anthropogenic warming.

More subtle is the question of how time lags play into the attribution of natural versus anthropogenic forcing in (*1*). Glaciers are superb measuring sticks of climate, because they ignore the fluctuations of day-to-day weather. The geometry of mountain glaciers reflects the integrated meteorological conditions over decades to centuries. Glacier motion transfers mass slowly downhill; it can take decades for the glacier terminus to respond to a shift in climate. It is thus difficult to determine the contributions of natural and anthropogenic forcing based on glacier length or area records.

Marzeion *et al.* overcome this problem by examining mass balance records, which reflect annual snowfall and snow/ice melt. Mass balance is tightly linked to annual climatology, without a lag, although there are gradual mass balance feedbacks associated with glacier geometric adjustments. It is therefore unsurprising that glacier mass loss increased and anthropogenic forcing rose above the noise in the late 1970s, as did global mean temperatures (*10*).

The transition from natural to anthropogenic forcing of glacier mass loss could also be inferred from the relative stabilization of glaciers in the 1960s and early 1970s, which preceded the recent reinvigorated retreat. It remains to be seen how glaciers will weather the world that awaits them in this century of intensified anthropogenic forcing. Based on Marzeion *et al.*'s results, the past three decades provide a good indication of what is to come. Retreating glaciers will continue to be symbols of climate change. ■

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