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Worldwide glacier retreat

Filed under: **Climate Science Instrumental Record Paleoclimate** — eric @ 18 March 2005 - ()

One of the most visually compelling examples of recent climate change is the retreat of glaciers in mountain regions. In the U.S. this is perhaps most famously observed in Glacier National Park, where the terminus of glaciers have retreated by several kilometers in the past century, and could be gone before the next century (see e.g. the USGS web site, **here**, and **here**). In Europe, where there is abundant historical information (in the form of paintings, photographs, as well as more formal record-keeping), retreat has been virtually monotonic since the mid 19th century (see e.g. **images of the glaciers at Chamonix**). These changes are extremely well documented, and no serious person questions that they demonstrate long term warming of climate in these regions. New work published in *Science* (**"Extracting a Climate Signal from 169 Glacier Records"**) highlights these results, and uses them to make a new estimate of global temperature history since about 1600 A.D., which agrees rather well with previous, independent temperature reconstructions.

Of course, as we frequently remind readers on this site, changes in one particular region do not necessarily translate to worldwide trends. That is why the work of such groups of scientists as the **World Glacier Monitoring Service**, which compiles observations on changes in mass, volume, area and length of glaciers, is important. From the compilations of WGMS (and many other groups and individuals), we know that glacier retreat is in fact an essentially global phenomenon, with only a few isolated (and well understood) counter-examples, such as western Norway. The figure at right shows an example from WGMS, as published in the 2001 IPCC report. (Click on the figure for details).The photos at left show **South Cascade Glacier** in Washington State in 1928 and 2000.

What causes glaciers to retreat like this? With the exception of glaciers that terminate in the ocean, and glaciers in the polar regions or at extreme high altitudes where the temperature is always below freezing, essentially just two things determine whether a glacier is advancing or retreating: how much snow falls in the winter, and how warm it is during the summer.

For typical glaciers in mid latitudes, the role of temperature is generally more important than winter precipitation. This is because a bit of extra heat in summer is a very efficient way to get rid of ice. A 1°C increase in temperature, applied uniformly across a glacier, is enough to melt a vertical meter of ice each year. For typical mid-latitude glaciers, winter snow accumulation is on the order of 1 m/year (ice equivalent — or about 3 m of snow). On balance then, a 1°C rise in summer temperature has roughly the same effect as a year in which no snow accumulates. Put another way, for every degree rise in summer temperature, an extra meter of ice-equivalent would be required to offset the extra loss. (This makes it clear why glaciers in coastal Norway are not as strongly influenced by temperature – at these locations, winter precipitation typically exceeds several ice-equivalent meters per year). To give another, more specific example, at a typical glacier on Mt. Baker, in Washington State, a summer temperature increase of 1°C translates to a ~150 m increase in the altitude of the equilibrium line (the point where annual ice accumulation = annual loss), and a resulting ~2 km retreat of the glacier terminus. The same change, if driven by winter precipitation, would require about a 25% decrease in local precipitation at this site.

What all this means is that glaciers comprise a rather nice “proxy” for climate change in general, and for temperature change in particular. Glaciologists have for many years used this fact to make estimates of temperature change from records of glacier change. This work received an important update in the journal *Science*, with the publication of **a paper by J. Oerlemans**, of Utrecht University. Oerlemans’s paper does three useful things. First, it provides a compilation of global trends in glacier terminus positions since 1600 A.D. Second, it uses this compilation to create a new estimate of global temperature change. Third it provides an estimate of uncertainties on the temperature estimates, taking into account plausible changes in winter precipitation.

Oerlemans’s reconstruction of global temperatures (largely from mid latitude glaciers) is entirely independent of the much talked about temperature records from other paleoclimate proxy data (e.g. **Moberg and others**, **Mann and others**, **Crowley and others**). Yet Oerlemans’s findings basically agree with the earlier results, as shown in the figure, below. Indeed, the reconstruction of temperature from glacier data is notable for having a rather distinctive **“hockey stick”** shape, the aspect of the original Mann, Bradley & Hughes reconstruction that seems to attract the most attention and criticism. This poses a substantial challenge to those who have dismissed the “hockey stick” as due to biases or errors. Some will of course quibble with this perspective, because the data prior to the 19th century are rather sparse. (Only a few records go back to the 17th and 18th centuries). However, the “hockey stick” shape is clearly in the data, from both the Northern and Southern hemispheres (see for example the data for Grindelwald, d’Argenti&#232re, and Franz Joseph in the figure at right).

Figure shows comparison of the Oerlemans reconstruction with those of Mann et al. 1999, and Moberg et al., 2005. Click on the figure for comparisons with other temperature reconstrutions.

A few comments:
First, the exact relationship between a glacier and temperature is a bit more complex than implied above, and also depends on the glacier geometry and aspect (which direction it is facing), and on radiative as well as sensible heat fluxes. (The difference between radiative and sensible heat fluxes may be thought of as the difference between the ambient temperature is, and how intense the sun is. We all have had the experience of feeling warmth when sitting

in the sun on a day when the air temperature is quite cold. Glaciers experience the same thing.) Oerlemans addresses this by using a simple linear model that relates the glacier length to temperature, with adjustments for the glacier geometry and the local annual precipitation for each glacier. It should be noted that a lot of work was required to do these calculations, much of it presumably by Oerlemans's student L. Klok. Many of the details are not given in the paper due to the short space provided by *Science*, but all the information most will want is in the **online Supplemental Data** on the *Science* website. (If you want more, see the paper by Klok and Oerlemans in ***The Holocene***.)

Second, Oerlemans's reconstruction doesn't say anything about the ongoing debate of whether the "Medieval warm period" was as warm as today. Certainly there is evidence that some glaciers were as small or smaller than they are today at some locations, around 1000 years ago. However, the extent to which the **"Medieval warm period"** was a pervasive, essentially synchronous retreat of glaciers worldwide (as is happening now) is still open to question (see e.g. **Bradley *et al.*, 2003**).

Finally, Oerlemans's work doesn't address whether or not the worldwide glacier retreat is part of a "natural" phenomenon. Indeed, the fact that glaciers were generally more advanced in the 19th century than they are today is exactly what gave rise to the term **Little Ice Age** (coined by a newspaper reporter in California, writing about F.E. Matthes work on glaciers in the Sierra Nevada). Again though, the evidence that the Little Ice Age advances were as synchronous worldwide as the current glacier retreats are today is **sketchy**.

In any case, what Oerlemans's paper does very well is to demonstrate (one more time) what we already knew: global temperatures have risen more than 0.5 degrees C in the last century (up to 1990 — we don't yet have a compilation of the latest data). As Oerlemans points out, the only way for this to be substantially in error is if there has been worldwide decreases in summertime cloudiness (by 30% or so!), or in winter precipitation (by 25%!). There is no evidence for either of these changes occurring, and if there were, it would be a remarkable discovery in and of itself.