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Worldwide Shrinkage of Glaciers

Is global warming the cause?

Basics of glacier mass balance

Shrinkage of glaciers is an ongoing phenomenon throughout the globe. The reduction of a glacier ice mass affects not only human lives through the depletion of local water resources and a rise in sea-levels but also discourages climber activity by altering the approach routes. These days many believe that the shrinkages result from global warming. However, glacial changes are induced not only by changes in air temperature but also by those in precipitation, dust fall, solar activity and so on. The author sincerely hopes that this article will help the reader understand that the shrinkage of glaciers is not a simple matter.

A glacier is defined as a slowly moving mass of ice. The extent of a glacier is affected by the 'income' and 'expense' of ice, also called accumulation and ablation in glaciological terminology. No glacier can exist without an ablation zone, a fact often forgotten since glaciers exist in cold climates at high elevations or high latitudes. Even in the world's coldest land, Antarctica, the ice sheet must lose a huge ice mass by calving of the ice shelf. Otherwise, without an ablation zone a glacier or ice sheet could expand forever (Figure 1).

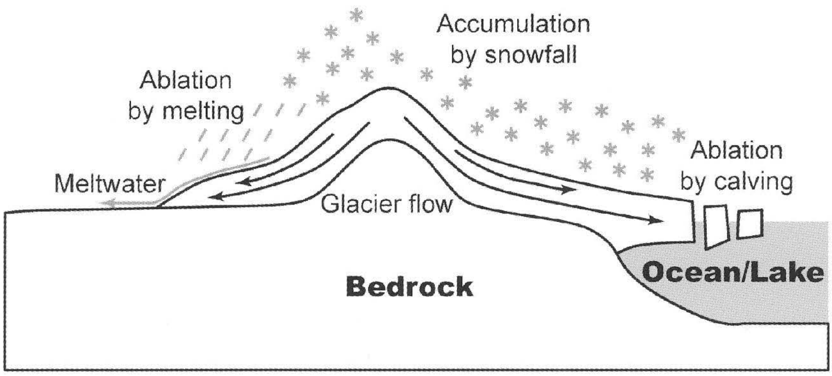

Figure 1. Schematic figure of mass balance of glacier and ice sheet.

The volume and areal extent of a glacier is determined by its 'mass balance' comprised of accumulation and ablation. If accumulation were to greatly exceed ablation, for instance, the glacier would expand its area until the balance between accumulation and ablation reached zero and *vice versa*. In order to understand the response of a glacier to climate change, we have to know what factors and their changes will affect accumulation and ablation.

Since glacier consists of ice mass, needless to say, snowfall is a key factor in its accumulation. The amount of snowfall fluctuates with the precipitation amount in a cold winter. In the Asian highland, however, most of the precipitation occurs in summer due to the Indian monsoon. Therefore, accumulations are affected not only by changes in the precipitation amount but also by changes in air temperature that determine the precipitation phase as one of snowfall or rainfall because the summer air temperature on the glacier fluctuates around 0℃.

The ablation process is rather complicated. In the case of glacier ice, it involves calving, melting and evaporation. Moreover their contribution to the total loss of glacier mass also depends on regional climate and topography. If a glacier ends its terminus in an ocean or lake, most of its ice is lost by calving, which accounts for most of the loss in the Antarctic and Greenland ice sheets, and the ice fields of Patagonia and Alaska. Because of its high latitude and incredibly cold climate, the Antarctic ice sheet expands toward the ocean despite the extremely small amount of inland precipitation. On the other hand, the enormous amount of precipitation in Patagonia drives the ice mass toward the low-elevation lakes or fjords. Colder and rather humid environments in Alaska and Greenland allow glaciers to end at the ocean. Moraine-dammed lakes that form at the termini when glaciers retreat affect glaciers in a similar way. Estimations of calving volume are very difficult since water level, water temperature, glacier movement and bedrock topography affect it in a complex way; it is said that the amount of calving is less strongly related with air temperature. TV grabs often show the collapse of a glacier fringe (Figure 2) into an ocean or lake in order to illustrate the harmful effects of global warming. However, since all glaciers inevitably have an ablation zone, such spectacular collapses of glacier termini are bound to occur either in a warming or cooling world. Hence, such scenes not only provide little information but actually mislead the public.

Figure 2. Collapse of Amery Ice Shelf, Antarctica.

Melting is the most dominant factor of ablation in mountain glaciers worldwide. Melts of snow and ice are caused by the absorption of heat energy from the atmosphere. Many meteorological parameters such as air temperature, surface reflectance of solar radiation, cloudiness, humidity, and wind speed can affect the generation of meltwater at the glacier surface. Generally speaking, however, it is the sum of positive temperatures in summer that most directly impacts the amount of melting. Evaporation is also a kind of ablation of a glacier ice mass. Since the amount of evaporation depends on the humidity, evaporation is a significant factor in the glacier mass balance in arid environments such as Kunlun, Tienshan, the Andes and Arctic Canada, but insignificant in humid environments like the Himalayas, Alps, Alaska and Patagonia.

Fluctuations of glaciers

The current total number of glacier worldwide amounts to 160000 (Figure 3). However, only 40 glaciers in the Northern Hemisphere have had their mass balance continuously monitored for more than 30 years (Figure 4); Figure 5 shows their cumulative mass balance. The shrinkage of glaciers since the 1940s seems to be clearly consistent with a warming trend in the Northern Hemisphere. On the other hand, Scandinavian glaciers are expanding even in a warming climate. This growth in glacial ice mass has been caused by the increase of snow accumulation around the Scandinavian Peninsula, which has exceeded the increase of melt due to warming. In the 1990s, ablation surpassed increased snowfall, and thus total glacial mass entered a negative phase. As mentioned above, the mass balance of glaciers is determined not only by changes in air temperature but also by changes in snow accumulation. In any case, most glaciers worldwide have tended to shrink over the last century. Although this worldwide phenomenon seems to be consistent with a warming trend since the 1970s, precipitation amounts have increased in the glacierized regions during that same period (Figure 6). In addition, regional and seasonal biases are also important (Figure 7). In the last several decades, warming has become more obvious in high latitudes in winter than in summer. With respect to glaciers, although warming in winter is not important since the air temperature still remains cold, it might induce an increase in snowfall such as occurred in Scandinavia. Warming in summer could seriously affect the negative glacier mass balance. In study of future climate, therefore, we have to consider the seasonality and locality of warming and changes in precipitation.

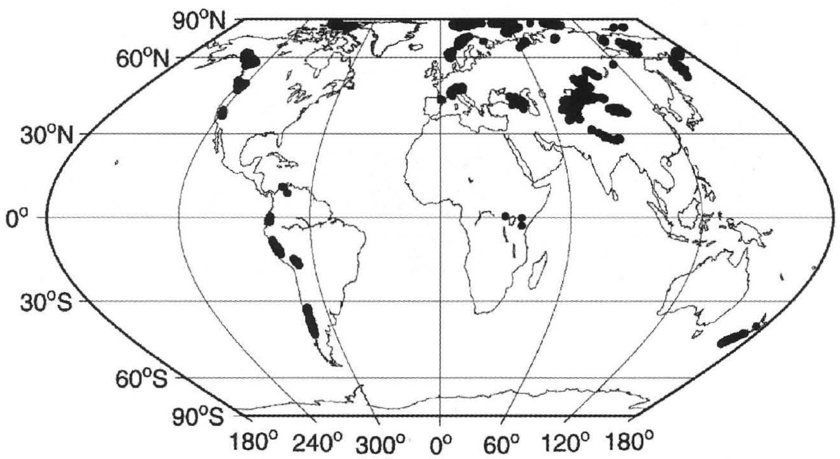

Figure 3. Glaciers worldwide.

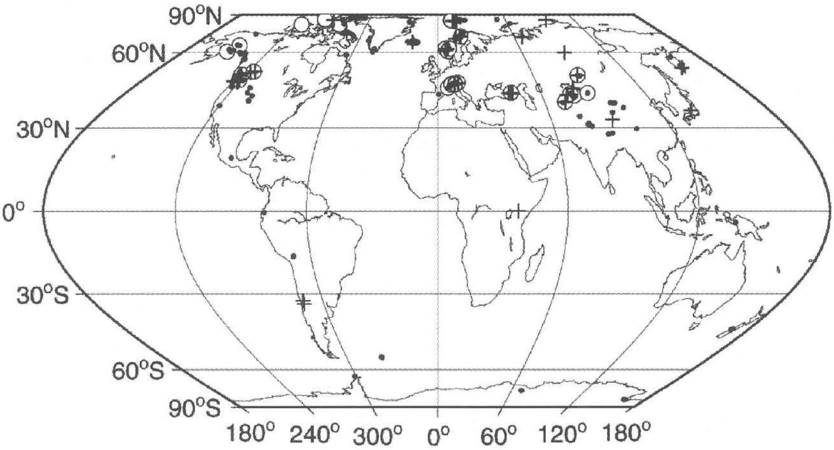

Figure 4. Glaciers monitored for mass balance for more than 30 years (open circles), 10 to 29 years (crosses) and less than 9 years (dots).

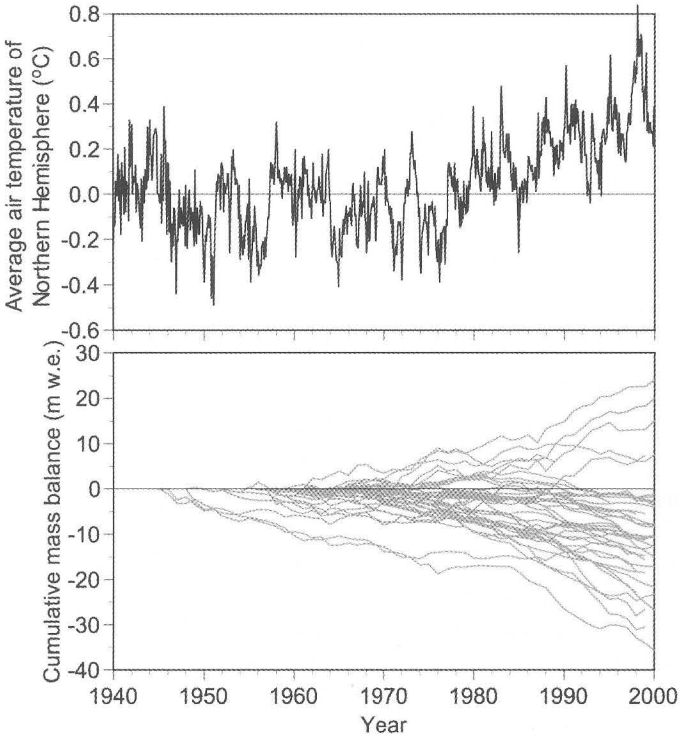

Figure 5. Average air temperature of the Northern Hemisphere (upper panel) and cumulative mass balance of 40 glaciers monitored for more than 30 years (bottom panel). Note that some glaciers have increased their ice mass despite global warming.

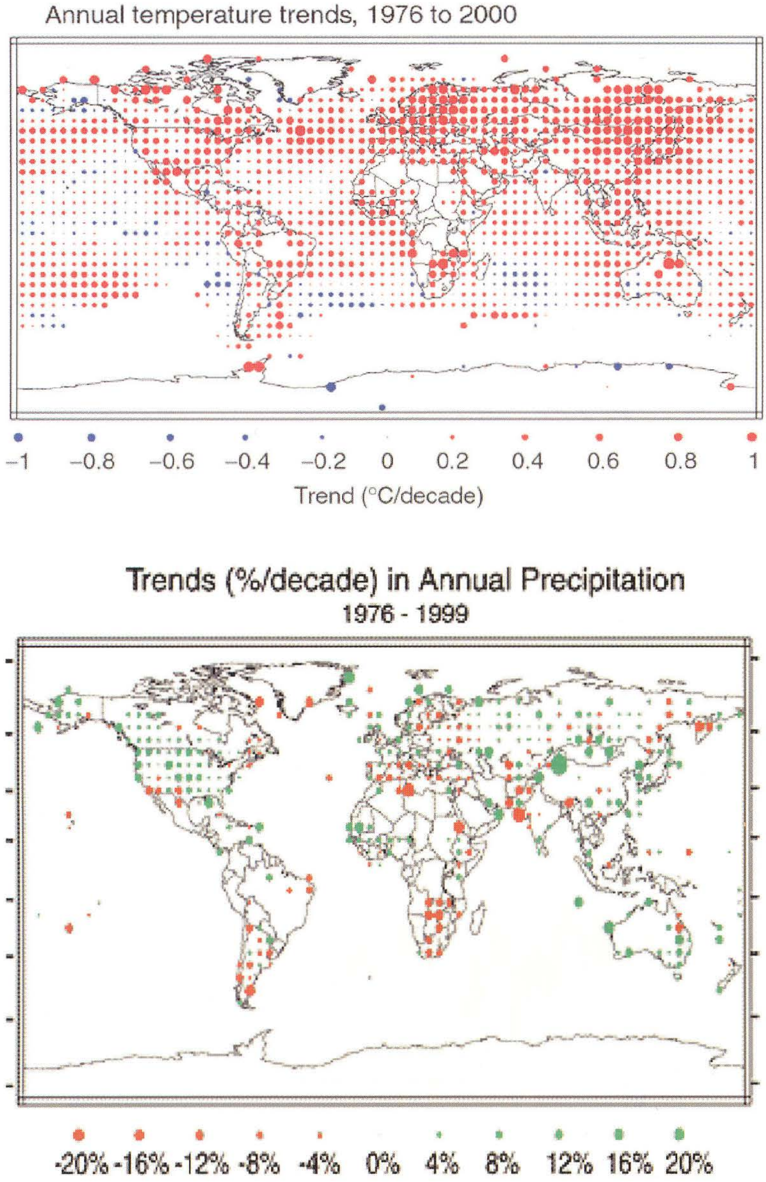

Figure 6. Trends in annual air temperature (upper panel) and precipitation (bottom panel) since 1976.

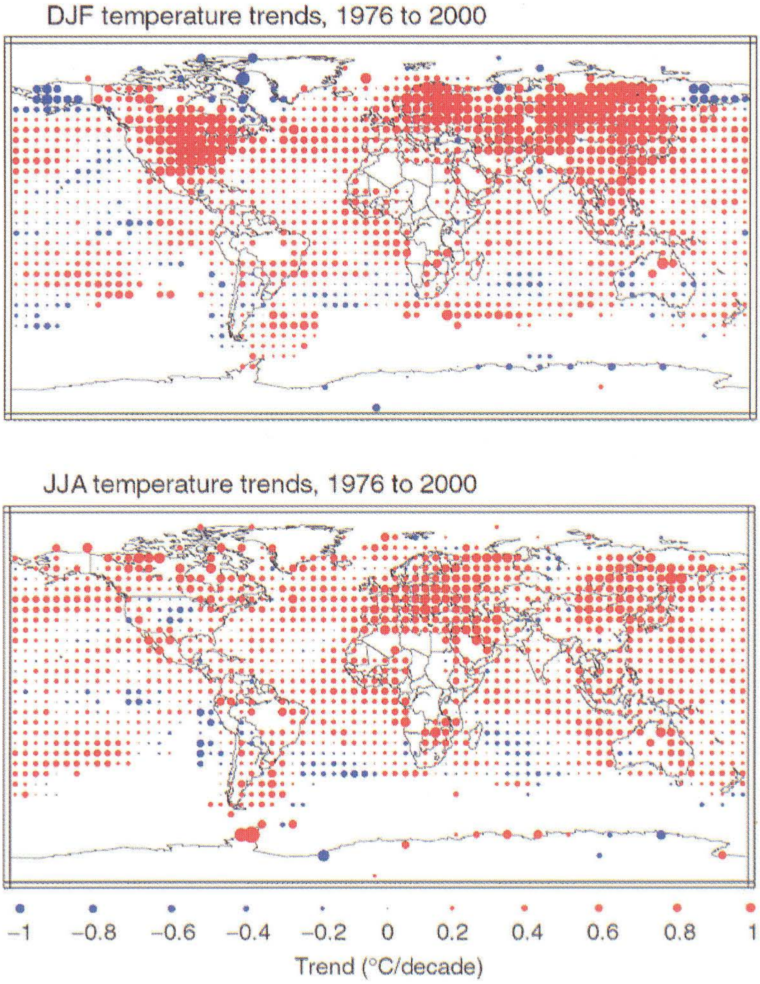

Figure 7. Trends of air temperature in winter (upper panel, December to February) and summer (bottom panel, June to August) since 1976.

Retreat and advance of glaciers

Glacial extent results from mass balance. The mass exchange rate (turnover time of the ice mass) and dynamics of glacier flow determine how fast/slow the glacier responds to changes in mass balance. The larger the glacier, the slower the response to climate change and *vice versa*. The temperature of glacier ice and the presence or absence of basal water strongly affect the flow speed of glaciers. In extremely rare cases, a 'surge glacier' often advances/retreats abruptly with no relation to climate change. The significant mass wastage observed in Alaskan and Patagonian glaciers in the last century has been caused by such surging glaciers.

Although the glacier shrinkage observed worldwide is probably caused by global warming, we have to keep mind that factors other than warming may be involved. With respect to climbing, some approach routes may become difficult and some excellent lines may be vanished due to global warming. On the other hand, Yosemite Valley remind us that environmental changes will provide us alternative opportunity for climbing because the valley was varied by huge ice in twenty thousand years ago. Although I don't agree with present-day wasteful living, nature of climate or environment is 'changing'. So, it is not necessary for climbers to moan or worry about changes in glaciers. You may find something new.

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