Earth Gauge

A National Environmental Education Foundation Program

Climate Change and Alpine Glaciers

Above: A view of glaciers, peaks and snowfield from a sub-alpine meadow in North Cascades National Park, Washington. Image: National Park Service.

Mountain ranges feature some of the most extreme, variable and rapidly changing environments on Earth. Average temperatures drop by about 3.8 degrees Fahrenheit per 1,000 feet gained in elevation. Wind speed also increases at higher elevations at a rate of about 7.5 miles per hour for every mile gained. Only specifically adapted, ground-hugging plants can survive in alpine areas above the tree line, which in many of the world's mountain ranges are above freezing for only a few months out of the year. During winter, most alpine animals either hibernate or migrate to lower altitudes. Today, these alpine zones serve as refuges for the remnant glaciers that covered much of the planet during the last glacial maximum about 20,000 years ago. As the climate warms, however, the lower elevation portions of glaciers shrink to maintain equilibrium with the global climate.

High Mountain Glaciers: To Melt or not to Melt

Alpine glaciers form where summer temperatures remain cold enough to keep the previous winter's snow from melting completely. How much of a glacier melts during summer versus how much ice it accumulates during winter determines a glacier's *mass balance*. Since *mass balance* is tightly coupled with temperature and precipitation, changes in glacial size on time scales of years to decades reflect changes in climate. Because high-altitude topography and geology is highly variable across relatively small geographic distances, the myriad microclimates mean that even neighboring glaciers can have different responses to the same regional climate trend. In the Northern Hemisphere, glaciers on south-facing slopes, for example, tend to melt more readily than glaciers on north-facing slopes. These differences make both monitoring and predicting changes in the Earth's hundreds of thousands of mountain glaciers difficult.

Sophisticated glacier mass balance models are employed to help understand the behavior of these key ice masses, which are important natural reservoirs for some of Earth's most populated regions. Models include factors such as:

- *Atmospheric Transmissivity* – How much solar radiation makes it to the Earth's surface, as opposed to being reflected or scattered by atmospheric aerosols and water vapor (clouds), has a strong effect on melt rates. In the European Alps, for example, despite higher air temperatures today, melt rates were slightly higher in the 1940s due to solar radiation at the surface being stronger because of fewer atmospheric pollutants.
- *Albedo of Surrounding Landscape* – Darker objects absorb more solar radiation than lighter objects, meaning they have a lower *albedo*. Darker surfaces, such as bare soil, shrubs, and rocks absorb more heat than ice and when exposed can create warmer microclimates that melt glaciers.

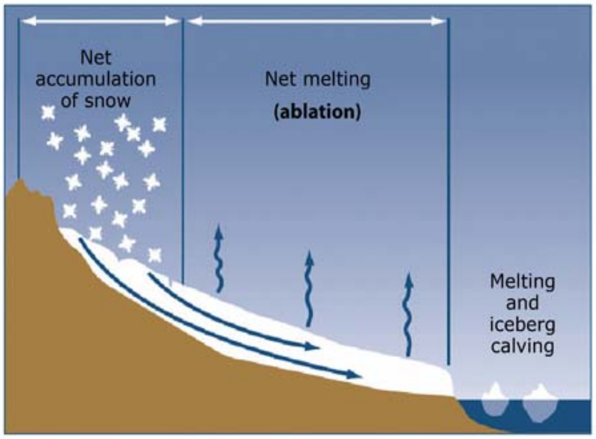
Above : "Dirty" snowpack and glaciers after a spring dust storm in Colorado. Image USGS.

- *Adiabatic Lapse Rates* – Atmospheric pressure and temperature are lower at higher elevations. The *dry adiabatic lapse rate* is the rate at which an air parcel that is not yet saturated cools as it rises. The *wet adiabatic lapse rate* is the rate at which saturated air cools and condenses as it rises, leading to cloud formation and precipitation. Regional differences in air temperature and moisture content affect the *wet adiabatic lapse rate* and glacial dynamics.
- *Glacial albedo* – Ice that has been on a glacier for several years tends to be darker and have a lower albedo than new ice. Dust and rock accumulation on glaciers also influence melt rates. A single dust storm in the Colorado Rockies cut the surface albedo of certain alpine zone in half, accelerating melt rates. On the other hand, if the dust, dirt and rock layer is sufficiently thick, it can insulate the glacier from melting.

Glacial Health: The AAR Measurement

Glaciers can be divided into two parts: (1) the *ablation zone*, where annual loss of snow and ice from melting, sublimation, and calving into lakes or the sea occurs at a faster rate than snow and ice gain and (2) the *accumulation zone*, where more snow accumulates and turns into ice each year than melts. The *accumulation area ratio (AAR)* is the ratio of the accumulation area to the glacier's total area. Generally, AAR values between 0.4 and 0.8 indicate healthy glaciers that are considered to be "in balance." AAR values below 0.4 mean that the glacier is thinning and retreating.

Less glacial area and lower glacial elevation mean that more bare earth around the glacier is exposed. The area's *albedo* is lower and more solar energy is being absorbed, warming the microclimate and accelerating melt. It also means that more older and darker ice is exposed, which also accelerates melt. AAR values below 0.4 indicate that the glacier is *overextended* or in *disequilibrium* with the current climate, and must shrink to a new extent in order to regain *equilibrium*. This process of finding equilibrium can happen quickly, particularly for small glaciers. Or, it can take tens of thousands of years, even if no further climate change occurs.



Above: A schematic diagram of different glacial zones. Note the melting and iceberg calving into the lake below at the glacier's terminus. Image: USGS.

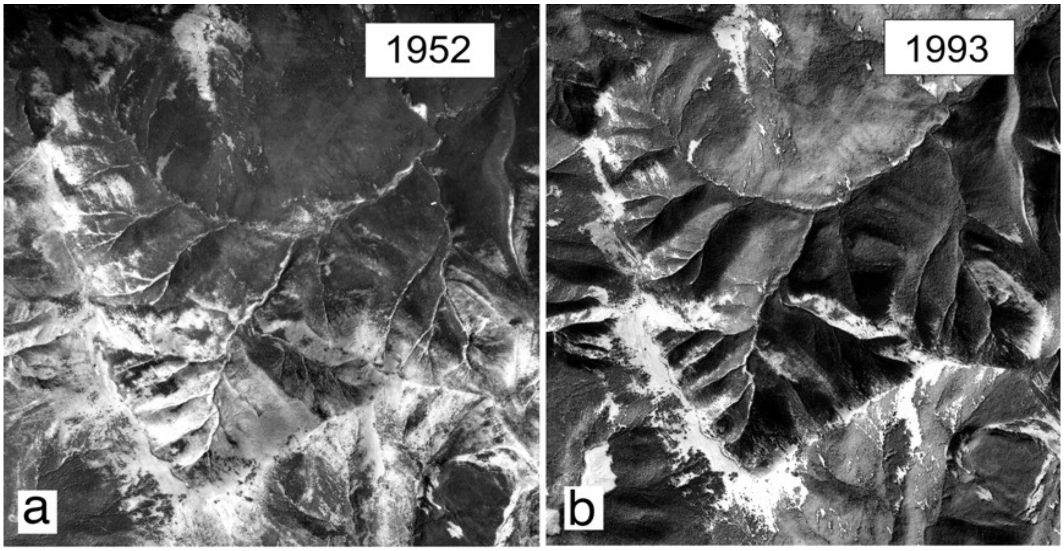
Regional Trends in Alpine Glacial Mass

North Cascades: Nine of 12 glaciers studied North Cascades National Park have experienced multiple years with AAR values below 0.3 since the early 1980s, and are considered to be in disequilibrium. Foss Glacier has lost 40 percent of its mass since 1979. Columbia Glacier, which needs an AAR of 0.62 to remain in equilibrium, has experienced six years with AAR values below 0.2 and its terminus, the outward edge of the glacier's ablation zone at any given point in time, has retreated by 300 feet.

Glacier National Park: Today, about 27 percent of the area of Glacier National Park covered by glaciers in 1850 is still covered; the number of glaciers has been cut from 150 to 37. Grinnell Glacier shrunk from an area of 1.11 square miles in the 1850s to less than 0.4 square miles today.

British Columbia: Covering over 11,000 square miles as recently as the 1980s, British Columbia's glaciers account for four percent of global and 23 percent of conterminous North American glacier cover. Melting of these glaciers between 1985 and 1999 accounted for about 8.3 percent of the mountain and ice cap contribution to global sea level rise experienced during this period.

Global: Areas of Earth with extensive glacial coverage are some of the most remote and least known. Despite better observations through satellites, assessments of ice mass loss depend on gross estimates. Best estimates suggest that on average, each square yard of glacial cover lost 387 pounds of mass each year between 1961 and 2004 due to glacial thinning or terminus retreat. This loss accounts for about 0.33 millimeters, or roughly 10 percent, of each year's global sea-level rise during this period.



Left: A comparison of aerial photographs of Jumpingpound Ridge, Alberta, Canada. Note the loss of ice mass between the two periods, as well as the darkening of the ground, which indicates increased forest cover.

Image: Roland J and Matter, SF. PNAS, 2007 – image may be used for non-commercial and educational use only. Please visit: http://www.pnas.org/site/misc/rightperm.shtml for further details.

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