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TOOLS OF THE TRADE

GIS reconstructions of former glaciers shed light on past climate

Reconstructions of former mountain glaciers provide a unique opportunity to collect data on Earth's paleoclimate. Glaciers have a simple relationship with climate: when it is cold and/or snowy, glaciers grow, and when it is warm and/or dry, they shrink. Both annual precipitation and summer temperature conditions control a line on a glacier called the equilibrium line altitude (ELA), above which is the accumulation zone (where glaciers gain mass) and below which is the ablation zone (where glaciers lose mass). Glaciers also leave behind landforms – like moraines – as they grow and retreat. Before computers, researchers used topographic maps and the locations of moraines as guides to extrapolate ice surfaces by hand and derive ELAs based on these surfaces. However, these approaches were time-consuming and subject to human error.

Today, researchers can use computer geographic information systems (GIS) to automatically reconstruct former ice surfaces and calculate ELAs. First, digital elevation data are obtained, usually from government agencies such as the United States Geological Survey. Using these data, former glacier extents are mapped using moraines as guides. Then, GIS tools based off empirical equations of ice flow ($\tau_b = \rho \times g \times H \times \sin \alpha$, where τ_b is the basal shear stress (usually 100,000 Pa for mountain glaciers); ρ is ice density; g is the gravitational acceleration (9.8 $m\,s^{-2}$); H is the ice thickness and α is the ice surface slope) are used to recreate past glacier surfaces. The ELA is commonly calculated using reconstructions of ice surfaces (or modern ice surfaces) and applying a standardized ratio between the accumulation and ablation zones. For example, an ELA calculated with a ratio of 0.6 defines the accumulation zone as occupying the upper 60% of a glacier surface area, and the ablation zone as constituting the bottom 40% of the glacier. The ELA is at the elevation of the boundary line between these two zones. With reconstructed ice surfaces of past glaciers or surfaces of modern glaciers as inputs, other GIS tools can calculate the ELA using user-defined ratios. Glaciologists have derived equations describing the relationship between the ELA and summer temperature and annual precipitation; making it possible to determine climate conditions from an ELA, or to calculate an ELA with precipitation and temperature data. Thus, comparing ELAs between modern glaciers (or hypothetical ELAs in areas with no modern glaciers calculated from climate data) and ELAs from former glaciers can be used as a paleoclimate proxy.

Credit: Kennedy C. George

These techniques are applicable across a wide geographic area, as mountain glaciers were present from the tropics to the polar regions during the Last Glacial Maximum (~25,000 years ago). This technique is now being applied to former mountain glaciers across Alaska, revealing that temperatures there were relatively mild during the Last Glacial Maximum despite global temperatures being much cooler than today.

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Competing interests
The author declares no competing interests.