Relationships between glacier dynamics and climate

Gwenn Flowers

Kaskawulsh Glacier (Flavien Beaud).

Glaciers and ice sheets store over two-thirds of Earth's freshwater and are presently contributing to rising sea levels. Understanding the behavior of these ice masses, including how they respond to a changing climate, is essential for our ability to predict their future evolution, better understand planetary albedo feedbacks (the Earth's reflection of radiation) and project future sea level rise.

AIMS OF THE PROJECT

The goal of the project was to understand the regional variability of glacier response to climate, and assess the role of glacier dynamics (flow) in determining this response. In particular, we set out to (1) measure regional climate variables important for glacier mass changes (e.g. temperature, radiation, precipitation), (2) monitor the glacier mass balance by measuring mass gain (snow accumulation) and losses (ablation), (3) characterize the dynamics of several targeted study glaciers, and (4) model the interaction between climate, glacier mass change and dynamics.

WHAT DID WE DO?

We installed 5 automatic weather stations in our 30 x 30 km study region, and over the course of several years measured the total winter snowfall and total summer melt across two study glaciers. This required the installation and maintenance of a spatially representative network of ablation stakes on each glacier that we measured each year, as well as the establishment of a seasonal stream gauge. Global Positioning System (GPS) measurements of markers drilled into the ice enabled us to calculate glacier flow speeds, while ice-penetrating radar was used to measure glacier depth and map out colder and warmer zones within the ice. Computer models of varying complexity were developed in our laboratory to (a) simulate glacier mass changes in response to measured climate variables, (b) explain the observed glacier flow regimes and (c) predict future changes in glacier thickness, extent, speed and temperature.

WHERE DID WE WORK?

The St. Elias Mountains of Yukon and Alaska are known for their extreme topography, rising from sea level along the Gulf of Alaska up to Mt. Logan (5,959 m), the highest point in Canada. This area also has an abundance of fast-flowing glaciers, making it an ideal setting in which to explore the relationship between climate and glacier dynamics. We worked on a small population of glaciers on the continental side of the St. Elias Mountains, in the traditional territory of the Kluane First Nation. The glaciers here, all subject to the same regional climate, represent a range of thermal and dynamic regimes and are accessible from the Kluane Lake Research Station.

WHAT DID WE FIND?

Glacier mass changes measured in our study area were in broad agreement with independent estimates of glacier mass change in the wider region, with our study glaciers experiencing net losses in all but one year. Despite this broad agreement, there were some significant and systematic differences in winter snow accumulation and summer melt between our targeted glaciers, which were only 10 km apart. The contrasting orientations and positions of these glaciers on opposite sides of the mountain range crest play an important role here.

Our investigation of glacier dynamics through observation and modelling yielded some surprising results. One of the study glaciers, known to have "surged" in the past, i.e. advanced rapidly down the valley, is now undergoing a "slow surge". This phenomenon is characterized by an unsustainably high flow rate, but one that falls short of what has traditionally been identified as a surge. Glaciers in this state have suffered a mass deficit in the period leading up to the surge, and may stop surging altogether if they continue to lose mass. Climate's fingerprints can now be detected in the changing dynamics of glaciers.

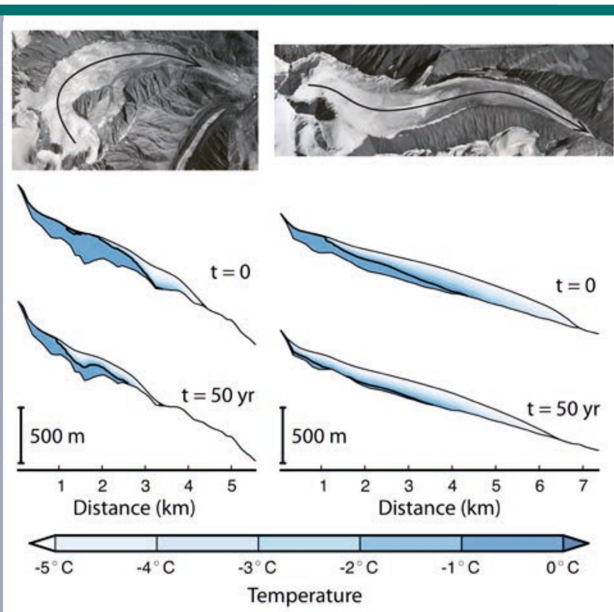
By imaging the ice interior with radar and making direct measurements of glacier temperature with digital borehole sensors, we found that many of the small glaciers on the continental side of the St. Elias Mountains are "polythermal". These glaciers have a zone of temperate close to (melting point) ice partially overlain by a thick shell of colder ice. Our models suggest that many of these glaciers will get colder as they retreat and disappear. When meltwater refreezes in a cold snowpack it releases a large amount of heat, which warms the snow that will eventually form glacier ice. The decline of a porous snowcover on these glaciers inhibits the retention of meltwater and the heat it provides, ultimately producing colder glacier ice. One of our study glaciers is expected to cool significantly in the future, while the other is not, due to differences in their geometries and flow regimes. This cooling may impact the glacier's ongoing response to climate, as colder ice flows more slowly down valley than temperate ice. The same physical processes may produce the opposite effect in other climate settings, including some parts of the Greenland Ice Sheet, where increased meltwater entrapment may warm the ice and produce faster ice flow from the continental interior to the ocean.

WHY ARE THE RESULTS IMPORTANT?

The results of this study are important, because they tell us that neighboring glaciers can respond differently to climate, and that the details of their geometries, temperatures and flow regimes can combine to produce unexpected behavior. As this new knowledge makes its way into the increasingly sophisticated models used by the scientific community, we will be better able to predict regional to global glacier change and its impact on planetary albedo, freshwater resources and sea-level.

THE ADVENTURE

Working on and around glaciers is fun, but can be dangerous. We do much of our work roped together as a team on skis or snowshoes, navigating crevasses (large cracks in the glacier surface often hidden under snow) with our instruments. A memorable survey was cut short when one of the graduate students fell through a snow bridge and into a crevasse. After 45 minutes of setting up pulley systems and hauling, we finally retrieved a wet and cold but happy student!



Projected changes in geometry and temperature for two different glaciers in the Donjek Range from present day (t=0, middle row) to 50 years into the future (bottom row). Images (top row) show the locations of the modeled profiles on aerial photographs of the study glaciers (left: surging glacier in 1951; right: glacier with no known surge history, 1977). Note the near-complete disappearance of temperate ice (darker blue) in the glacier on the right after 50 years (Figures from Wilson and others (2013)).

Photo wider -> (JJA)

Snow pit (Laurent Mingo).

Further information

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