Module 3: Glaciers, Snow & Water

A snowflake is an aggregation of frozen water crystals. The size and shape of a snowflake depends on the air temperature when it forms.

In the mountains, the majority of snow falls in the winter and melts in the summer. What snow that doesn't melt remains and has more snow added the next winter. The snow that remains is consolidated into **firn** – which is granular snow that looks a little like sugar but has not yet been compressed into ice.

Glaciers are snow and firn that are transformed into ice by gravity. Gravity also makes glaciers flow downhill by deforming ice and by sliding on wet deformable sediment at a glacier's bed. A glacier flows downhill like an escalator and transports rocks that fall on them at the end of the glacier as a terminal moraine. If not enough snow accumulates year after year to turn snow into ice, then a seasonal snow patch occurs.

The top part of a glacier is the **accumulation zone**; the bottom part is the **ablation zone**. At the end of summer, the ablation zone is ice at the surface because the snow cover has melted. In the accumulation zone snow remains because at the higher elevation air temperature is not warm enough to melt the snow.

Sun, snow, and ice interact to make a glacier. Snow is bright and ice is dull when viewed with your eyes. The amount of sunlight a glacier absorbs or reflects is called **albedo**. Snow in the accumulation zone absorbs ¼ of the sunlight falling on it. Ice in the ablation zone absorbs ¾ of the sunlight falling on it. The temperature of the air will melt the snow, but what's more interesting is how the albedo of snow increases snow melt. If it absorbs the energy, and it starts to melt into water, that water has a lower albedo and absorbs the heat rather than reflecting it, resulting in even more melt. And any rock residue, dust, and dirt are dark in colour and will absorb more heat, increasing the melt. In this way, air pollution exacerbates glacial retreat.

If you lose the fresh snow, the ice is darker itself and just absorbs more solar radiation, so melting and sublimation appears more intense, and the ice loss increases.

As glaciers melt, layers of pollution, what were once airborne particles that condensed out of the atmosphere as rain or snow have become part of glaciers and so as their layers melt and these pollutants are exposed, you then are dealing with contaminated water.

Anthropogenic contaminants in glaciers are a significant concern. Black carbon, microplastics and other contaminants, as well as volcanic ash and soil deposits are transported through the atmosphere and deposited over glacier and snow-covered areas. This has been seen around the world. In the Andes, traces of lead and mercury have been found in the 1,200-year-old Quelccaya

Ice Cap in Peru. These were the chemicals used after the Spanish occupation in the silver mines of Potosi, Bolivia. This is one of the earliest examples of anthropogenic air pollution.

Axel-Heiberg Island in the Canadian High Arctic. Photo by Dr. Laura Thompson, Queen's University.

Snow in isolated patches or on glaciers can also have algae grow on it. The algae are sometimes called **watermelon snow** because they are red, and some people think the snow actually smells like watermelon. The algae live in the meltwater between snow grains. They are photosynthetic and make the snow absorb more sunlight which promotes snow melt. Snow algae genus Sanguina, Chloromonas, and Chlainomonas are found in summer snowfields in southwestern British Columbia.

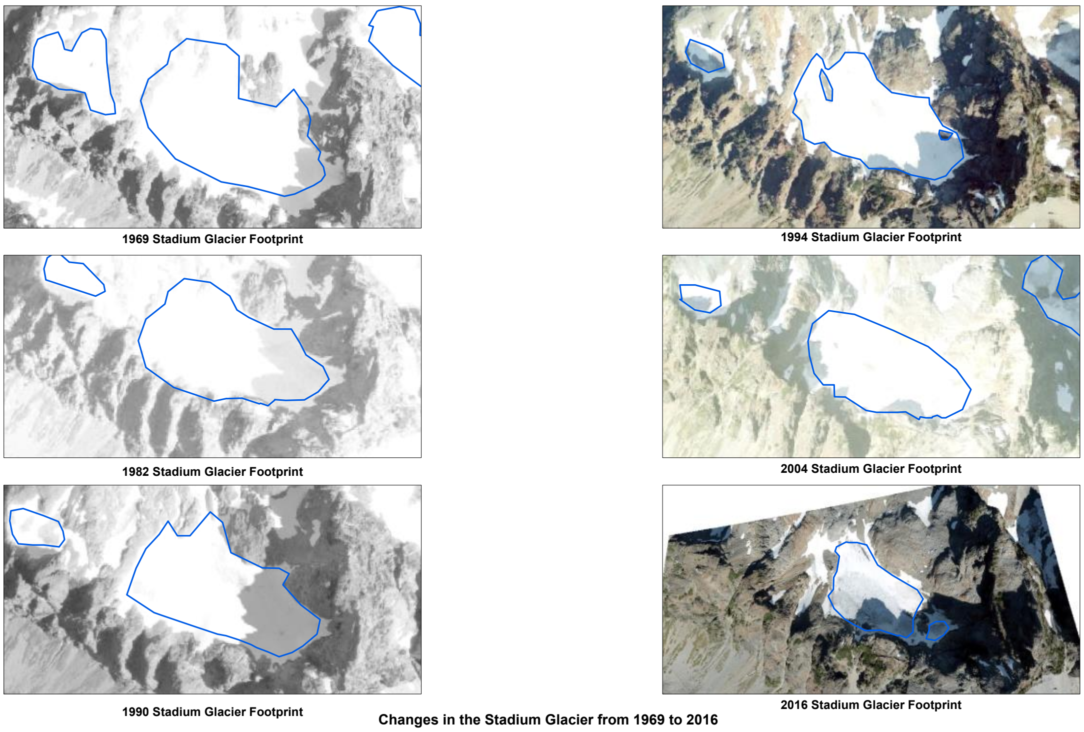
Vowell Glacier in Bugaboo Provincial Park. Photo by Scott Williamson.

Flowing glacier ice can form crevasses when the ice is stretched (strained). A crevasse will form when the glacier turns around a bend or rapidly loses elevation, such as flowing over a rock ridge.

Glaciers and snow patches are both important for contributing melt water to streams and rivers in the summer. They are also important in keeping streams and rivers water temperature lower than if they were fed only by rain. Many species of animals, including fish and amphibians, are very sensitive to water temperature.

Retreating glaciers also contribute to slope instability on our mountains and increased natural hazards like landslides of rock, regolith, and glacial lake outbursts.

Let's look at a glacier right here, Stadium Glacier which sits in a cirque next to Skypilot at 1,740 metres. In fact, here's more of a step-by-step view of the retreat of this glacier:



Changes in the Stadium Glacier from 1969 to 2016

Figure by Robert Plummer.

And as you can see, the little glacier to the upper left of Copilot has disappeared entirely. We also have a picture of its 2021 size relative to 1984. The black polygon is the glacier outline on September 2, 2021. This polygon sits on a Landsat image of the Glacier from September 28, 1984. The glacier has lost a lot of ice. So instead of annual melt where the snow on top of the ice melts away, but the ice remains, we have a glacier that is retreating and will disappear.

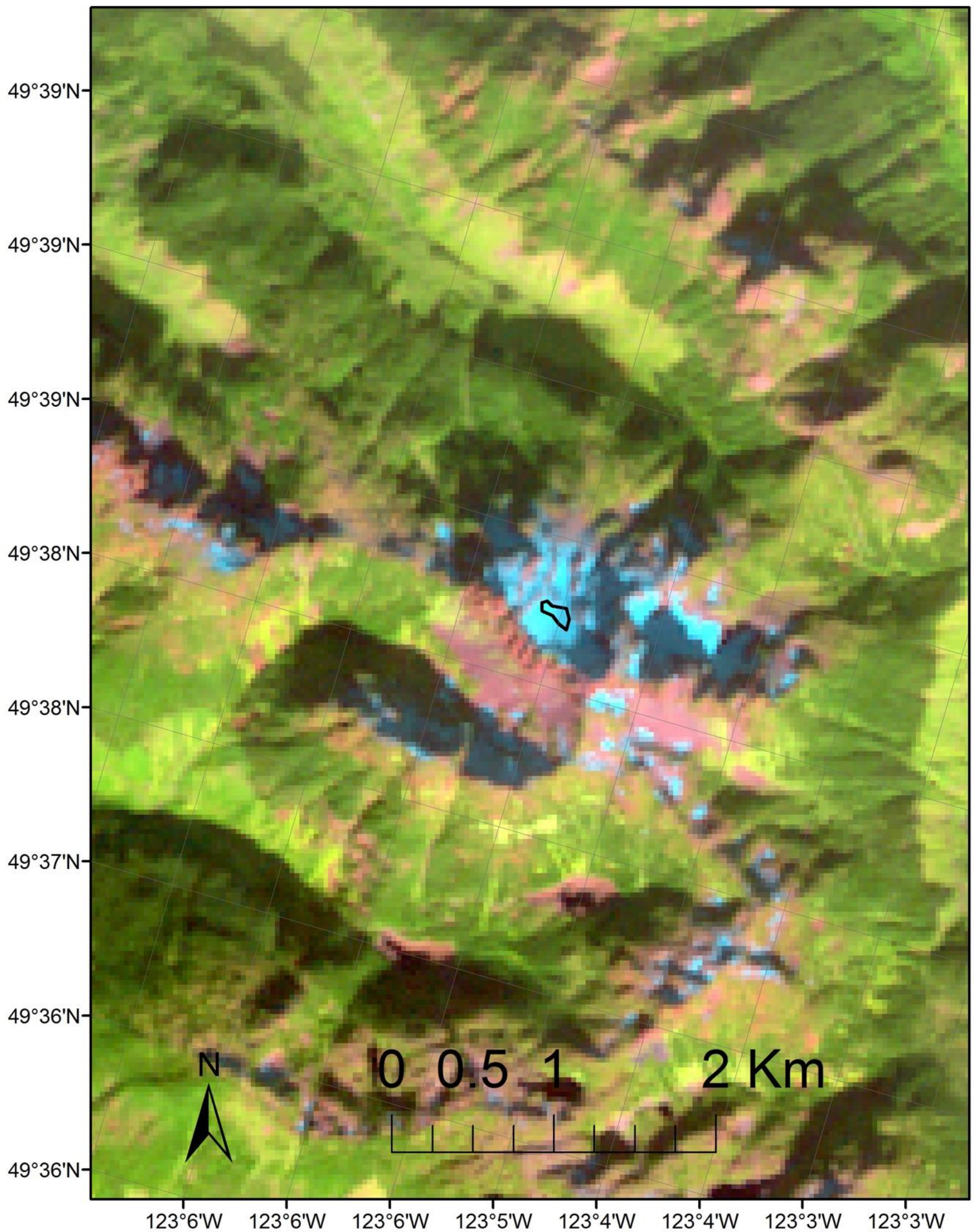

49°39'N
49°39'N
49°39'N
49°38'N
49°38'N
49°37'N
49°36'N
49°36'N
N
0 0.5 1 2 Km
123°6'W
123°6'W
123°6'W
123°5'W
123°4'W
123°4'W
123°3'W
123°3'W

Figure by Scott Williamson.

What's the big deal about retreating glaciers?

They provide the water for rivers down the mountains and into the valleys below. They provide our drinking water, the water we use to generate hydroelectric power and for farming and raising livestock.

The glaciers in the Canadian Rockies provide the water for rivers in the Prairies to the east. Runoff from the eastern slopes of the Rocky Mountains provides water to rivers in Alberta, Saskatchewan and Manitoba.

The glaciers in the Hindu Kush Himalaya provide water to almost 2 billion people, that's one-quarter of the world's population. The HKH stretches 3500 km across eight countries: Afghanistan, Bangladesh, Bhutan, China, India, Myanmar, Nepal and Pakistan. It's the source of ten significant rivers: the Amu Darya, Indus, Ganges, Brahmaputra (Yarlungtsanpo), Irrawaddy, Salween (Nu), Mekong (Lancang), Yangtse (Jinsha), Yellow River (Huanghe), and Tarim (Dayan.)

You will sometimes hear mountains being described as **water towers**. The three key regions around the globe where water towers are most threatened and are supplying water resources for large human populations: Hindu Kush-Himalaya (especially the Indus and Ganges watersheds, which are the first and tenth most relied-upon water towers in the world, respectively,) the southern Andes (Chile or southern Patagonia is the fourth most relied-upon global water tower,) and western Canada (the Fraser and Columbia River watersheds are ranked fifth and sixth most relied upon, respectively.)

The Himalayas contain the third largest number of glaciers in the world, only surpassed by the Arctic and Antarctic. This includes Khumbu Glacier on Everest, the highest glacier in the world. Because of this, the Himalayas are often dubbed the "Third Pole."

The five most relied-upon systems by continent:

- Asia: Indus, Tarim, Amu Darya, Syr Darya, Ganges-Brahmaputra
- Europe: Rhône, Po, Rhine, Black Sea North Coast, Caspian Sea Coast
- North America: Fraser, Columbia and Northwest United States, Pacific and Arctic Coast, Saskatchewan-Nelson, North America-Colorado
- South America: South Chile, South Argentina, Negro, La Puna region, North Chile

Water towers are at risk due to the threats of climate change, growing populations, mismanagement of water resources, and other geopolitical factors.

Where more snow melts from a glacier each year than it receives, its end or **'snout'** will retreat uphill. As it does so, large volumes of regolith previously deposited from the ice may remain perched along the sides of its valley, often precariously (particularly when the retreat is rapid). These accumulations are unlikely to be stable and may suddenly give way and move rapidly down-slope – particularly with the addition of water and/or seismic shaking.

Glacial retreat, Mount Dhaulagiri, Nepal. Photo by Robert Plumber.

Glaciers can move from a few cm a day to a few hundred metres a day. The underside of the glacier moves more slowly than its top. With global warming, however, glaciers sometimes look like they're moving backwards. Because as they melt, the terminus, or end of a glacier is higher rather than lower on the mountain as you might expect from gravity. This is **glacial retreat**.

Activity: How is a chewy chocolate bar like a glacier?

What you will need:

1 Volunteer
1 Mars Bar that's been in the freezer for 5 minutes

A Mars Bar is long and linear, u-shaped on bottom with steep sides, like a glacier.

It is flat on the bottom and steep on the sides, like a glacier.

Please gently bend your MB. You'll see it develops cracks like the crevasses of a glacier. The top layer of a glacier is brittle. It's the **rigid zone**.

Please pull apart your MB. The caramel undergoes "plastic flow", like the inside top layers of a glacier. This is the **plastic zone** of a glacier.

The nougat layer underneath is formed like **firn**, glacial ice and snow, compressed, less bendy. It's the intermediate stage between accumulated snow from snowfall and ice.

It leads to the basal sliding zone, and the deepest layer of compressed ice in a glacier.

If this were a Snickers bar, the peanuts could be the rocks carried along on the glacier. These are the **erratics**.

Tip your glacier so that it is on a slope. Which is the **accumulation zone**? Which is the **ablation zone**? Where is its **'snout'**?

Lastly, please bite into the end of your Mars Bar; this is **glacier retreat**!

What this demonstrates is that different glacial materials flow at different rates under different conditions, and how pressure from the top layers pushes down and compresses the lower layers into glacial ice. Gravity further pulls the glacier downhill.