Mountain Sustainability Education Program

Contents

About this program

The Mountain Sustainability Education Program, a collaboration between Sea to Sky Gondola, Mountain Research Initiative, GEO Mountains, the University of Calgary, and the Arctic Institute of North America, provides a set of teaching resources designed for learners of all ages.

Educators from around the world are free to use, adapt and further develop the course materials, in accordance with the license specified. Please kindly inform us by writing to education@seatoskygondola.com. Any feedback can also be sent to this address. If you extend the course (e.g. prepare region-specific case studies, cover additional topics etc.) and would like us to consider including this material in subsequent updates, please do not hesitate to get in touch.

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Why create a Mountain Sustainability Program?

- To recognize the United Nation's declaration of 2022 as the *International Year of Sustainable Mountain Development*, and Canada's 2019 Declaration of a Climate Emergency;
- Because mountains are under various pressures, putting their sustainability at risk, there is a need for youth to appreciate the importance of mountain conservation issues;
- Because there is a need for a mountain sustainability program that deals with mountains as systems, encouraging students to consider atmosphere, geosphere, hydrosphere, biosphere, and anthroposphere in relation to each other;
- To raise awareness that mountain sustainability is a global issue, and the benefit of comparative methodology and transboundary collaboration;
- To enrich the educational experience of visitors to Sea to Sky Gondola with a unique scientific course for children and adults on mountain sustainability issues;

- To share educational capacities and knowledge with respect to mountains on a global basis.

What is sustainable mountain development?

- Sustainability is the process of living within the limits of available physical, natural and social resources in ways that allow life to thrive in perpetuity;
- Prevents the depletion of natural resources;
- Improves the quality of human life at present and for future generations;
- Achieves a balance of long-term economic growth while preserving the environment;
- Has a low impact on the environment and wildlife;
- Land use that preserves ecological balance;
- Is aligned with the United Nations Development Program's Sustainable Development Goals for 2030.

The Mountain Sustainability Course Notes designed for Grades K-3, 4-6, and 7-12, are our featured programs. Each includes a combination outdoor learning and activities to accommodate a blend of learning-styles, so there is something to engage each student. There are opportunities for emotional learning and reflection at the beginning and end. They are interdisciplinary crosscuts of mountain sustainability subjects. For Grades K-3, the focus is on biodiversity and mountain stewardship and excludes natural hazards. Grades 4-6 look in more detail and mountain creation and destruction and include an introduction to adaptations to climate change. Grade 7-12 have increased focus on mountain conservation and resilience initiatives, and social justice issues. All age groups do a weather measurement activity to stress the importance of climate change, and of being active contributors to citizens science initiatives.

The Modules function primarily as a library from which to draw subject-specific information.

The Mountain Sustainability education program was made possible by support from Sea to Sky Gondola, the Mountain Research Initiative, GEO Mountains, the University of Calgary and the Arctic Institute.

This course was created by Michael Allchin, Martha Warren, and Scott Williamson. For further information, please contact education@seatoskygondola.com.

Thanks to James Thornton, Carolina Adler, David Hik, Christy Allan, Arron Vickery, Cynthia Chung, Rebecca Goudy, Karin Burns, Robert Plummer, Mollie Greenfield, and Steve Clough for their assistance with this project.

Sea to Sky Gondola is situated on the traditional, ancestral and unceded territory of the Coast Salish peoples – the Skwxwú7mesh (Squamish), Tsleil-Waututh & Musqueam First Nations.

#mountainsmatter

Grades K-3

Mountain Sustainability Course Notes (Grades K-3)(1)

Resources:

"On My Mountain" by Francois Aubineau
Hand sanitizer
Mars Bars
Towel or blanket, folded lengthwise
MS K-3 Field Guides
Pencil
Compass
Anemometer
Thermometer
Soil thermometer

Please see corresponding
Mountain Sustainability K-3 Field Guide

Notes to teachers and education guides: This is a circular program. We start by asking students what being on the mountain means to them. Their answer will be something along the lines of *"When I come to a mountain, I feel free/I can breathe/I'm out of the classroom/it reminds me of hiking with my family/I feel peaceful/I want to ski/I am afraid of bears…"*

At the end of the program, students have 15 minutes to reflect individually to embed some of the learned material on an emotional and visceral level by completing their sketches from their observations on the hike.

3 Things-to-Do at the end of the program are to empower this age group to build good habits of involvement in citizen-science, observation and record-keeping, and sharing and caring for mountains.

Mountain creation/destruction/movement.

How does the mountain feel under your feet?
Solid, hard?

What if I told you it was moving? What if I told you it was moving so slowly that you can't even feel it?

The earth is covered by large plates of rock and on top of them sit the land and ocean. The plates of rock are always moving. They bump into each other. They slide overtop and below each other. They push up through the land and ocean on top of them as mountains and sometimes as volcanoes. Even as we stand here now, mountains are rising out of the earth, and moving, and changing shape. Himalaya mountains are rising more than 1 cm a year! Mountains growing as fast as your fingernails!

So we have rock pushing through the land and ocean because the plates underneath are colliding, pushing into each other. These are fold mountains.

Activity 1: The Beach Towel Shuffle

Stand or sit on either end of a stack of towels or a large blanket. Here, you and your classmates will act as the layer of earth's crust found just below the surface (a.k.a. tectonic plates). As you shuffle towards your partners on the opposite side of the towel, watch as the folds and creases are formed in the towel or, in our example, the earth. This is similar to how the movement of earth's crust creates folded mountains!

> Examples: the Andes in South America are fold mountains. They are the longest mountain range in the world, and still grow about 10 cm every hundred years.

How else are mountains made? Volcanoes! Where magma, hot liquid rock, is pushed up through the earth's crust, it cools into rock, and more magma comes up and cools on top of that, and on top of that, until you have a volcano.

Mount Garibaldi is a volcano– last erupted about 8,000 to 13,000 years ago. It's dormant now.

And what if magma is pushed only part-way through the earth's crust and not all the way through, and it pushes the land up above it? Those are dome mountains.

Now let's look at what shapes our mountains.

Mountains and weather

Mountains influence on weather – rain and snow fall on mountaintops more than down below because it's colder up on a mountain. As air rises to pass over a mountain, it cools and can't hold as much moisture so it lets it go as rain. So one side of a mountain often gets more rain than the other.

Weather's influence on mountains – wind – trees grow in funny shapes, their trunks sometimes twisted, with short branches often growing off only one side, few leafy trees/bushes (salal!)

- Shape of trees you'll notice:
  - ***Krummholz*** = stunted or deformed vegetation in the subalpine
  - ***Flagging*** = where you have growth on only one side of a tree due to winds

Subalpine tree growth.
Photo by Martha Warren

Easier for plants in the subalpine to have needles instead of leaves so they don't have to wait to grow new leaves in Spring to create food for themselves from sunlight!

Activity 2: Recording weather

Support students in completing weather section of Field Guide. Small groups, 3-4 students.
Weather experiments: anemometer, soil thermometer, compass
How to measure wind direction? Wind direction – observation of vegetation, flagging, wet finger, compass…
How to measure the air temperature? Thermometer.
How to measure wind speed and temp? Anemometer (Repeat after me, ane-mometer!)
Soil thermometer. Measure 5 cm below ground. Measure the surface temperature. Then measure the air temperature 2 metres above.
Soil temp is important because warmer temperatures accelerate chemical weathering on mountains and determine what will grow. If our mountains grow warmer with climate

change, what changes in plants will we see? What changes will happen for microorganisms so small we can't even see them with the naked eye?

Mountains and water/glaciers.

Glaciers form when layers of snow pile up over time. The weight of the snow squeezes it into a layered sheet of ice, and it begins to move slowly, pulled by gravity, scraping over everything in its path. It will sculpt the mountain and carve deep valleys. The Átl'ka7tsem/*Howe Sound* was carved by glaciers. It will leave scratches on the mountain. It will carry rocks of all sizes with it.

Activity 3: How is a chewy chocolate bar like a glacier?

You will need:
1 volunteer
1 Mars Bar or chewy chocolate bar that's been in the freezer for 5 minutes

How is a *Mars Bar* like a glacier?

A Mars Bar is long and linear, u-shaped on bottom with steep sides, like a glacier.
It's 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 a 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 called erratics.
Lastly, please bite into the end of your MB; 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.

You can see often see striations, scrapes left on rock by a glacier as it moves. And talus or skree, loose rock from erosion.

The water that comes from glaciers and snow melt is very important to us. It’s what we drink.

What else erodes our mountains?

1. rivers;

Weathering and erosion by water, Sea to Summit Trail, Squamish, British Columbia.
Photo by Martha Warren

2. vegetation – lichen (fungus and algae together.) Plants and tree roots break up the rock of the mountain. Lichens slowly dissolve mountain rock, along with wind, ice and water, break down the rock into soil;
3. Us! Walking on the mountains.

Biodiversity.

What are the differences in the physical appearance of the environment up here at 885 metres? How does the summit of our mountain, in the subalpine, look different to the coastal rainforest at base below? (Smaller trees, not as thick of underbrush, not as much plant diversity).

Subalpine areas can be buffeted by hurricane force winds, scoured by ice crystals, and weighted down by heavy snow—life can be a challenge for mountain trees. At the upper edges, centuries old trees may sprawl along the ground bowing before the wind.

What do you see growing on the mountain? The plants that grow in this rocky soil have to be very hardy.

If mountain climates change, what lives on the mountains will also change. Plants and animals adapt to life on the mountain.

Goats and warmer winters. If trees start growing higher up the mountainside, then there will be less of the lichens, ferns, grasses, herbs, and shrubs that goats eat now. And goats will also have to go higher up the mountain in the summer to stay cool.

Yaks in Nepal can't live at the elevation they used to because it's too warm now for them. So they are moving further up the mountains for a cooler environment. They live in a smaller area. Water is harder to find and they need to be able to find food to eat.

Vernal pools/ephemeral wetlands – these are shallow ponds of water in the winter and spring, and dry out to be mud and dirt in the summer and fall. So they only contain water for part of the year. So what can live in these? Frogs. Salamanders. When mountain climates change, if there are longer droughts, these species can't live there.

Activity 4: Hike

Theme: Interconnectedness

Look for things like -

Átl'ka7tsem/*Howe Sound* fjord
Duff
Lichen
Old Man's Beard
Salal
Tree roots breaking up rock to make soil
Nurse logs
Krummholz and flagging trees
Vernal pools/ephemeral wetlands
Erratics
Folded mountains – Skypilot, Copilot, the Ledge
Volcano – Mount Garibaldi
Olsen Creek
Woodpecker holes

How are animals adapted to live in the subalpine? Here are some examples:

The Red Breasted Sapsucker get their name from how they eat! The drill rows of holes into tree trunks and then returning to those holes later to feed on the running sap and the insects attracted to it. Hummingbirds also use the Sapsucker feeding holes. The Rufous Hummingbird will follow the Sapsucker around during the day, feeding at the wells the Sapsucker keeps flowing.

Cougars will use the thick underbrush of the forest for shelter and to stalk its prey. Squamish is located in prime cougar habitat. Cougars are active throughout the year and are elusive animals that prefer to avoid contact with humans. Cougars prefer habitats with dense underbrush and rocky areas for stalking, but can also live in open areas.

Can you spot any places chipmunks might live? They live in trees and gather food on the ground in areas with underbrush, rocks, and logs, where they can hide from predators like hawks, foxes, coyotes, weasels, and snakes. They feed on insects, nuts, berries, seeds, fruit, and grain which they stuff into their cheek pouches and carry to their burrow or nest to store. Chipmunks hibernate, but instead of eating a lot and fattening up before they sleep, they keep a store of nuts and seeds to eat throughout the winter.

Activity 5: How do we live together on a mountain and look after it? Read aloud On My Mountain by Abineau.

Half of the story is from the wolf's point of view. When you flip the book over, it's the same text, word-for-word, from the shepherd's point of view. Have a discussion about sharing and preserving mountain resources for others.

3 Things-To-Do:

What are 3 things you can do to share your mountain with other living things – animals, plants, and people?

1. Stay on the trails
2. Take your garbage with you
3. Look but don't touch

Activity 6: What do mountains mean to you?

Individual work. 15 minutes to complete sketches in Field Guide from the hike.

WATER AND GLACIERS

Discussion:

- Where does our water come from?

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

- Length
- Layers
- Movement

EVIDENCE OF ANIMALS

Draw and label any evidence of animals that you see on the mountain today. This may include tracks, feathers, markings on trees, etc...

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Activity Booklet for Sustainable

MOUNTAINS

SEA TO SKY GONDOLA

.... 's

Field Guide

WEATHER

What is the weather like today? Circle your answer(s).
Today, it is:

sunny | partly sunny | cloudy | windy

rainy | snowy | stormy | other: _______

Temperature:
It feels________________________

THE MOUNTAIN TODAY

Draw a sketch of the mountain today. Include everything you can see and feel, (i.e., clouds, snow, rain, wind).

Discussion:
- Why does weather matter? For example, what would happen if it got too hot or too cold on the mountain?

HOW ARE MOUNTAINS MADE?

Types of Mountains:

VOLCANOES

FOLDED MOUNTAINS

"THE MOUNTAIN SHUFFLE"

Stand on either end of a stack of towels or a large rug. Here, you and your classmates will act as the layer of earth's crust found just below the surface (a.k.a. tectonic plates). As you shuffle towards your partners on the opposite side of the rug, watch as the folds and creases are formed in the rug or, in our example, the earth. This is similar to how the movement of earth's crust creates folded mountains!

EXAMPLES OF FOLDED MOUNTAINS

Machapuchare, Annapurna Region, Nepal

Sky Pilot and Co-Pilot, BC, Canada

PEOPLE AND MOUNTAINS

How do mountains help people?

How do people HURT mountains and the plants and animals that live on them?

What can we do to HELP mountains?

3 THINGS TO DO

1. Stay on the trails.
2. Take your trash with you.
3. Look, but don't touch or take the plants with you.

Grades 4-6

Mountain Sustainability Course Notes (Grades 4-6)

Resources:

“The Hike” by Alison Farrell
“How to Make a Mountain in Just 9 Simple Steps and only 100 Million Years” by Amy Huntington
Hand sanitizer
Mars Bars
MS 4-6 Field Guides
Pencils
Compass
Anemometer
Thermometer
Soil Thermometer
Laminates of Stadium Glacier retreat photos
Thumball

Please see corresponding
Mountain Sustainability 4-6 Field Guide

Notes to teachers and education guides: This is a circular program. We start by asking students what being on the mountain means to them. Their answer will be something along the lines of *“When I come to a mountain, I feel free/I can breathe/I’m out of the classroom/it reminds me of hiking with my family/I feel peaceful/I want to ski/I am afraid of bears…”*

At the end of the program, students have 15 minutes to reflect individually to embed some of the learned material on an emotional and visceral level by writing a poem, sketching a landscape or anything they feel inspired to record in answer to the question: “What do mountains mean to you.” For those who want to share what they’ve done, they can post a photo of their work on social media with #mountainsmatter.

3 Things-to-Do at the end of the program are intended to empower this age group to build good habits of involvement in citizen-science, observation and record-keeping.

Activity 1: Thumball

	**Thumballs:** Stand in a circle. Toss the ball to a student who has to answer the (random icebreaker-type) question where their thumb is on the ball. Then ask them “What does being out today on a mountain feel like to you?” e.g. freedom, fresh air, quiet, out of the classroom, being close to nature, enjoying the views…

Definitions of a mountain:

There are many definitions of what should be called a mountain. One is that a mountain is a mountain if it rises more than 300 metres above the surrounding area. Another is that a mountain is a mountain if the people living near it consider it to be a mountain!

How to measure a mountain:

There are also many views on how to measure a mountain. Mount Everest is known as the highest mountain in the world. It’s 8,840 metres and still growing. That’s measuring it from sea-level to its highest peak. But if you measure mountains from their actual base, where they protrude from the earth’s crust at land or sea, Mauna Kea, the volcano in Hawaii is the highest, at almost 10,000 metres! When you measure Mauna Kea from sea level, though, it’s only about 4,000 metres.

What if we measured mountains from the earth’s core to a mountain’s peak? Then Chimborazo in Ecuador would be the highest mountain in the world. But because we measure freestanding mountains, from where sea meets land, Mount Everest is considered to be the highest.

How tall can mountains grow? They can’t get much bigger than 9,000 metres because gravity is pulling the mountain back towards the earth, and the base of the mountain has to support it that pressure. If there is water around the base of the mountain, like the volcano, Mauna Kea, that will help support the weight. If it’s a freestanding mountain, and there isn’t sufficient support, the base of the mountain will start to liquify.

So you can get much higher mountain somewhere with less gravity, like on Mars, where Olympus Mons is 25,000 metres high.

Mountain creation/destruction/movement.

How does the mountain feel under your feet?

Solid, hard?

What if I told you it was moving? What if I told you it was moving so slowly that you can't even feel it?

The earth is covered by large plates of rock and on top of them sit the land and ocean. The plates of rock, tectonic plates, are always moving. They bump into each other. They slide overtop and below each other. They push up through the land and ocean on top of them as mountains and sometimes as volcanoes. Even as we stand here now, mountains are rising out of the earth, and moving, and changing shape. Himalaya mountains are rising more than 1 cm a year! Mountains growing as fast as your fingernails!

So we have rock pushing through the land and ocean because the plates underneath are colliding, pushing into each other. These are called fold mountains.

> Examples: the Andes in South America are fold mountains. They are the longest mountain range in the world, and still grow about 10 cm every hundred years.

How else are mountains made? Volcanoes! Where magma, hot liquid rock, is pushed up through the earth's crust, it cools into rock, and more magma comes up and cools on top of that, and on top of that, until a volcano is formed.

Mount Garibaldi is a volcano. It last erupted about 8,000 to 13,000 years ago. It's dormant now.

And what if magma is pushed only part-way through the earth's crust and not all the way through, and it pushes the land up above it? Those are called dome mountains.

Now let's look at what shapes our mountains.

Mountains and weather

Mountains influence on weather – rain and snow fall on mountaintops more than down below because it's colder up on a mountain. As air rises to pass over a mountain, it cools and can't hold as much moisture so it lets it go as rain. So one side of a mountain often gets more rain than the other.

Weather's influence on mountains – wind makes trees grow in funny shapes, their trunks sometimes twisted, with short branches often growing off only one side, few leafy trees/bushes (salal!).

- Shape of trees you'll notice:
    - ***Krummholz*** = stunted or deformed vegetation in the subalpine
    - ***Flagging*** = where you have growth on only one side of a tree due to winds

Subalpine tree growth.
Photo by Martha Warren

It's more efficient for plants in the subalpine to have needles instead of leaves so they don't have to wait to grow new leaves in Spring to create food for themselves from sunlight through the process of photosynthesis!

Why measure the weather?

Similar to the North and South Poles, mountains are experiencing faster rates of climate-change, and this could have a huge impact on us as people. Most research date comes from Utah, Colorado and Tibet. Areas already in crisis include the Andes and the Hindu Kush Himalaya. So we need to collect data; we need to keep track of the weather so we can see how it's changing over time, and then try to prepare and adapt to the new conditions.
Because mountains, and vegetation, and animals will have to adapt in response. Where a mountain was once cold and dry, but has become warmer and more humid, how will the vegetation change? How will natural hazards be different? How will animals and

humans adapt? How will our water availability from glaciers and snow packs change? These are the big questions of mountain sustainability.

Activity 2: Recording weather

Support students in completing weather section of Field Guide. Small group work of 3-4 participants.

Weather experiments: anemometer, soil thermometer, compass.
How to measure wind direction? Wind direction – observation of vegetation, flagging, wet finger, compass…
How to measure the air temperature? Thermometer.
How to measure wind speed and temp? Anemometer (Repeat after me, ane-mometer!)
Soil thermometer. Measure 5 cm below ground. Measure the surface temperature. Then measure the air temperature 2 metres above.
Soil temp is important because warmer temperatures accelerate chemical weathering on mountains and determine what vegetation will grow. If our mountains grow warmer with climate change, what changes in plants will we see? What changes will happen for microorganisms so small we can't even see them with the naked eye?

Mountains and water/glaciers.

Glaciers form when layers of snow pile up over time. The increasing weight of the snow compresses it into a layered sheet of ice that begins to slide slowly down the mountain. It's pulled along by gravity, scraping over everything in its path. It will sculpt the mountain and carve deep valleys. The Átl'ka7tsem/*Howe Sound* was carved by glaciers.

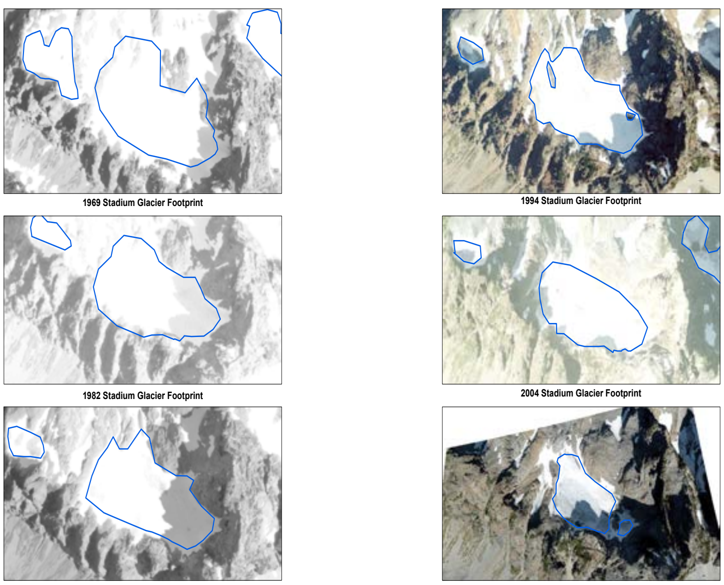
Glaciers erode, wear away, parts of the mountain as they slide down, dragging rocks along with them. Glaciers form when layers of snow pile up over time. The weight of the snow squeezes it into a layered sheet of ice, and it will begin to move slow, due to gravity, scraping over everything in its path. It will sculpt the mountain and carve deep valleys. It will scrape up the mountain. It will carry rocks of all sizes with it.

Glaciers can move from a few centimetres 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 called glacial retreat.

Our local mountains, Skypilot, Copilot and the Ledge, have retreating glaciers. Stadium Glacier sits in a cirque, a bowl-shaped indentation, next to Skypilot.

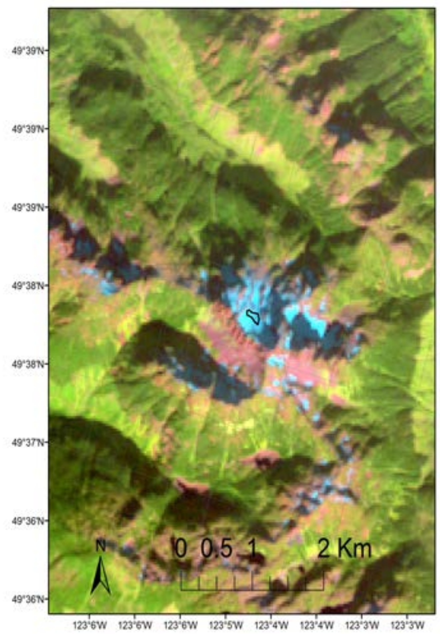
Skypilot, Copilot and the Ledge.
Photo by Martha Warren

The figure below on the left show the size of the glacier from 1969 to 2016. What is it doing? (Getting smaller!) In the picture on the right, the blue in the Landsat image is from September 1984. The tiny black polygon you see is the glacier outline in September 2021.



Changes in the Stadium Glacier from 1969 to 2016

Figure by Robert Plummer



Stadium Glacier September 28, 1984 (blue) and September 2, 2021 (black polygon)

Figure by Scott Williamson

Activity 3: How is a chewy chocolate bar like a glacier?

How is a *Mars Bar* like a glacier?

You will need:
1 volunteer
1 Mars Bar or other chewy chocolate 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's 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 a 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 called erratics.
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.

You can see often see striations, scrapes left on rock by a glacier as it moves. And talus or skree, loose rock from erosion.

The water that comes from glaciers and snow melt is very important to us. 60-80% of our fresh water comes from glaciers. It's what we drink. It's what we use for hydroelectric power. It's used for farming. So there is concern that our glaciers are retreating.

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

Besides wind and rain and glaciers, what else weathers and erodes our mountains?

1. rivers;
2. vegetation – lichen (fungus and algae together.) Plants and tree roots break up the rock of the mountain. Lichens slowly dissolve mountain rock, along with wind, ice and water, break down the rock into soil;
3. Us! Walking on the mountains.

Biodiversity.

What are the differences in the physical appearance of the environment up here at 885 metres? How does the summit of our mountain, in the subalpine, look different to the coastal rainforest at base below? (Smaller trees, less underbrush, less plant diversity).

Subalpine areas can be buffeted by hurricane force winds, scoured by ice crystals, and weighted down by heavy snow—life can be a challenge for mountain trees. At the upper edges, centuries old trees may sprawl along the ground bowing before the wind. The plants that grow in this rocky, colder soil have to be very hardy.

If mountain climates change, what lives on the mountains will also change. Plants and animals adapt to life on the mountain.

Mountain goats are affected by warmer winters. If trees start growing higher up the mountainside, then there will be less of the lichens, ferns, grasses, herbs, and shrubs that goats currently eat. They will also have to go higher up the mountain in the summer to stay cool.

Yaks in Nepal can't live at the elevation they used to because it's too warm now for them. So they are moving further up the mountains to reach a cooler environment, forcing them into a smaller area where it's harder to find food and water.

Vernal pools/ephemeral wetlands – these are shallow ponds of water in the winter and spring, and dry out to be mud and soil in the summer and fall. So they only contain water for part of the year. What can live in these? Frogs. Salamanders. When mountain climates change, if there are longer droughts, these species can't live there.

Activity 4: How do we live together on a mountain and look after it?

Read The Hike by Alison Farrell to point out the planning, observations of the biodiversity.

Discussion points: What do the hikers write in their sketchbooks?

What might you include in your field guide?
Why should we record what we observe?
They ate the berries! When would it be safe to eat wild berries? Is it a sustainable thing to do when you visit a mountain?
Where is a good place to look for animal tracks?

Activity 5: Hike

Theme: Interconnectedness

Look for things like -

Átl'ka7tsem/*Howe Sound* fjord
Duff
Lichen
Old Man's Beard
Salal

Tree roots breaking up rock to make soil
Nurse logs
Krummholz and flagging trees
Vernal pools/ephemeral wetlands
Erratics
Folded mountains – Skypilot, Copilot, the Ledge
Volcano – Mount Garibaldi
Olsen Falls
Woodpecker holes
Felsic/mafic dykes
Striations
Regolith

How have animals adapted to live in the subalpine? Here are some examples:

The Red Breasted Sapsucker get their name from how they eat! They drill rows of holes into tree trunks and then returning to those holes later to feed on the running sap and the insects attracted to it. Hummingbirds also use the Sapsucker feeding holes. The Rufous Hummingbird will follow the Sapsucker around during the day, feeding at the wells of sap that the Sapsucker keeps flowing.

Cougars will use the thick underbrush of the forest for shelter and to stalk their prey. Squamish is located in prime cougar habitat. Cougars are active throughout the year and are elusive animals that prefer to avoid contact with humans. Cougars prefer habitats with dense underbrush and rocky areas for stalking, but can also live in open areas.

Can you spot any places chipmunks might live? They live in trees and gather food on the ground in areas with underbrush, rocks, and logs, where they can hide from predators like hawks, foxes, coyotes, weasels, and snakes. They feed on insects, nuts, berries, seeds, fruit, and grain which they stuff into their cheek pouches and carry to their burrow or nest to store. Chipmunks hibernate, but instead of eating a lot and fattening up before they sleep, they keep a store of nuts and seeds to eat throughout the winter.

The black bear's greatest adaptation to living on the mountain is its ability to eat many different things. From fruits and nuts, grasses, twigs, and honey, to grubs, insects, fish, and small mammals. Its molars are great for grinding up foods and its large canine teeth for ripping apart fish. Bears can smell food up to 20 miles away. Their sense of smell also helps them locate other bears and detect and avoid danger. Bears have huge, strong legs to move or bend large objects like rocks or tree trunks to get to food. They have large, padded feet and strong, curved claws to climb trees easily to get to fruit.

Their long and sticky tongue can reach insects in trees. They can even separate and spit out unwanted nuts or berries without using their paws.

What do you think will happen if our mountains get warmer? Some species will move higher up due to climate change.

Yaks in Nepal can't live at the elevation they used to. They can't tolerate the warming climate. But as a species moves up a mountain for the cooler environment, the area they live in is smaller. If the glaciers are retreating, there may be less water to drink and less vegetation to eat. Maybe these animals will need shade or they'll suffer heat stress.

For caribou in the Rocky Mountains' Jasper Park, it's difficult to dig through the deeper snowpack further up the mountain to find food. Instead, they stand on snow to eat lichen from trees. But if a snowpack is reduced or gone completely, the caribou are unable to reach arboreal lichens. Caribou use high-elevation snow-patches for respite from summer heat and insects.

Measuring biodiversity is important so we can see how species are adapting to global climate change. Watching the Himalayan yak, for example, may tell us a lot about how cattle and other animals will be impacted by climate change.

Man-made disturbances such as recreational hiking can have an adverse effect on plant biodiversity. We've seen the destruction of lichen and vegetation on sides of trails at Sea to Sky Gondola. Here on Mount Habrich, we used to have lipstick cladonia growing along the sides of our trails. It's a kind of lichen, fungi and algae together, with small leaves and red caps. When people don't stay on the trail and walk on this lichen, it disappears.

3 Things-To-Do:

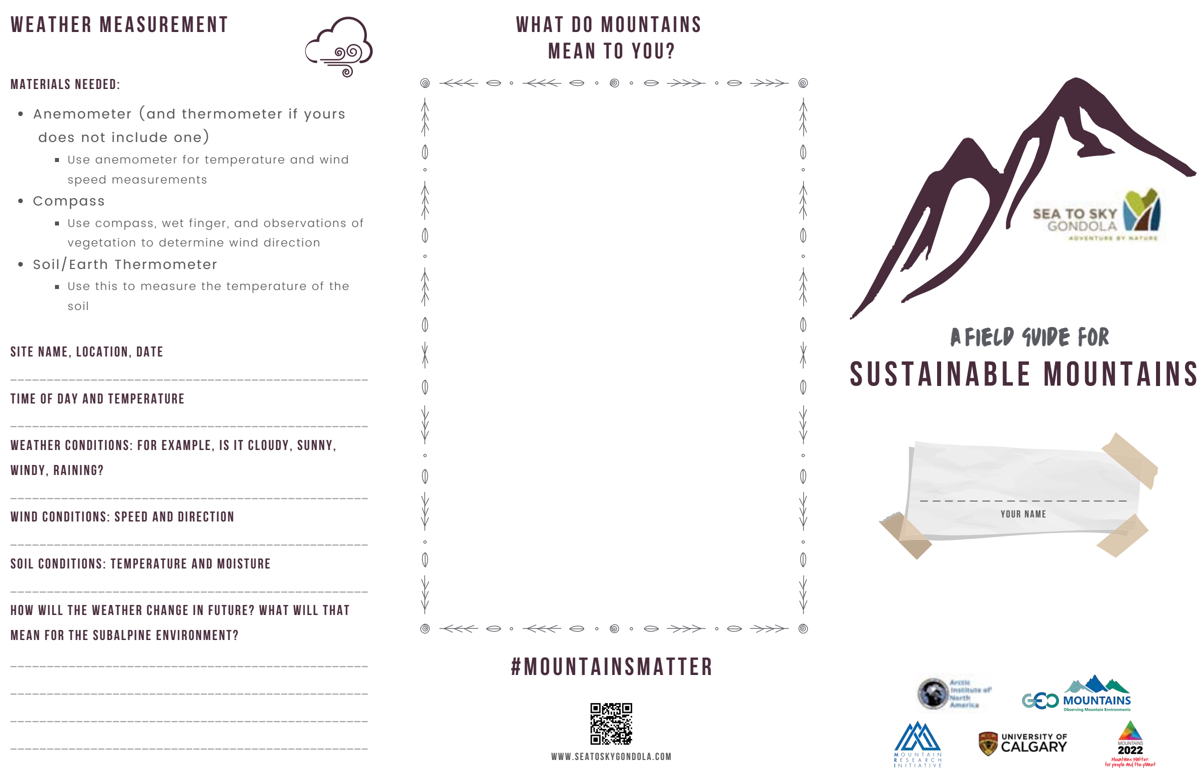
What are 3 things you can do to contribute to mountain sustainability? (Give students time to think and complete this section of the Field Guide.) Some ideas…

- Stay on the trails
- Take your trash with you
- Look but don't touch
- Water conservation – buckets in your backyard, or downpipes from the roof to fill barrels
- Plant restoration
- Watch your plastics

Activity 6: What do mountains mean to you?

Individual work. 15 minutes to complete.

We've come full-circle, back to the question: What do mountains mean to you? Write a poem, sketch, doodle, or explain why mountains matter or what they mean to you. Use the space on the back of you Field Guide for this. If you want to keep your work private, that's fine; if you'd like we can take a photo of your work to post (without your name) on social media with the hashtag #mountainsmatter. This will help increase awareness about the issues of mountain sustainability.



WEATHER MEASUREMENT

MATERIALS NEEDED:

- Anemometer (and thermometer if yours does not include one)
  - Use anemometer for temperature and wind speed measurements
- Compass
  - Use compass, wet finger, and observations of vegetation to determine wind direction
- Soil/Earth Thermometer
  - Use this to measure the temperature of the soil

SITE NAME, LOCATION, DATE

TIME OF DAY AND TEMPERATURE

WEATHER CONDITIONS: FOR EXAMPLE, IS IT CLOUDY, SUNNY, WINDY, RAINING?

WIND CONDITIONS: SPEED AND DIRECTION

SOIL CONDITIONS: TEMPERATURE AND MOISTURE

HOW WILL THE WEATHER CHANGE IN FUTURE? WHAT WILL THAT MEAN FOR THE SUBALPINE ENVIRONMENT?

WHAT DO MOUNTAINS MEAN TO YOU?

#MOUNTAINSMATTER

WWW.SEATOSKYGONDOLA.COM

A FIELD GUIDE FOR

SUSTAINABLE MOUNTAINS

YOUR NAME

WATER AND GLACIERS

Discussion:

- Where does our water come from?

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

- Length
- Layers
- Plasticity of movement

PEOPLE AND MOUNTAINS

How do mountains help people?

How do people HURT mountains and mountain biodiversity?

What can we do to HELP mountains?

3 THINGS I CAN DO

1. ____________________
2. ____________________
3. ____________________

HOW TO MAKE A MOUNTAIN

Fill in the blanks. This section of the field guide pairs with the story "How to Make a Mountain" by Amy Huntington.

What do we need to make a mountain?

First and foremost, we need some big, big _ _ _ _ _ _ _ _ _. We must also have a wide variety of _ _ _ _ _ _ _ _ _ and _ _ _ _ _ _ _ _ _ that can help sustain one another within the mountain ecosystem. A reliable _ _ _ _ _ _ _ _ _ source is essentail for all life on the mountain. Lastly, and most importantly, we need lots and lots of _ _ _ _ _ _ _ _ _ _.

ROCKS **ANIMALS** **TIME** **WATER** **PLANTS**

"SUSTAINABILITY IS THE PROCESS OF LIVING WITHIN THE LIMITS OF AVAILABLE PHYSICAL, NATURAL AND SOCIAL RESOURCES IN WAYS THAT ALLOW LIFE TO THRIVE IN PERPETUITY."

CHALLENGE TIME: BIODIVERSITY ABC'S

Biodiversity is defined as the variety of living things (plants, animals, insects, etc.,) that you can find in one area. How many living things can you name in this mountain environment that begin with each letter of the alphabet? Complete the chart below!

A- ________	N- ________
B- ________	O- ________
C- ________	P- ________
D- ________	Q- ________
E- ________	R- ________
F- ________	S- ________
G- ________	T- ________
H- ________	U- ________
I- ________	V- ________
J- ________	W- ________
K- ________	X- ________
L- ________	Y- ________
M- ________	Z- ________

Grades 7-12

Mountain Sustainability Course Notes (Grade 7-12) (1)

Resources:

Hand sanitizer
Mars Bar (5 minutes in freezer)
Thumball
MS 7-12 Field guides
RH Worksheets – 1 per group
Sling psychrometer
Anemometer
Soil thermometer
Compasses
Pencils
Laminates

Please see corresponding Mountain Sustainability course Field Guide (Grades 7-12)

Notes to teachers and education guides: This is a circular program. We start by asking students what being on the mountain means to them. Their answer will be something along the lines of *"When I come to a mountain, I feel free/I can breathe/I'm out of the classroom/it reminds me of hiking with my family/I feel peaceful/I want to ski/I'm afraid of bears…"*

At the end of the program, students have 15 minutes to reflect individually to embed some of the learned material on an emotional and visceral level by writing a poem, sketching a landscape or anything they feel inspired to record in answer to the question: "What do mountains mean to you?" For those who want to share what they've done, they can post a photo of their work on social media with #mountainsmatter.

The 3 Things-to-Do at the end of the program are intended to empower this age group to build good habits of involvement in citizen-science, observation and record-keeping.

Activity 1

	**Thumballs:** Make a circle. Toss the ball to a student who has to answer the (random icebreaker-type) question where their thumb is on the ball. Then ask them "What does being out today on a mountain feel like to you?" e.g. freedom, fresh air, quiet, out of the classroom, being close to nature, enjoying the views…

Definitions of a mountain

There are many definitions of what should be called a mountain. One is that a mountain is a mountain if it rises more than 300 metres above the surrounding area. Another is that a mountain is a mountain if the people living near it consider it to be a mountain!

How to measure a mountain

There are also many views on how to measure a mountain. Mount Everest is generally considered to be the highest mountain in the world and it is still growing. It is 8,840 metres, that is, if you measure it from sea-level to its highest peak. But if you measure mountains from their actual base, where they protrude from the earth's crust at land or sea, Mauna Kea, the volcano in Hawaii is the highest, at almost 10,000 metres!.When you measure Mauna Kea from sea level, however, it is only about 4,000 metres.

What if we measured mountains from the earth's core to a mountain's peak? Then Chimborazo in Ecuador would be the highest mountain in the world. But because we measure freestanding mountains, from where sea meets land, Mount Everest is the highest.

How tall can mountains grow? They can't get much bigger than 9,000 metres because gravity has the effect of pulling the mountain back towards the earth, and the base of the mountain has to support that pressure. If there is water around the base of the mountain, like the volcano, Mauna Kea, that will help support the weight. If it's a freestanding mountain, and there isn't sufficient support, the base of the mountain will start to liquify.

It is possible to find much higher mountains in places with less gravity, like on Mars, where Olympus Mons is 25,000 metres high.

Mountain Creation: Long Story Short

If we want to understand how mountains are formed and raised, we need first to know something about the Earth's structure, and how it continues to evolve. (This is a seriously condensed version!)

We understand our planet's structure to comprise a solid-iron Inner Core at the centre, with a liquid-iron Outer Core circulating around it, and a Mantle of hot, 'plastic' rocky material moving very sluggishly around that.

The outer shell of the Earth – the crust – is the relatively thin layer of solid rock which forms the ocean floor, islands and continents. Oceanic crust is thinner – about 5 km to 10 km thick – than continental crust, which is mostly 30 km to 50 km, sometimes (around high mountain ranges) as much as 80 km, thick. When we look at average crustal thickness in comparison with the Earth's total diameter, it is thinner than a hen's eggshell in relation to the egg!

We can think of different areas of oceanic and continental crust as being a bit like pieces in a giant jigsaw puzzle, covering the entire planet. These pieces are called 'plates'. We know that new oceanic crust is formed by volcanic eruptions – almost always under the ocean – along the edges of pairs of oceanic plates, where those parts of the mantle which are less dense, and melt at relatively low temperatures and pressures, ooze out through cracks between the plates.

In other regions, where an oceanic plate and a continental plate are pushed against each other along their edges, one of these has to give. The thinner, denser oceanic plate is pushed underneath the edge of the (thicker, more buoyant) continental plate, back down towards the mantle. This is known as 'subduction'.

Not far offshore from the west coast of British Columbia, there are examples of both a constructive spreading ridge and a destructive subduction zone. While new ocean crust continues to be generated to the west of Vancouver Island, by remnants of what was once the Pacific mid-oceanic ridge (Juan de Fuca Ridge), the oceanic plate to the east of this margin (Juan de Fuca plate) is being subducted beneath continental North America (marked by the Cascadia Trench).

Magma, lava and volcanoes: igneous mountain-building processes

As the oceanic plate descends beneath the continental margin, it encounters higher temperatures and pressures, and begins to melt. Some parts of the rock forming the oceanic crust melt earlier, at shallower depths: being less dense and more fluid, these partial melts – we can think of them as 'bubbles' of magma – tend to move up through the edge of the continental crust, exploiting any lines of weakness in the structure. Some of these pathways are themselves likely to have been formed by stresses driven by the plate-to-plate collision and subduction. As the magma moves, it may also melt surrounding rock, which is added to the mix.

The combination of horizontal pressure along the plate-margins at the surface ,(folding and faulting), together with some vertical pressure from magma forcing upward from the regions of melting oceanic crust (doming,) are important mechanisms by which mountains begin to be raised.

If the magma finds its way to the surface, it will erupt as a volcano. Once a route has been forced from deep in the crust all the way to the surface, it tends to be exploited repeatedly by successive pulses of magma. Many of the mountains along BC's coast were formed in this way: through long periods of time, repeat eruptions of molten rock (now, when it appears on the Earth's surface, called lava) add more and more material to each vent.

Building mountains by folding and faulting

Did you ever do that demonstration in elementary school, where you take a towel, fold it lengthwise, and then slowly slide the two ends towards each other to cause folds in the towel? As two plates are pushed against each another, compression forces the rock to change shape. This is known as deformation.

More rarely, two units of continental crust might be pushed against one another. In this case, there's no backing-down: it's a full-on collision, and the forces generated are immense. Through time, great chunks of land – known as terranes – formed new additions to BC and the western side of Canada, carried on the subduction-driven conveyor of the Pacific oceanic plate. With each new collision, new mountains were pushed up on the surface. This is also the origin of the Himalayas, formed by the northward collision of the Indian sub-continent (which it really is, in geological terms!) with south-central Asia.

"Himalayas - Aerial view" by Dr. Partha Sarathi Sahana is licensed under CC BY 2.0.

Ductile or plastic deformation results in 'folding'. Depending on the nature and scale of the stress applied, this may affect anything from an individual unit of rock to entire mountains.

"Rocky Mountains" by U.S. Geological Survey is licensed under CC BY 2.0.

If you fly over the Rocky Mountains on a clear day, you will see something like the image above – each ridge is a unit of rock which was folded by compressional stress, before ultimately failing (faulting), and being pushed sideways and upwards over the unit below it. The largest mountain ranges around the world – the Himalayan ranges, Rockies, Andes, European Alps, and much older ranges, of which only the exposed roots are now visible – have all been formed primarily by this process.

Mountain Destruction: Long Story Short

When large masses of rock are accumulated at or pushed to high elevations, they are immediately exposed to a wide range of destructive forces, which will – over tens to hundreds of millions of years – work to transform mountains, first into hills, and eventually to lowlands.

Arguably the most important influence is the range of meteorological (weather) conditions: mountains are exposed to stronger winds, higher precipitation, and wide ranges of temperature. Another important factor is gravity: raising something up gives it 'potential energy': if it is (or bits of it are) freed from whatever was previously keeping it in place, gravity will tend to move it to lower levels.

These processes work at a range of scales, from the microscopic to the truly enormous. The two main stages involve firstly the disaggregation or destruction of the rock itself, and then the transport of the resultant particles.

Weathering
Rocks are 'picked apart' by a combination of processes known as 'weathering'. In general, weathering transforms solid rock into smaller pieces, called regolith, down through smaller and smaller particles: it may even dissolve a rock completely, so that it becomes part of a liquid. Weathering may take the following forms:

- **physical weathering:** mechanical stresses imposed on and within rock-units;
  - freeze-thaw cycles of water / ice cause cracking, deepening and widening cracks in rock by expansion and contraction: water finds its way into crevices, and – when it freezes – expands, forcing the crack wider, and flexing it again when it melts
  - extreme temperatures may also drive expansion (hot) / contraction (cold)
  - hydraulic fracturing – the varied impacts and forces of flowing water
  - abrasion – disaggregation by direct impact from particles (from boulders to fine sand) carried by wind or water (arguably a form of erosion, rather than weathering)
- **chemical weathering:** reactions between the rock's constituent minerals and external agents;
  - when minerals in rocks are unstable in the chemical conditions to which they are exposed (temperature, pressure, moisture, acidity, etc), they may react and break down
  - this is particularly true for volcanic rocks, in which the mineral crystals cooled rapidly, without time to take chemical forms more suited to stability at surface conditions
  - as the more vulnerable minerals break down through reaction with atmospheric gases and water-borne chemicals, they leave the less vulnerable (more stable) particles behind, leaving them more vulnerable to disaggregation from the parent rock
  - some rocks are made largely of minerals which dissolve in water: for example, limestone is composed very largely of calcium carbonate
  - accelerated by moisture and warmer temperatures
- **biological weathering: the activities of living organisms:**
  - burrowing
  - root action
  - bio-chemical weathering (eg by lichens)
- we can also think of the direct effects of human activities – mining is a good example
  Once regolith particles – bits of the original rock – have been detached or disaggregated from their parent rock, they are liable to be moved. In mountain settings, this happens mainly under the influence of gravity, ice, and water (and just possibly wind).

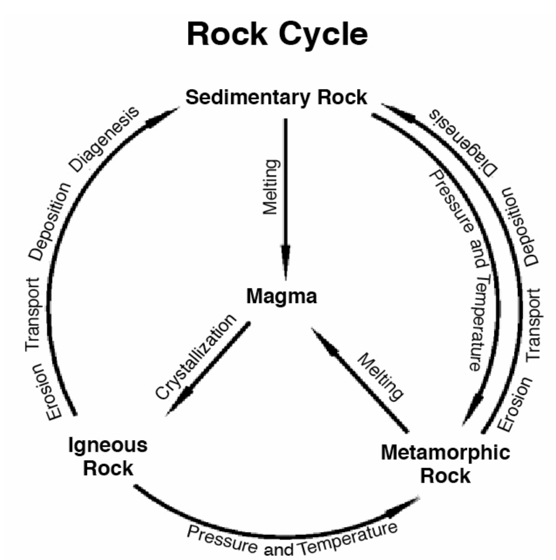
Transportation of regolith by gravity
Relatively small particles and volumes of regolith may accumulate close to their source – perhaps just falling a short way down-slope under gravity – or may be transported great distances by water (including ice) and/or wind, undergoing further transformation as it travels. These accumulations are known as talus or skree. Similar processes on different types of rock may lead to the accumulation of gravels, sand or finer particles. Most of the time, these talus or scree slopes find a natural configuration of internal organization and slope which permits them to be quite stable: they may even support the growth of vegetation, the roots of which help to anchor the loose, unconsolidated material. In general, a vegetated – particularly a forested – slope will be more stable than one without vegetation: this is partly because the roots bind the material together

more cohesively, and partly because the vegetation canopy reduces and spreads-out the direct effects of rainfall and surface flows.
However, sometimes this balance or equilibrium is disrupted, and the slope may slide or flow. Most often this is through the reduction of friction by adding water from ***heavy rainfall or rapid snowmelt***. It is also possible that these events may be provoked by shaking (during an earthquake), or even by animals (including humans!) walking across the slope and dislodging important 'anchors'. It follows from the point above that removing the vegetation – again, particularly trees – from a slope will increase its vulnerability to erosion and 'mass-wasting'.
The regolith transported downhill or downstream by these processes will contribute to the formation of new (sedimentary) rocks on the floodplains of rivers and in the ocean.
Glaciers represent immensely powerful agents of erosion and transportation. Formed initially as patches of snow which do not melt through successive summers, they begin to flow downhill under their own weight. As they do so, a complex range of processes works to weaken, disaggregate and move enormous volumes of rock along their paths. We'll talk about glaciers more in a minute.
In summary, we have the transformation of bedrock to regolith by:

Physical – mechanical stress on rock
Chemical – chemical reaction between minerals in the rock
Biological – physical and chemical but by plants and animals. Eg lichen secretes acids that break down the rock.

Having generated regolith from the bedrock, what happens next? Where does it go?

Do you remember learning the rock cycle in Grade 4?



https://commons.wikimedia.org/wiki/File:Rock_cycle.gif

You have the mass wasting, the redistribution of regolith under gravity. EROSION = redistribution of regolith by FLOWING MEDIA, namely:

Water (fluvial erosion)
Ice (glacial erosion)
Wind (aeolian erosion)

The particles on Highline Trail, for example, are redistributed to the bottom of the trail.

Regolith on Highline Trail, Sea to Sky Gondola, Squamish, British Columbia.
Photo by Martha Warren

The regolith from the summit is redistributed to the bottom of Átl'ka7tsem/*Howe Sound*.

What we have is this constant movement in our mountains, where some mountains are rising, some are becoming small, weathering and eroding. Some mountains in the Himalayas are still rising at 1 cm a year due to crustal uplift.

We've talked about weathering, now let's look for moment at weather, as in climate.

As already mentioned above, mountains are exposed to stronger winds, higher precipitation, and wide ranges of temperature. Alongside weather, there is the issue of climate.

The energy that runs the Earth's weather comes from the sun. Weather is a product of solar energy and water vapour (which is a condensable gas) in our atmosphere. Like carbon dioxide, water vapour is a greenhouse gas. Greenhouse gases partially trap the energy radiated from the Earth's surface that is warmed by sunlight.

Scientists are seeing that mountain regions of the world are warming faster than the global average.

Why do we care about weather on the mountains?

Water vapour in the air is significant in terms of climate change and changes to mountains from climate change. Humidity is a big part of global warming. The big is question is how mountains create weather, and how mountains are changed by weather.

How do our mountains create weather? Mountains, topographically, are rainmakers. So for us here, air moves eastward off the Pacific Ocean, hits the mountains, begins to rise; cools as it moves up and over the mountain, resulting in clouds and rain, and as it continues east, we have these "rainshadows," these dry areas. So the west side of the mountains are wetter than the east; kind of a windward/leeward difference. The proper name is the orographic effect.

You see this all over the world. The same phenomenon happens with the Tibetan Plateau, where it's very dry, being on the leeward or rainshadowed-side of the Himalayas and the Kunlun Mountains and the Quilian Mountains in China.

As in circumpolar regions, mountains are experiencing faster rates of climate-change, introducing major implications for humankind and the ecosystems on which we depend. This is due to mountains extending above the surface boundary layer into the free atmosphere and are more directly exposed to major incoming weather systems. Extreme climate change is happening at above 3000 metres, with 90% of data coming from Utah, Colorado and Tibet. Areas already in crisis are the Andes and the Hindu Kush Himalaya.

So with climate change you see increasing mountain exposure to hazards such as storms, landslides, avalanches. But it's not just increased air temperature that's the issue. Rather, it's the increased humidity coming from warm air holding more water vapour and warming seas and land releasing more water into the atmosphere through evaporation.

Again, why do we care about weather? Because mountains, and vegetation, and animals will have to adapt in response. Where a mountain was once, say, cold and dry, but is now warmer and more humid, how will the vegetation change? How will natural hazards be different? How will animals and humans adapt? How will our water *availability from glaciers and snowpacks change? These are the big questions of mountain sustainability.*

Activity 2: Measuring the weather

What you will need: Outdoor thermometer, anemometer, soil thermometer, compass, sling psychrometer, Relative Humidity Chart.

How to measure wind direction? – observation of vegetation, flagging, wet finger, compass.

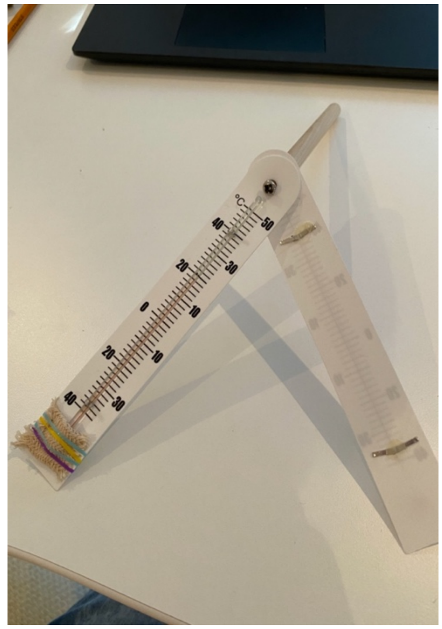
How to measure wind speed and temp? - anemometer and thermometer.

How to measure soil temperature? - soil thermometer. Measure 5 cm below ground. Measure the surface temperature. Then measure the air temperature 2 metres above. Soil temp is important because warmer temperatures accelerate chemical weathering on mountains and determine what vegetation will grow. If our mountains grow warmer with climate change, what changes in plants will we see? What changes will happen for microorganisms so small we can’t even see them with the naked eye?

How to measure relative humidity (RH)? – sling psychrometer. Dip sock at end of wet-bulb thermometer in water. Whirl sling psychrometer in air until you get a wet-bulb thermometer reading (approximately 5 minutes.) The spinning causes moisture in the sock to evaporate and has a cooling effect on the bulb. The difference between the wet and dry bulb temperatures help you find Relative Humidity. e.g. If the dry bulb measures 25C and the wet bulb measures 18C, then you have a wet bulb difference of 7C. Find the dry bulb measurement on the left of the chart and read across to the right, you have a Relative Humidity of roughly 50%. This cooling process, the evaporation of the water on the wet bulb thermometer, tells us how much water vapour is in the air today. As a result of the spinning, the sock at the end of the wet bulb thermometer undergoes a rapid cooling effect at a faster rate. Saturated water vapour would be 100% RH; No water vapour at all in the air would be 0% RH. Evaporation is faster when humidity is low, and as RH increases, the evaporation rate decreases.

SEA TO SKY GONDOLA

Relative Humidity																	
	Difference between wet and dry bulb temp																
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Dry bulb temp	0	81	64	46	29	13											
	2	84	68	52	37	22	7										
	4	85	71	57	43	29	16										
	6	86	73	60	48	35	24	11									
	8	87	75	63	51	40	29	19	8								
	10	88	77	66	55	44	34	24	15	6							
	12	89	78	68	58	48	39	29	21	12							
	14	90	79	70	60	51	42	34	26	18	10						
	16	90	81	71	63	54	46	38	30	23	15	8					
	18	91	82	73	65	57	49	41	34	27	20	14	7				
	20	91	83	74	66	59	51	44	37	31	24	18	12	6			
	22	92	83	76	68	61	54	47	40	34	28	22	17	11	5		
	24	92	84	77	69	62	56	49	43	37	31	26	20	15	10	5	
	26	92	85	78	71	64	58	51	46	40	34	29	24	19	14	10	5



Glaciers, Snow & Water

Glaciers form when layers of snow pile up over time. The weight of the snow squeezes it into a layered sheet of ice, and it begins to move slowly, pulled by gravity, scraping over everything in its path. It will sculpt the mountain and carve deep valleys. The Átl'ka7tsem/*Howe Sound* was carved by glaciers. It will leave scratches on the mountain. It will carry rocks of all sizes with it.

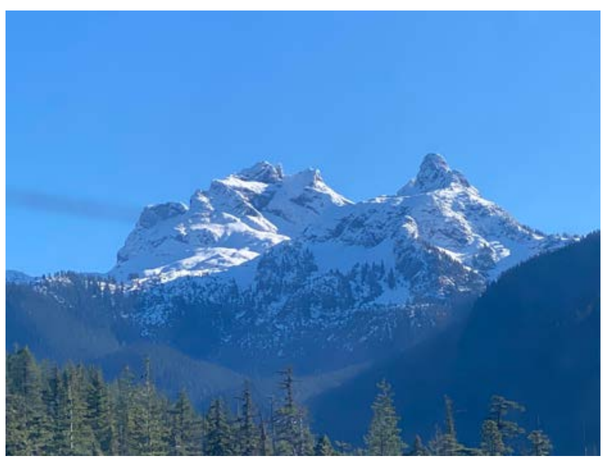
Glaciers erode, wear away, parts of the mountain as they slide down, dragging rocks along with them. Glaciers form when layers of snow pile up over time. The weight of the snow squeezes it into a layered sheet of ice, and it will begin to move slow, due to gravity, scraping over everything in its path. It will sculpt the mountain and carve deep valleys. It will scrape up the mountain. It will carry rocks of all sizes with it.

As large volumes of ice, they act as 'cold sinks', lowering the range of temperatures in the air around them: this in turn means that freeze / thaw weathering is more likely through longer periods of the (otherwise) warmer months. Where ice freezes onto rock, the latter – potentially of very large sizes – may be 'plucked' from their origins and moved by the ice, potentially for long distances. The rocks within the ice scrape and 'bulldoze' the surface as the glacier moves, further abrading and eroding the landscape (and the regolith itself, which tends to take on a rounded shape). This excavating action carves deep U-shaped valleys with steep sides – down which yet more regolith is able more easily to fall, under gravity. Also under and in front of the ice, meltwater streams flow, doing the same kind of work as those generated by rainfall and snowmelt, as described above.

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

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 called glacial retreat.

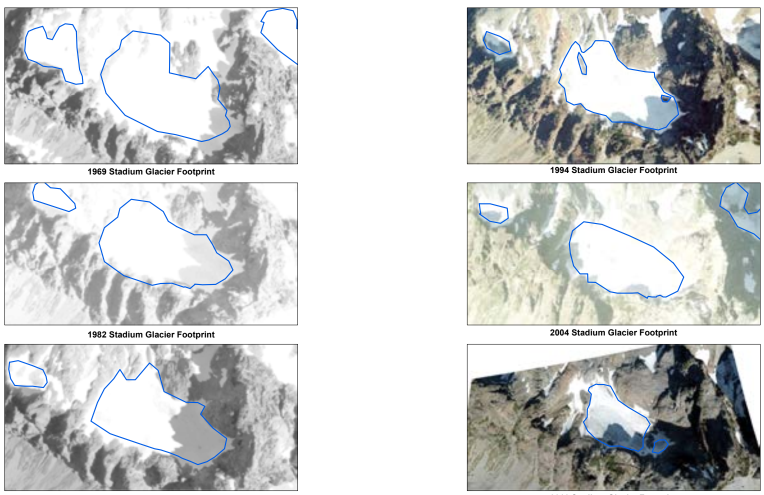
Skypilot, Copilot and the Ledge, in Squamish, British Columbia, have retreating glaciers. Stadium Glacier sits in a cirque, a bowl-shaped indentation, next to Skypilot, at 1,740 metres.



Skypilot, Copilot and the Ledge, Squamish, British Columbia.
Photo by Martha Warren

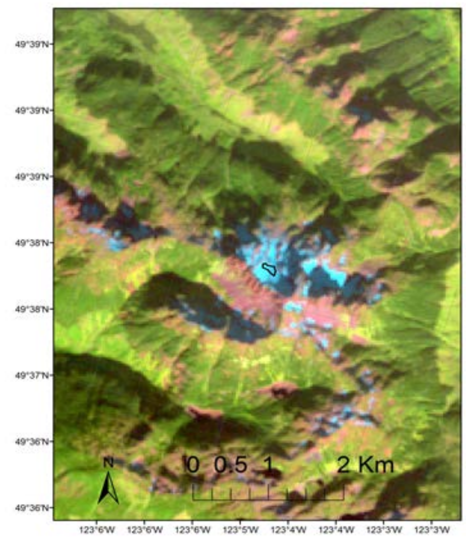
The photos below on the left show the size of Stadium Glacier from 1969 to 2016. What's it doing? (Getting smaller!) In the picture on the right, the blue in the Landsat image is from September 1984. The tiny black polygon you see is the glacier outline as at September 2021.

The glacier has lost a lot of ice. 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.



Changes in the Stadium Glacier from 1969 to 2016

Figure by Robert Plummer



Stadium Glacier September 28, 1984 (blue) and September 2, 2021 (black polygon)

Figure by Scott Williamson

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.

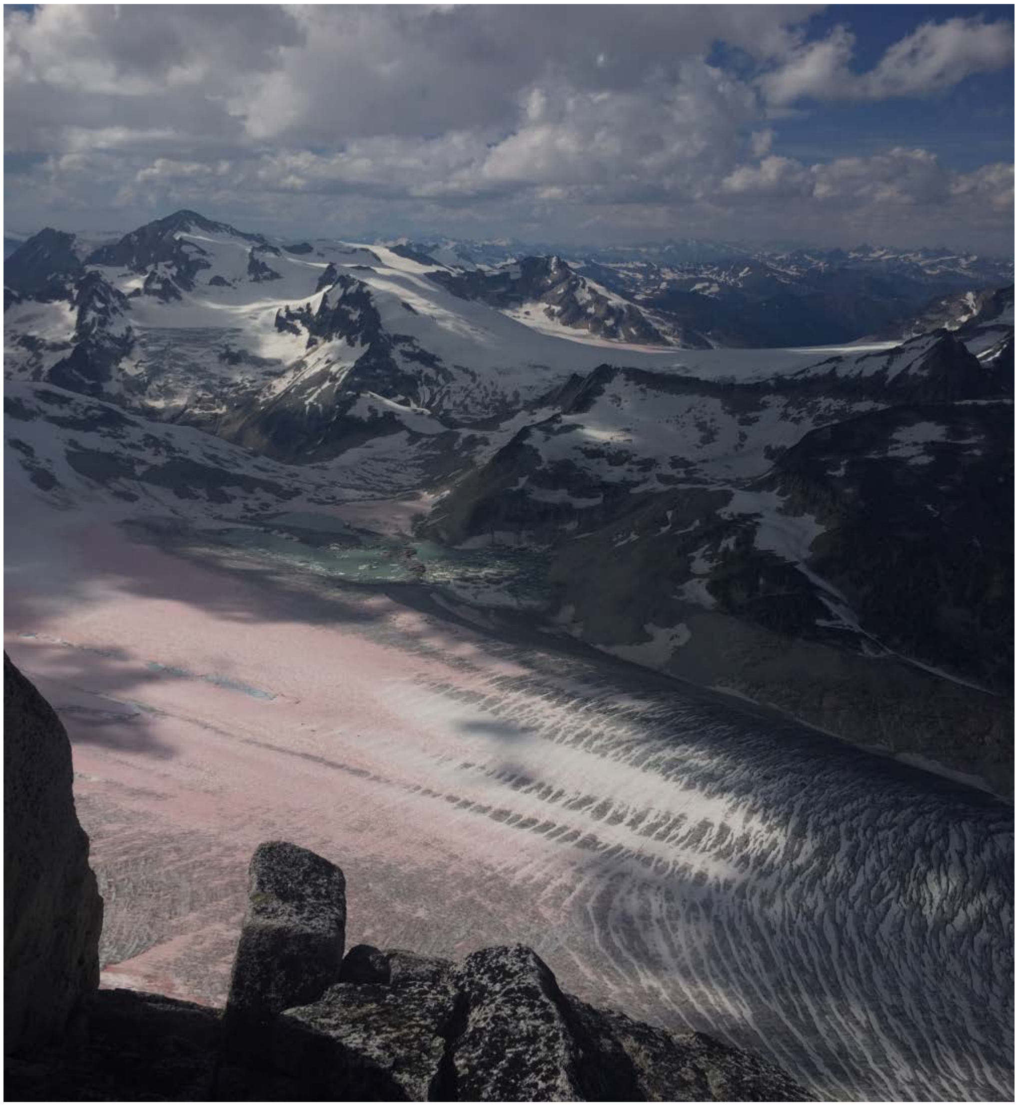
Axel-Heiberg Island Qikiqtaaluk Region, Nunavut.
Photo by Dr. Laura Thompson, Queen's University.

Glaciers are basic 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. So a glacier flows downhill like an escalator and transport 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. *Have you noticed that 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 and reflects the rest. Ice in the ablation zone absorbs ¾ of the sunlight falling on it.

Snow in isolated patches or on glaciers can have algae grow on it. The algae are sometimes called watermelon snow because it is red, and some people think it smells like watermelon. The snow algae live in the meltwater between snow grains, is photosynthetic and makes the snow absorb more sunlight which promotes snow melt.



Vowell Glacier, Bugaboo Provincial Park, British Columbia.
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. Fun fact - you can approximate how glacier crevasses form using a chocolate bar with a soft centre.

Activity 3: How is a chewy chocolate bar like a glacier?

You will need:
1 volunteer to handle the chocolate bar
1 Mars Bar or other chewy chocolate 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's 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 a 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, the erratics.
Tip your glacier so that it's on a slope. Which is the accumulation zone? Which is the ablation zone? Where is the 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.

You can see often see striations, scrapes left on rock by a glacier as it moves. And talus or skree, loose rock from erosion.

The water that comes from glaciers and snow melt is very important to us. 60-80% of our fresh water comes from glaciers. It's what we drink. It's what we use for hydroelectric power. It's used for farming. So there is concern that our glaciers are retreating.

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

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.

Biodiversity

Which plant and animal species will adapt as our mountains change?

Charles Darwin studied Galapagos Finches and discovered that when bad weather affected plant growth and there were fewer seeds to eat, the finches had to eat larger seeds not normally a part of their diet to survive. Only the ones with large enough beaks to eat the larger seeds survived. The survivors had offspring with large beaks, and this inherited trait was passed on in reproduction. The species thereby evolved to have larger beaks than before, and this adaptation to their environment is natural selection.

What are the differences in the physical appearance of the environment at the Sea to Sky Gondola summit at 885 metres? How does the summit of our mountain, in the subalpine, look different to the coastal rainforest at base below? (Smaller trees, less underbrush, less plant diversity.)

The subalpine forest is a transition zone from dense forest below to alpine tundra above treeline. Subalpine areas can be buffeted by hurricane force winds, scoured by ice crystals, and weighted down by heavy snow—life can be a challenge for mountain trees. As a transition zone from dense forest below to alpine tundra above treeline, the treeline is not really a line, but rather a zone where trees gradually get smaller and more stunted until conditions are too challenging for tree growth. At the upper edges, centuries old trees may sprawl along the ground bowing before the wind. The plants that grow in these soils must be very hardy.

- Shape of trees you'll notice:
  - ***Krummholz*** = stunted or deformed vegetation in the subalpine
  - ***Flagging*** = where you have growth on only one side of a tree due to winds
  - And what are they growing out of? Rock!

Subalpine tree growth.
Squamish, British Columbia
Photo by Martha Warren

How have animals adapted to live in the subalpine? Here are some examples:
The Red Breasted Sapsucker get their name from how they eat! They drill rows of holes into tree trunks and then returning to those holes later to feed on the running sap and the insects attracted to it. Hummingbirds also use the Sapsucker feeding holes. The Rufous Hummingbird will follow the Sapsucker around during the day, feeding at the wells of sap that the Sapsucker keeps flowing.

Cougars will use the thick underbrush of the forest for shelter and to stalk their prey. Squamish is located in prime cougar habitat. Cougars are active throughout the year and are elusive animals that prefer to avoid contact with humans. Cougars prefer habitats with dense underbrush and rocky areas for stalking but can also live in open areas.

You will mostly likely see chipmunks on our hike. They live in trees and gather food on the ground in areas with underbrush, rocks, and logs, where they can hide from predators like hawks, foxes, coyotes, weasels, and snakes. They have striped bodies for camouflage. They have claws and are able climbers. They feed on insects, nuts, berries, seeds, fruit, and grain which they stuff into their cheek pouches and carry to their burrow or nest to store. Chipmunks hibernate, but instead of eating a lot and fattening up before they sleep, they keep a store of nuts and seeds to eat throughout the winter. They reduce their respiration and heart rate when food is scarce and reduce their overall body temperature. Chipmunks have 2-8 live young, once or twice per year. (Why might that be?) It is because they are food for so many other animals.

The black bear's greatest adaptation to living on the mountain is its ability to eat many different things. From fruits and nuts, grasses, twigs, and honey, to grubs, insects, fish, and small mammals. Its molars are great for grinding up foods and its large canine teeth for ripping apart fish. Bears can smell food up to 20 miles away. Their sense of smell also helps them locate other bears and detect and avoid danger. Bears have huge, strong legs to move or bend large objects like rocks or tree trunks to get to food. They have large, padded feet and strong, curved claws to climb trees easily to get to fruit. Their long and sticky tongue can reach insects in trees. They can even separate and spit out unwanted nuts or berries without using their paws.

What do you think will happen if our mountains get warmer? Some species will move higher up due to climate change.

Mountain goats are affected by warmer winters. If trees start growing higher up the mountainside, then there will be less of the lichens, ferns, grasses, herbs, and shrubs that goats currently eat. They will also have to go higher up the mountain in the summer to stay cool.

Yaks in Nepal can't live at the elevation they used to because it's too warm now for them. So they are moving further up the mountains to reach a cooler environment, forcing them into a smaller area where it's harder to find food and water.

Vernal pools/ephemeral wetlands – these are shallow ponds of water in the winter and spring, and dry out to be mud and soil in the summer and fall. So they only contain water for part of the year. What can live in these? Frogs. Salamanders. When mountain climates change, if there are longer droughts, these species can't live there.

For caribou in the Rocky Mountains' Jasper Park, it is difficult to dig through the deeper snowpack further up the mountain to find food. Instead, they stand on snow to eat lichen from trees. But if a snowpack is reduced or gone completely, the caribou are unable to reach arboreal lichens. Caribou use high-elevation snow-patches for respite from summer heat and insects.

Measuring biodiversity is important so we can see how species are adapting to global climate change. Watching the Himalayan yak, for example, may tell us a lot about how cattle and other animals will be impacted by climate change.

Remember that man-made disturbances such as recreational hiking can have an adverse effect on plant biodiversity. We've seen the destruction of lichen and vegetation on sides of trails at Sea to Sky Gondola. There used to be *lipstick cladonia* - a kind of lichen, fungi and algae together, with small leaves and red caps. It's still present elsewhere on the mountain but has disappeared from the sides of the trail because visitors from the mountain keep walking on it.

Activity 4: Field Guide Group Discussion

Whole group exercise using Field Guide Discussion Points. Read each point aloud and discuss.
If there is time, complete the Salal and Mountain Goat case studies.

Activity 5: Hike

Watch for…

Erratics
Felsic/mafic dykes
Pluck marks
Abrasions
Biological weathering: lichen, tree roots, us walking on it…
Skypilot/Copilot jagged tops, rust coloured horizontal stripes are chemical weathering
Stadium Glacier retreat
Krummholz
Flagging
Regolith
Duff
Skree
Volcano - Mount Garibaldi
Átl'ka7tsem/Howe Sound fjord
Lichen
Old Man's Beard
Salal
Vernal pools/ephemeral wetlands
Colour of water – rock flour in glacial runoff
Olsen Falls
Woodpecker holes

Mountains and People

Mountains have always been a source of inspiration for spirituality, traditions, and the arts.
Take **Mount Olympus**. It's one of the highest peaks in Europe, and to the ancient Greeks, it was the home of the Greek Gods who lived on Mytikas Peak.
Haleakela volcano in Hawaii was considered to be *wao akua*, or "the realms of the gods" by the Polynesians, and many religious ceremonies are still held on the rim of the summit and in the crater to this day.

What about art inspired by mountains? I think of the Group of Seven – Lawren Harris' Mount Robson, and Norval Morrisseau's Riding the Great Thunderbird to the Mountain World.

When you think of mountains and literature, what do you think of? I think of **Thomas Mann's The Magic Mountain** and **Li Bai's** poetry: *"We sit together, the mountain and me, until only the mountain remains."*

And what about mountains as inspiration for music? From **Modest Mossorgsky's Night on Bald Mountain** to **John Denver's Rocky Mountain High**. I also think of music outdoors on mountains: the Vancouver Symphony Orchestra playing outdoors at Whistler and the Squamish Constellation Festival.

What else are mountains to us? They are borders, geopolitical divides. The border between British Columbia and Alberta is in the Rocky Mountains; the boundary between France and Spain is along the Pyrenees Mountains; the boundary between Italy and France is the Alps. Historically, countries chose mountains as borders because they could defend themselves from attacks by their neighbours. And in severely rugged mountain areas, we still see that today. In the Himalayas between India and China, and in the Andes between Chile and Argentina.

But we also see efforts of international cooperation on some mountain borders. For example, near Testa Grigia peak, the Theodol glacier's retreat has moved a hotel on the Swiss-Italian border requiring 100 metres of border to be redrawn.

Efforts in cross-border cooperation and collaboration such as those seen with the Hindu Kush Himalayan Monitoring and Assessment Programme, which includes India, Pakistan, China, Nepal, Afghanistan, Bangladesh, Bhutan, and Myanmar, is another example of transboundary cooperation. What do they cooperate on? One initiative is mapping human-wildlife conflict hotspots in the Eastern Himalaya. They know they want to enhance wildlife habitats and corridors, and like us in Canada, they have bears (Himalayan Black Bears,) and antelope (Tibetan antelope,) deer (musk deer,) gaur (Indian bison,) but also the Asian elephant, royal Bengal tiger, snow leopard, and red panda.

Another example of transboundary collaboration is the Kangchenjunga Landscape Initiative. The Southern side of Mount Kangchenjunga is shared by three countries, Bhutan, India and Nepal. They cooperate on sustainable use of resources, environmental conservation and economic development. They map human-wildlife conflict hotspots.

They have also had a "Yaks Across Borders" exchange to encourage yak conservation. Yaks provide milk and meat. Their hides are used. Their dung is burned as fuel for cooking and heat. They are also used for transport. Yak herding has been important in this region for 4,500 years, but as borders were militarised between the countries, the herds couldn't mix anymore, and Yak herder communities suffered. Under this program, Bhutan gave yak bulls to India and Nepal, and it is hoped this transboundary interaction between the herders will be ongoing.

In many parts of the world, mountain economies are based on agriculture or mining, and the people living there tend to be poor. These areas have limited infrastructure, service, and opportunities. For many mountains, the issues are around farming and livestock and how to introduce best farming practices for sustainable food production. Or they're around mitigation of the impact of natural resource extraction, and the introduction of more sustainable enterprises to take its place.

Mountain tourism brings income and economic benefits to mountain communities, but the challenge is how to manage the environmental, social, and cultural impacts of that. Recreational tourism and associated infrastructure, commercial and residential development raise the question of how to prevent damage through over-activity; and particularly, how to share benefits from tourism to local populations, including indigenous peoples.

The question is whether economic growth happens in a socially and culturally appropriate and equitable way? Locations for second homes, such as in Nainitial, Uttarakhand, in India, and in Whistler, British Columbia, in Canada, put property prices and many local services beyond the means of local populations. And when land cover changes with development, is there the infrastructure to support it in terms of transit, clean water, sewage treatment, garbage and power? While tourism offers benefits in terms of employment opportunities and to the economy as a whole, the challenge is how to guard against over-exploitation and increasing dependence on low-wage jobs in tourism and pressure on local populations to out-migrate from the community. This is the case for Sherpas in Khumbu, Nepal, the gateway to Mount Everest, and in the Alps, and in the Rocky Mountains.

What are the solutions? Some employers provide staff housing. Will we need employer-paid supplements like a cost-of-living allowance you see in some expensive urban centres like London, or point of sale subsidies like to you see in remote wilderness regions like Canada's North?

When we think of mountains and people, we should also look at ethnogeology, how geological features are understood by indigenous communities. The Stawamus Chief Mountain right next to us was considered to be a longhouse turned to stone. There are traditional Quechua stories from the Andes of the most powerful spirits living on mountain summits. Mountains are often sacred sites, and many religions make pilgrimages to mountains: Wtai Shan and Emei Shan in China; Mount Sinai in Egypt; Gangotri in India; Meteora in Greece.

Legends and oral tradition are of cultural significance, but also of evidentiary significance. Oral histories of floods and volcanic eruptions are used by archaeologists, geographers, and geologists as corroborating evidence to piece together geological history. The Gunditjmara in Australia are an example of this. There is archaeological evidence of their occupation of 13,000 years, but they're telling stories describing the formation of the Budj Bim volcano, a geological event from 37,000 years ago. These indigenous archives of oral tradition as geological history are of great importance.

The good news is there are opportunities for cooperation and collaboration to protect and preserve our mountains and mountain. There are many international organizations doing this, for example, the Adaptations at Altitude program of the Swiss Agency for Development and Cooperation, GEO Mountains lead by the Mountain Research Initiative and the National Research Council of Italy, the Mountain Societies Research Institute of the University of Central

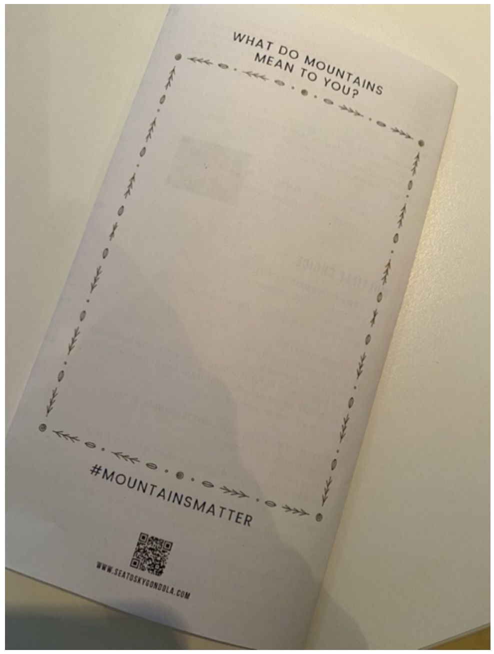
Asia, the High Mountain Summit of the World Meteorological Organization, the Canadian Mountain Network, to name a few.

This course is a cooperative effort between Sea to Sky Gondola, the Mountain Research Institute and GEO Mountains at the University of Bern in Switzerland, the University of Calgary and the Arctic Institute. The teaching materials for this course are posted for public use on the GEO Mountains website as open source learning, so anyone, anywhere in the world, has access to them.

The question is how can you contribute to mountain sustainability?

Pick 3 Things-To-Do for yourself. Will it be to stay on the trail? Volunteer? Participate in Citizen Science (like iNaturalist https://www.inaturalist.org.) Watch your plastics; Try using a carbon emissions calculator?

Activity 6: What do mountains mean to you?
Individual work. 15 minutes to complete “What do mountains mean to you?”
We’ve come full circle, back to the question of what mountains mean to you: Write a poem, sketch, doodle, or explain why mountains matter or what they mean to you. Use the space on the back of you Field Guide for this. You may choose to keep your work private. If you would like, we can take a photo of your work to post (without your name) on social media with the hashtag #mountainsmatter. Or you can do this yourself. This will help increase awareness about the issues of mountain sustainability.


WHAT DO MOUNTAINS MEAN TO YOU?
#MOUNTAINSMATTER
WWW.SEATOSKYGONDOLA.COM

WEATHER MEASUREMENT

MATERIALS NEEDED:

- Anemometer (and thermometer if yours does not include one)
  - Use anemometer for temperature and wind speed measurements
- Compass
  - Use compass, wet finger, and observations of vegetation to determine wind direction
- Soil/Earth Thermometer
  - Use this to measure the temperature of the soil
- Sling Psychrometer
  - Use this to measure relative humidity

YOUR NAME

____

SITE NAME, LOCATION, DATE

____

TIME OF DAY AND TEMPERATURE

____

WEATHER CONDITIONS: FOR EXAMPLE, IS IT CLOUDY, SUNNY, WINDY, RAINING?

____

WIND CONDITIONS: SPEED AND DIRECTION

____

SOIL CONDITIONS: TEMPERATURE AND MOISTURE

____

HOW WILL THE WEATHER CHANGE IN FUTURE? WHAT WILL THAT MEAN FOR THE SUBALPINE ENVIRONMENT?

____

____

____

____

WHAT DO MOUNTAINS MEAN TO YOU?

#MOUNTAINSMATTER

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FIELD GUIDE FOR SUSTAINABLE MOUNTAINS

SEA TO SKY GONDOLA

"SUSTAINABILITY IS THE PROCESS OF LIVING WITHIN THE LIMITS OF AVAILABLE PHYSICAL, NATURAL AND SOCIAL RESOURCES IN WAYS THAT ALLOW LIFE TO THRIVE IN PERPETUITY."

CASE STUDY: MOUNTAIN GOATS

The greatest natural threats to mountain goats are starvation in late winter, avalanches, falls from steep cliffs and predation.

Mountain goats depend on body fat reserves accumulated in summer and fall to survive the brutal cold and wind of winter. Feed is available under the snow but offers little ________________. Feeding in winter may just maintain health. Goats spend a lot of time sleeping in winter to lower the demand for ______________. They also restrict their movements and may range in a small area for the winter.

In winter, goats prefer sunny south-facing slopes where snow cover is thin and plants start new growth early. _______________ may occur in late winter and early spring when fat reserves are depleted and new plant growth is delayed by deep snow.

While they _________ well to cold temperatures and winter wind, they suffer in the summer heat. The southern boundary of their range is defined by heat stress mountain goats would suffer in areas to the south or at lower elevations.

_______________ will impact mountain goats in two ways. Higher temperatures will cause trees to grow at higher elevations on mountainsides which will shrink the available alpine area. Climate change will also increase temperature and force mountain goats _______________ on a mountain to avoid summer heat. This double squeeze will reduce mountain goat habitat and may reduce the abundance and variety of feed plants. Most remain in the herd, but a few will _____________ and join other herds. ______________ for survival are thereby shared with other herds.

CALORIES HIGHER DISPERSE
TRAITS ADAPT
CLIMATE CHANGE STARVATION NUTRITION

CASE STUDY: SALAL

By retaining ______________ year-round, these species reduce the energy and time needed to invest annually in new leaves, a clear advantage in places where the growing season is ___________. Being evergreen, salal retains its leaves and stems so they can instantly photosynthesize when the snow cover is removed.

SALAL STUDY CONTINUED

Being ______________ rather than annual is an adaptation that makes living in the alpine more efficient. Perennial plants have a life cycle that occurs over two or more years. Even if the plants are _______________ and lose leaves during the winter, they do not need to invest annually in building a root structure, and can leaf out using ________________ stored over winter in their roots.

As mountains are subject to higher mean temperatures, cold adapted species decline. Seasonal snow cover is reduced, mountain vegetation will be subject to more extreme weather – frequent droughts, wildfires, and flooding.

SHORT ENERGY PERENNIAL
DECIDUOUS FOLIAGE

DISCUSSION POINTS

WHAT IS A BLACK BEAR'S GREATEST ADAPTATION?
a) an extensive DVD collection
b) their charm
c) an ability to eat many different things

THE GALAPAGOS FINCHES ARE:
a) a rock band from the 60's
b) expensive sneakers
c) an example of natural selection at work: the birds with larger beaks being able to eat larger seeds not ordinarily part of their diet to survive

BIRDS THAT DO NOT MIGRATE BUT CANNOT ADAPT TO SURVIVE THE WINTER ARE
a) the Toronto Blue Jays
b) Angry Birds
c) unlikely to survive to pass on their genetic traits

SUBDUCTION IS
a) a type of international electronic espionage
b) layers of cheese, salami, tomatoes, ham, lettuce, and pickles
c) a collision between two of Earth's tectonic plates, where one plate sinks into the mantle
underneath the other plate

DISCUSSION CONTINUED

ROCK, DUST AND SOIL SITTING ATOP A LAYER OF BEDROCK IS
a)Legolas
b) Basilisk
c) Regolith

KRUMMHOLZ IS
a) A traditional German shortbread cookie
b) A cordless vacuum cleaner
c) Stunted or deformed vegetation in the subalpine

FLAGGING IS
a) How you start a Formula One race
b) What you wave on Canada Day
c) Where there's growth on only one side of a tree due to winds

HOW DO GROUSE SURVIVE THE SUBALPINE WINTER?
a) They watch Netflix
b) They play outdoor hockey
c) They do not migrate. They have snowshoes-like lateral extensions of the scales of their toes. They also burrow into the snow, which keeps them warm and protects them from predators.

WHO DISCOVERED NATURAL SELECTION?
a) Justin Trudeau
b) Dua Lipa
c) Charles Darwin

A LARGE ROCK THAT IS DIFFERENT FROM SURROUNDING ROCK AND WAS TRANSPORTED FROM ITS ORIGINAL LOCATION BY A GLACIER IS CALLED AN
a) Elliptic
b) Eccentric
c) Erratic

ANIMALS THAT DON'T ADAPT TEND TO BE
a) Voted off the island
b) Survivors of the Fittest
c) Unlikely to pass on their genetic traits to a new generation

Relative Humidity

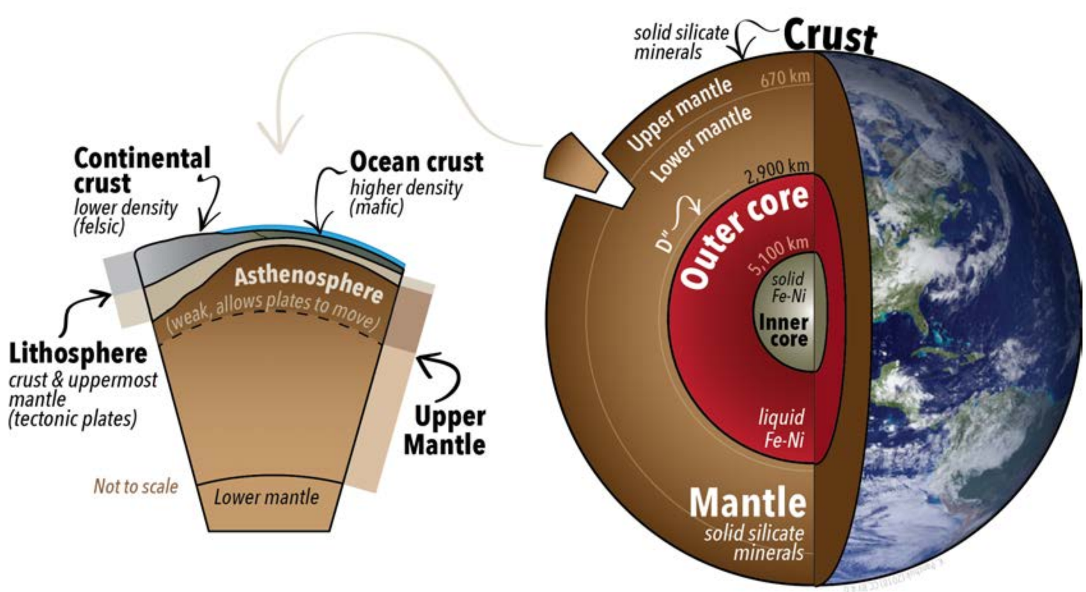
Dry bulb temp	Difference between wet and dry bulb temp															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
0	81	64	46	29	13											
2	84	68	52	37	22	7										
4	85	71	57	43	29	16										
6	86	73	60	48	35	24	11									
8	87	75	63	51	40	29	19	8								
10	88	77	66	55	44	34	24	15	6							
12	89	78	68	58	48	39	29	21	12							
14	90	79	70	60	51	42	34	26	18	10						
16	90	81	71	63	54	46	38	30	23	15	8					
18	91	82	73	65	57	49	41	34	27	20	14	7				
20	91	83	74	66	59	51	44	37	31	24	18	12	6			
22	92	83	76	68	61	54	47	40	34	28	22	17	11	5		
24	92	84	77	69	62	56	49	43	37	31	26	20	15	10	5	
26	92	85	78	71	64	58	51	46	40	34	29	24	19	14	10	5

Modules 1-6

Module 1: Mountain Building

How are mountains formed?

If we want to understand how mountains are formed and raised, we need first to know something about the Earth's structure, and how it continues to evolve
We understand our planet's structure to comprise a solid-iron inner core at the centre, with a liquid-iron outer core circulating around it, and a mantle of hot, 'plastic' rocky material moving very sluggishly around that.



The Earth's crust to inner core by Karla Panchuk (2018) CC BY 4.0. Earth photo by NASA (n.d.) Public Domain view source

The outer shell of the Earth – the crust – is the relatively thin layer of solid rock which forms the ocean floor, islands and continents. Oceanic crust is thinner – about 5 km to 10 km thick – than continental crust, which is mostly 30 km to 50 km, sometimes (around high mountain ranges) as much as 80 km, thick. When we look at average crustal thickness in comparison with the Earth's total diameter, it is thinner than a hen's egg-shell in relation to the egg!
We can think of different areas of oceanic and continental crust as being a bit like pieces in a giant jigsaw puzzle, covering the entire planet. These pieces are called 'plates'. We know that new oceanic crust is formed by volcanic eruptions – almost always under the ocean – along the edges of pairs of oceanic plates, where those parts of the mantle which are less dense, and melt at relatively low temperatures and pressures, ooze out through cracks between the plates.
These oceanic-to-oceanic plate boundaries, identified as sub-oceanic mountain chains formed from young volcanic rocks, are known as 'constructive plate margins'. A good

example of such a 'mid-oceanic ridge' can be seen all the way up the centre-line of the Atlantic Ocean: new oceanic crust forms along this line, as the ocean is slowly (at about the rate a finger-nail grows) being pulled apart by global-scale crustal forces, and so grows wider. The ridge, and the margin along its centre, can even be seen above sea-level, in the country of Iceland, and a few other islands along its course.

By tracing a wide variety of different clues back through the geological record, we have come to understand that the continents of North and South America, and Europe and Africa, once formed a continual landmass: even today, we can see that their coasts could more or less fit together. As they were slowly pulled apart – mainly under the influence of the circulating mantle material below – the Atlantic Ocean developed between them.

In other regions, where an oceanic plate and a continental plate are pushed against each other along their edges, one of these must give. The thinner, denser oceanic plate is pushed underneath the edge of the (thicker, more buoyant) continental plate, back down towards the mantle. This is known as 'subduction'.

Not far offshore the west coast of British Columbia (BC), Canada, there are examples of both a constructive spreading ridge and a destructive subduction zone. While new ocean crust continues to be generated to the west of Vancouver Island, by remnants of what was once the Pacific mid-oceanic ridge (Juan de Fuca Ridge), the oceanic plate to the east of this margin (Juan de Fuca plate) is being subducted beneath continental North America (marked by the Cascadia Trench). (Note that most of the spreading-ridge itself has also already disappeared in this way.)

Magma, lava and volcanoes: igneous mountain-building processes

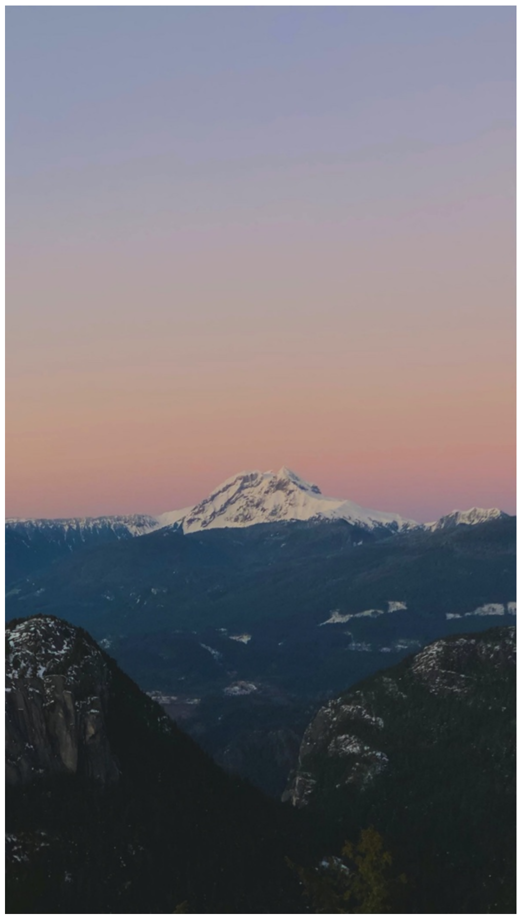
As the oceanic plate descends beneath the continental margin, it encounters higher temperatures and pressures, and begins to melt. Some parts of the rock forming the oceanic crust melt earlier, at shallower depths: being less dense and more fluid, these partial melts – we can think of them as 'bubbles' of magma – tend to move up through the edge of the continental crust, exploiting any lines of weakness in the structure. Some of these pathways are themselves likely to have been formed by stresses driven by the plate-to-plate collision and subduction. As the magma moves, it may also melt surrounding rock, which is added to the mix.

The combination of horizontal pressure along the plate-margins at the surface (folding and faulting,) together with some vertical pressure from magma forcing upward from the regions of melting oceanic crust (doming,) are important mechanisms by which mountains begin to be raised.

If the magma finds its way to the surface, it will erupt as a volcano. Once a route has been forced from deep in the crust all the way to the surface, it tends to be exploited repeatedly by successive pulses of magma. Many of the mountains along British Columbia's coast were formed in this way: through long periods of time, repeat eruptions of molten rock (now, when it appears on the Earth's surface, called lava) add more and more material to each vent.

Often, along a boundary between an oceanic and a continental plate, the chemical composition of the melt makes it quite sticky or viscous, so the lava does not flow far before it solidifies. Another result is that it's not easy for gases to escape – until the pressure builds sufficiently for a major explosion.

Volcanoes associated with sporadic explosive eruptions are often found in mountain ranges along coastal margins next to subduction zones – for example in the Cascade, Coast, and Andes ranges. One of the best-known examples of a major explosive eruption of this type was at Mount St Helens (Washington State) in 1980. Because the 'sticky' lava does not flow very far, these volcanoes can eventually build high mountains – such as Mount Meager, Mount Garibaldi, Mount Baker, and Mount Rainier.



Mount Garibaldi, British Columbia, is a volcano formed by sporadic eruptions.
Photo by Olivier Lattaro.

Where the route between the magma's origin and the surface is shorter, in areas where the crust is thinner, or it has been split by other forces, the lava tends to be much more fluid, so it flows further, sometimes forming an extensive plateau. The longest lava flow known from the geological record was over 500 km. Eruptions in Hawaii often provide a good example of fluid lava flows – but examples of these are also found across large areas of British Columbia (e.g. Wells Gray Provincial Park) and in the Columbia River basalts of Washington or Oregon. It's thought that these might have been made possible by crustal thinning occurring behind the coastal mountain ranges.

Regardless of the lava's viscosity – on encountering the much cooler, low-pressure conditions at the surface compared to those deeper in the crust, it solidifies rapidly. This limits the time available for mineral crystals to form and develop, so volcanic rocks tend to be very fine-grain. The most extreme example of this is when the melt cools almost instantly, with no time at all for crystallization, forming volcanic glass. Obsidian is a type of volcanic glass: high-quality obsidian from deposits on Mt Edziza, in northwestern British Columbia, was highly prized by Indigenous peoples for making tools and spear and arrow points and traded extensively – as far as northern Alberta and Alaska.

In contrast, magma which does not reach the surface – despite pushing upward through the lower to middle sections of the crust, quite possibly causing uplift by 'doming' as it does so – never encounters that sudden surface-shock. It cools over much longer durations, giving time for the various chemical constituents of the melt to migrate, organize themselves, and begin to form and develop crystals. The longer the magma takes to cool, the larger the crystals – particularly those which form last in the cooling process – might grow.

Building mountains by folding and faulting

As two plates are pushed against one another, compression forces the rock to change shape: this is known as deformation. At an ocean-continent collision, these forces are limited by the subduction of the oceanic plate – it deflects below the continental crust, rather than colliding with it fully. Nevertheless, appreciable deformation occurs, helping – along with (and in some ways aiding) the volcanic activity – to build the mountains along the continental margin.

More rarely, two units of continental crust might be pushed against one another. In this case, there's no backing-down: it's a full-on collision, and the forces generated are immense. Through time, great chunks of land – known as terranes – formed new additions to British Columbia and the western side of Canada, carried on the subduction-driven conveyor of the Pacific oceanic plate. With each new collision, new mountains were pushed up on the surface. This is also the origin of the Himalayas, formed by the northward collision of the Indian sub-continent (which it really is, in geological terms!) with south-central Asia.

Different rocks respond to compression in different ways under different conditions. Some are relatively brittle, others ductile ('bendable'). Their mechanical response to stress will vary, depending on how this stress is applied in relation to the alignment of the rock units; their physical composition and overall morphometry (form, dimensions); and how deep they are within the crust (and thus the surrounding temperatures and pressures.)

"Himalayas - Aerial view" by Dr. Partha Sarathi Sahana is licensed under CC BY 2.0.

Ductile or plastic deformation results in 'folding'. Depending on the nature and scale of the stress applied, this may affect anything from an individual unit of rock to entire mountains. Generally, small folds are found on larger folds, which in turn are on still larger folds. Although upward folds (anticlines) often form higher land than the downward folds (synclines), sometimes this can be reversed – the initial uplands are more vulnerable to erosion and may be rapidly stripped away: this may in turn expose softer rocks beneath, which are then exploited by major forces such as glaciers and rivers, and thus become lowlands and valleys. In extreme cases, 'over-folding' may completely invert entire geological sequences, turning them upside-down.

Again depending on the physical characteristics of the rock, the nature of the applied stress, and the surrounding conditions of temperature and pressure, a unit of rock may at some point fail, splitting apart: this is 'faulting'. In compressional settings, where major geological units are being squeezed, faults often develop after folding has progressed beyond a particular limit. However, in brittle rock conditions, faulting may occur more rapidly, with no folding involved. As well as through compression, faults may result from extension (pulling apart) and shear (lateral or sideways tearing). The complex rage of stresses and mechanisms arising from mountain-building events may result in all of these being found within the same region. There is no guarantee that rock which moves upward as a result of faulting will continue indefinitely to form higher ground: the combination of exposure, erosion and different rock-unit resistances may in time reverse this relationship. So far, we have been thinking mainly about subduction zones, where an oceanic plate dives below the edge of a continental plate. However, the greatest compressional stresses in rocks at and near the surface occurs when two units of continental crust are being pushed against one another. These forces tend to generate regional-scale folding and faulting. The planes along which these 'thrust faults' form tend to be at quite shallow angles to the surface: these discontinuities or breaks in major geological units enable enormous sub-units to move horizontally (and also vertically).

"Rocky Mountains" by U.S. Geological Survey is licensed under CC BY 2.0.

If you fly over the Rocky Mountains on a clear day, you will see something like the image above – each ridge is a unit of rock which was folded by compressional stress, before ultimately failing (faulting), and being pushed sideways and upwards over the unit below it. The largest mountain ranges around the world – the Himalayan ranges, Rockies, Andes, European Alps, and much older ranges, of which only the exposed roots are now visible – have all been formed primarily by this process.

Module 2: Mountains, Climate & Weathering

Climate & Weather

Mountains influence and even create weather. Topographically, mountains are rainmakers. On the west coast of British Columbia, air moves eastward off the Pacific Ocean. As it hits the mountains, it begins to rise. The air then cools as it moves up and over the mountains, resulting in clouds and rain, and as it continues east, there are "rain shadows," dry areas. So the west side of the mountains are wetter than the east, with a kind of a windward/leeward difference. The proper name for this is the **orographic effect**.

You see this all over the world. The same phenomenon happens with the Tibetan Plateau, where it is very dry, being on the leeward or rain shadowed side of the Himalayas and the Kunlun Mountains and the Quilian Mountains in China.

As in circumpolar regions, mountains are experiencing faster rates of climate-change, introducing major implications for humankind and the ecosystems on which we depend. This is due to mountains extending above the surface boundary layer into the free atmosphere and are more directly exposed to major incoming weather systems. Extreme climate change is happening at above 3000 metres, with 90% of data coming from Utah, Colorado and Tibet. Areas already in crisis are the Andes and the Hindu Kush Himalaya.

So with climate change you see increasing mountain exposure to hazards such as storms, landslides, and avalanches. But it's not just increased air temperature that's the issue. Rather, it is the increased humidity coming from warm air holding more water vapour and warming seas and land releasing more water into the atmosphere through evaporation.

Context: So why do we care about weather? Because mountains, and vegetation, and animals will have to adapt in response. Where a mountain was once, say, cold and dry, but is now warmer and more humid, how will the vegetation change? How will natural hazards be different? How will animals and humans adapt? How will our water availability from glaciers and snowpacks change? These are the big questions of mountain sustainability.

When you look at what they are measuring at basecamp of Mount Everest (at 5,013 metres), it is temperature, wind, pressure, and humidity. Soil temperature data are not a standard weather measurement at weather stations but are of increasing interest in terms of climate change. For plants to grow and germinate to full maturity, we need to know what's happening at specific depths in the soil, and that will help determine what will grow on our mountains in the future.

Interesting weather facts and definitions:

Weather is a general term for changes in water vapour phase (rain, snow) and air pressure differences (wind).

Climate is the statistical analysis of long-term weather measurements.

The energy that runs the Earth's weather comes from the sun. Weather is a product of solar energy and water vapour in our atmosphere. Like carbon dioxide, water vapour is a **greenhouse gas**. Greenhouse gases partially trap the energy radiated from the Earth's surface that is warmed by sunlight.

The troposphere is the lowest part of the atmosphere. It is about 14 km thick at the equator and about 8 km thick at the poles. The troposphere contains most of the Earth's oxygen and water vapour. None of the mountains of Earth extend above the troposphere into the stratosphere. Earth's atmosphere is mostly nitrogen (~70%). The majority of aerosols (very small suspended solid particles in the atmosphere) are found below ~3000 m. These include black carbon from incomplete combustion of fossil fuels, wildfires, and sea salt aerosols from the ocean.

Atmospheric pressure is the weight of the air around you. Atmospheric pressure drops as altitude increases. The pressure of the atmosphere at sea level is slightly greater than 100 kPa (kilopascals.) The pressure at the top of mount Everest is about 30 kPa. At the top of the Sea to Sky Gondola the air pressure is approximately 90 kPa. It's a good weather indicator. Low pressure systems involve wind and precipitation; high pressure systems are clear.

Lapse rates are the rate of temperature change as you move upward through the earth's atmosphere. Warm air is buoyant. When warm air rises it cools. In winter this relationship can be reversed, especially in snow covered mountain areas. This is because cold air sinks and pools at the valley bottom. In winter, mountain peaks can be much warmer than the temperature at valley bottom. This is called an **inversion**.

Anabatic winds are warm upslope winds that blow up a mountainside when the mountain surface is warmer than the surrounding air. **Katabatic winds** are cool winds that blow downslope under the force of gravity when the mountain surface is colder than the surrounding air.

Alpenglow is the red tinge mountain regions have at sunrise or sunset. The sun's rays at sunrise or sunset travel through much more of the atmosphere than during the daytime. The more distance sun light travels through the lower portion of the atmosphere the more of the short wavelengths of light (blue light) gets scattered by aerosols in the atmosphere.

The remaining longer wavelengths of light are predominantly red, which gives the rosy colour to mountains.

Activity: Measuring the weather

What you will need: Outdoor thermometer, anemometer, soil thermometer, compass, sling psychrometer, Relative Humidity Chart.

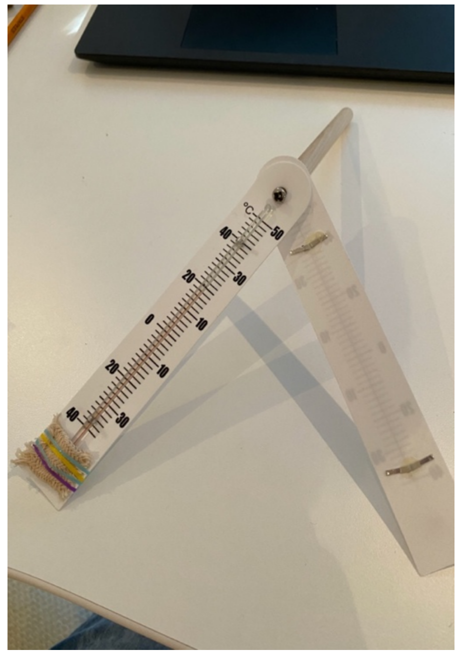
How to measure wind direction? – observation of vegetation, flagging, wet finger, compass.

How to measure wind speed and temp? - anemometer and thermometer.

How to measure soil temperature? - soil thermometer. Measure 5 cm below ground. Measure the surface temperature. Then measure the air temperature 2 metres above. Soil temp is important because warmer temperatures accelerate chemical weathering on mountains and determine what vegetation will grow. If our mountains grow warmer with climate change, what changes in plants will we see? What changes will happen for microorganisms so small we can't even see them with the naked eye?

How to measure relative humidity (RH)? – sling psychrometer. Dip sock at end of wet-bulb thermometer in water. Whirl sling psychrometer in air until you get a wet-bulb thermometer reading (approximately 5 minutes.) The spinning causes moisture in the sock to evaporate and has a cooling effect on the bulb. The difference between the wet and dry bulb temperatures help you find Relative Humidity. e.g. If the dry bulb measures 25C and the wet bulb measures 18C, then you have a wet bulb difference of 7C. Find the dry bulb measurement on the left of the chart and read across to the right, you have a Relative Humidity of roughly 50%.
This cooling process, the evaporation of the water on the wet bulb thermometer, tells us how much water vapour is in the air today. As a result of the spinning, the sock at the end of the wet bulb thermometer undergoes a rapid cooling effect at a faster rate. Saturated water vapour would be 100% RH; No water vapour at all in the air would be 0% RH. Evaporation is faster when humidity is low, and as RH increases, the evaporation rate decreases.

Relative Humidity																	
	Difference between wet and dry bulb temp																
Dry bulb temp		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	0	81	64	46	29	13											
	2	84	68	52	37	22	7										
	4	85	71	57	43	29	16										
	6	86	73	60	48	35	24	11									
	8	87	75	63	51	40	29	19	8								
	10	88	77	66	55	44	34	24	15	6							
	12	89	78	68	58	48	39	29	21	12							
	14	90	79	70	60	51	42	34	26	18	10						
	16	90	81	71	63	54	46	38	30	23	15	8					
	18	91	82	73	65	57	49	41	34	27	20	14	7				
	20	91	83	74	66	59	51	44	37	31	24	18	12	6			
	22	92	83	76	68	61	54	47	40	34	28	22	17	11	5		
	24	92	84	77	69	62	56	49	43	37	31	26	20	15	10	5	
	26	92	85	78	71	64	58	51	46	40	34	29	24	19	14	10	5



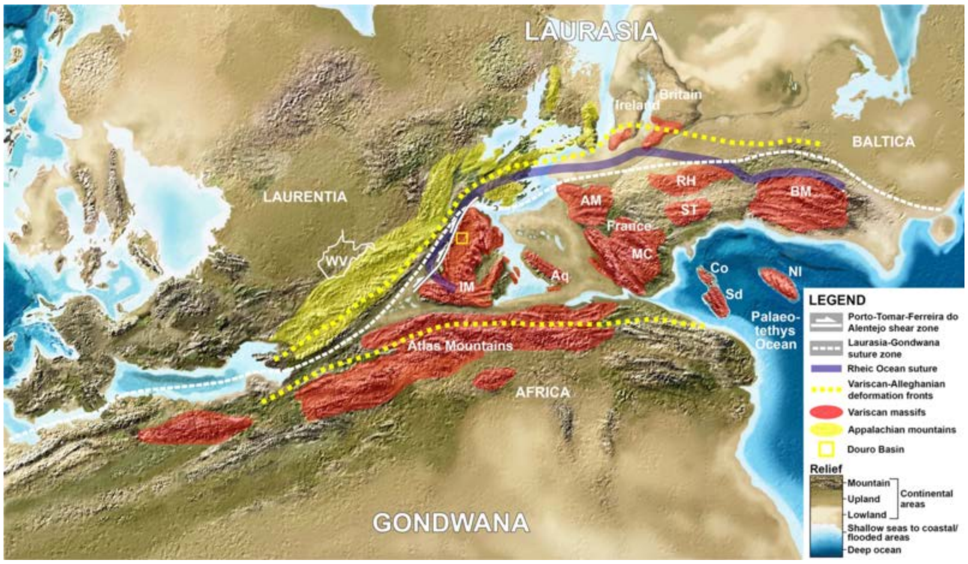
Relative Humidity Chart and sling psychrometer for use in calculating relative humidity.
Photo by Martha Warren.

Laying Mountains Low: Weathering, Erosion, Transportation

As we have seen above, mountains can create weather. Weather also changes mountains.

It is sometimes said that "what goes up, must come down": this is no less the case with mountains. When large masses of rock are accumulated at or pushed to high elevations, they are immediately exposed to a wide range of destructive forces, which will – over tens to hundreds of millions of years – work to transform mountains, first into hills, and eventually to lowlands.

As an example – the Appalachian Mountains (eastern North America), Scottish Highlands and other ranges were formed when several continental masses collided to form the 'super-continent' of Pangea, between 350 and 300 million years ago. At this time, these mountains – few of which are now taller than 1000 m – would have been comparable in size to today's Himalayas, the highest of which are over 8000 m in elevation. Now, we are just seeing remnants of the deep 'roots' of those mountain ranges.



https://en.wikipedia.org/wiki/File:Pangea_mountains.webp

A great many natural processes and forces combine to lay mountains low. Arguably the most important influence is the range of meteorological (weather) conditions: mountains are exposed to stronger winds, higher precipitation, and wide ranges of temperature. Another important factor is gravity: raising something up gives it 'potential energy': if it is (or bits of it are) freed from whatever was previously keeping it in place, gravity will tend to move it to lower levels.

These processes work at a range of scales, from the microscopic to the truly enormous. The two main stages involve firstly the disaggregation or destruction of the rock itself, and then the transport of the resultant particles. This happens in a variety of ways.

Weathering

Rocks are 'picked apart' by a combination of processes known as 'weathering'. In general, weathering transforms solid rock into smaller pieces, called regolith, down through smaller and smaller particles: it may even dissolve a rock completely, so that it becomes part of a liquid. Weathering may take the following forms:

Physical weathering: mechanical stresses imposed on and within rock-units;

- freeze-thaw cycles of water / ice cause cracking, deepening, and widening cracks in rock by expansion and contraction: water finds its way into crevices, and – when it freezes – expands, forcing the crack wider, and flexing it again when it melts
- extreme temperatures may also drive expansion (hot) / contraction (cold)
- hydraulic fracturing – the varied impacts and forces of flowing water
- abrasion – disaggregation by direct impact from particles (from boulders to fine sand) carried by wind or water (arguably a form of erosion, rather than weathering)

Chemical weathering: reactions between the rock's constituent minerals and external agents;

- when minerals in rocks are unstable in the chemical conditions to which they are exposed (temperature, pressure, moisture, acidity, etc.) they may react and break down
- this is particularly true for volcanic rocks, in which the mineral crystals cooled rapidly, without time to take chemical forms more suited to stability at surface conditions
- as the more vulnerable minerals break down through reaction with atmospheric gases and water-borne chemicals, they leave the less vulnerable (more stable) particles behind, leaving them more vulnerable to disaggregation from the parent rock
- some rocks are made largely of minerals which dissolve in water: for example, limestone is composed very largely of calcium carbonate
- accelerated by moisture and warmer temperatures

Biological weathering: the activities of living organisms;

- burrowing
- root action
- bio-chemical weathering (eg by lichens)


Biological weathering by roots and lichens. Sea to Sky Gondola.
Photo by Martha Warren.

We can also think of the direct effects of human activities – mining is a good example.

Once regolith particles – bits of the original rock – have been detached or disaggregated from their parent rock, they are liable to be moved. In mountain settings, this happens mainly under the influence of gravity, ice, and water (and just possibly wind).

When a piece of rock stays in one place, this shows that the combination of the gravitational force on that mass of rock, the slope of the ground, and the frictional roughness of both the surface and the rock are in balance. If the slope should get steeper, or the frictional 'sticking power' reduces, then the rock will tend to move downhill. It is possible that the slope could get steeper, if it is being worn away by weathering, or an erosional force such as flowing water or ice. It is also possible for the friction between rock and surface to be reduced: most often this happens by adding water, from rainfall or snowmelt.

It's useful to distinguish between the steady processes of weathering and disaggregation which generate quite small particles of regolith, and those – rarer – situations in which very large volumes of rock and/or of accumulated unconsolidated regolith may suddenly detach and move down-slope, in potentially highly hazardous events. The latter will be covered in Module 4 Natural Hazards.

Transportation of regolith by gravity

Relatively small particles and volumes of regolith may accumulate close to their source – perhaps just falling a short way down-slope under gravity – or may be transported great distances by water (including ice) and/or wind, undergoing further transformation as it travels.

Along the feet of many steep slopes, particularly in areas which have quite dry climates, and experience variation between temperatures above and below freezing during part of the year, it is common to see large accumulations of angular regolith, which – having disaggregated from the parent rock (primarily by freeze-thaw) – then falls down the slope to join the growing pile. These accumulations are known as talus or scree. Similar processes on different types of rock may lead to the accumulation of gravels, sand or finer particles.

Most of the time, these talus or scree slopes find a natural configuration of internal organization and slope which permits them to be quite stable: they may even support the growth of vegetation, the roots of which help to anchor the loose, unconsolidated material. In general, a vegetated – particularly a forested – slope will be more stable than one without vegetation: this is partly because the roots bind the material together more cohesively, and partly because the vegetation canopy reduces and spreads-out the direct effects of rainfall and surface flows.

However, sometimes this balance or equilibrium is disrupted, and the slope may slide or flow. Most often this is through the reduction of friction by adding water from heavy rainfall or rapid snowmelt. It is also possible that these events may be provoked by shaking (during an earthquake), or even by animals (including humans!) walking across the slope and dislodging important ‘anchors.’ It follows from the point above that removing the vegetation – again, particularly trees – from a slope will increase its vulnerability to erosion and ‘mass-wasting’.

Transportation of regolith by water

Water is an extremely important agent for the transportation of regolith. Mountain landscapes – particularly those on the windward sides of ranges – experience high rainfall and snowfall (not least by their upward deflection of weather systems into cooler air, prompting condensation of water vapour, and thus enhancing precipitation). Frequent replenishment of water from rainfall keeps many small, energetic streams flowing. As they do so, they carve deeper valleys, in turn encouraging gravitational movement of regolith into these same watercourses. The erosional power of these streams is particularly strong during major rainstorms and rapid snowmelt. As they flow through steep, rugged terrain, these fast-running mountain streams transport the regolith itself e.g. Berg Lake Trail 2020:

https://www.cbc.ca/news/canada/british-columbia/berg-lake-trail-mount-robson-provincial-park-flooding-1.6097648

https://www.therockymountaingoat.com/2021/07/dozens-evacuated-by-air-after-berg-lake-flash-flood/

https://www.therockymountaingoat.com/2021/10/kinney-lake-trail-closes-for-maintenance-damage-assessment-continues/

This journey is often quite violent, resulting in further attrition of the regolith, from larger, more angular to smaller, more rounded particles. The abrasive action of these particles helps to excavate the stream valleys even further, making them deeper and steeper, and so encouraging the whole process to intensify.

When you look at a mountain or hillside, the gullies and valleys you can see have all been formed almost entirely by this process, so helping – bit by bit – to make the uplands lower. It is also worth noting that the regolith transported downhill / downstream by these processes will contribute to the formation of new (sedimentary) rocks on the floodplains of rivers and in the ocean.

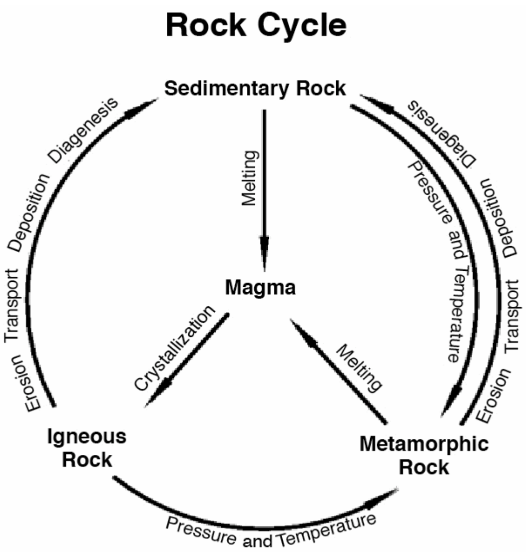
Transportation of regolith by ice

In high mountains, where snow has accumulated and persisted year after year without completely melting, glaciers, icefields and ice caps may be found. Mountain ice of these types is under extreme threat as a result of rising temperatures in the atmosphere and ocean. Recent studies (Bevington Menounos, 2022) have suggested that the entirety of glacial ice in western Canada could melt before 2100.

Glaciers represent immensely powerful agents of erosion and transportation. Formed initially as patches of snow which do not melt through successive summers, they begin to flow downhill under their own weight. As they do so, a complex range of processes works to weaken, disaggregate and move enormous volumes of rock along their paths.

As large volumes of ice, they act as ‘cold sinks’, lowering the range of temperatures in the air around them: this in turn means that freeze / thaw weathering is more likely through longer periods of the (otherwise) warmer months. Where ice freezes onto rock, the latter – potentially of very large sizes – may be ‘plucked’ from their origins and moved by the ice, potentially for long distances. The rocks within the ice scrape and ‘bulldoze’ the surface as the glacier moves, further abrading and eroding the landscape (and the regolith itself, which tends to take on a rounded shape). This excavating action carves deep U-shaped valleys with steep sides – down which yet more regolith is able more easily to fall, under gravity. Also under and in front of the ice, meltwater streams flow, doing the same kind of work as those generated by rainfall and snowmelt, as described above.

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. Glaciers and examined in more depth in Module 3 Glaciers, Snow and Water.



https://commons.wikimedia.org/wiki/File:Rock_cycle.gif

To summarize, what we are seeing is the rock cycle at work: mass wasting and the redistribution of regolith under gravity, with erosion being the redistribution of regolith by flowing media, namely: water (fluvial erosion); ice (glacial erosion); and wind (aeolian erosion.)
The particles on Highline Trail, for example, are redistributed to the bottom of the trail.

Regolith on Highline Trail, Sea to Sky Gondola, Squamish, British Columbia.
Photo by Martha Warren

The regolith from the summit at Sea to Sky Gondola is redistributed to the bottom of Átl'ka7tsem/*Howe Sound*. There is a constant movement in mountains, where some mountains are rising, some are becoming smaller, weathering and eroding. Some mountains in the Himalayas are still rising at 1 cm a year due to crustal uplift.

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.

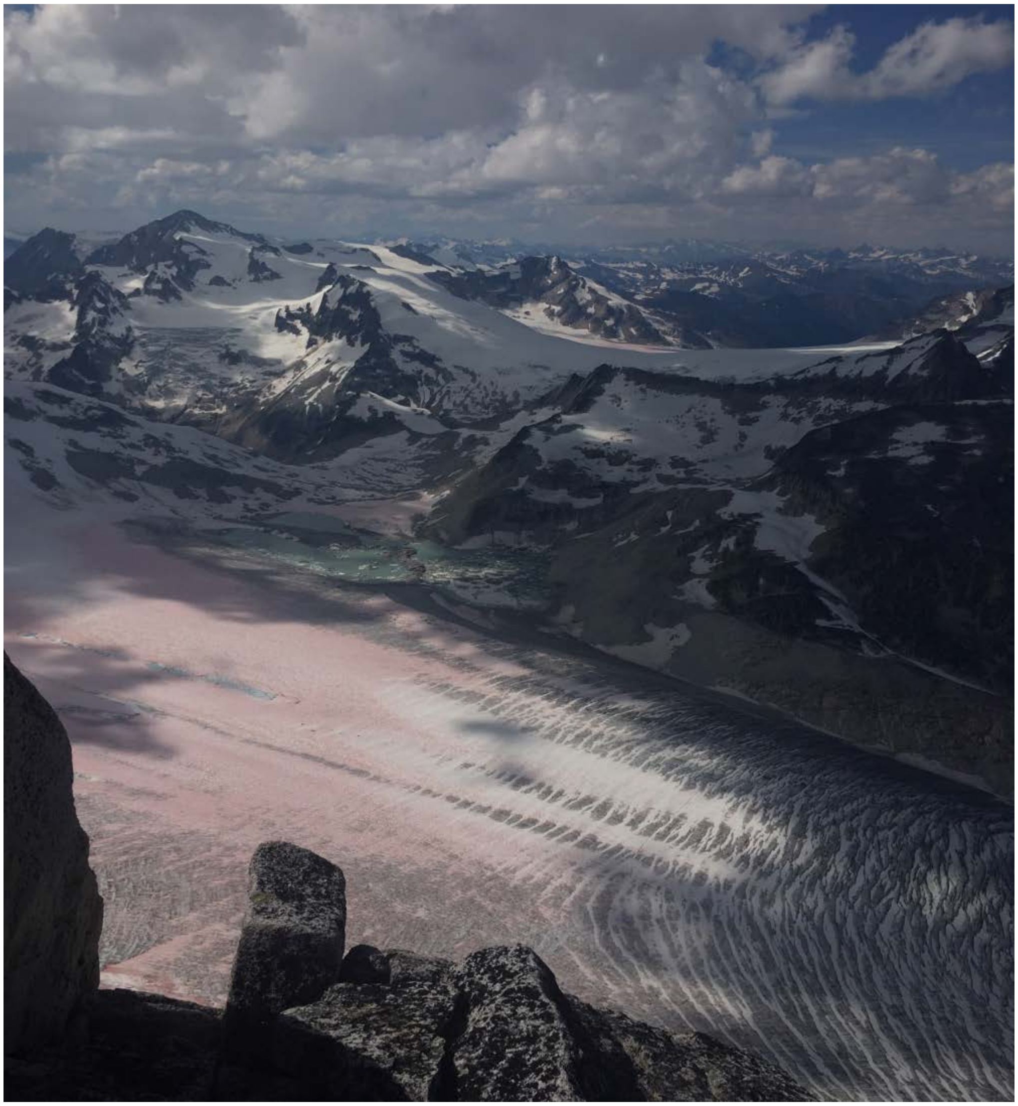
If you lose the fresh snow, the ice is darker itself and just absorbs more solar radiation, so melting and sublimation appears more intense, and the ice loss increases.

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.



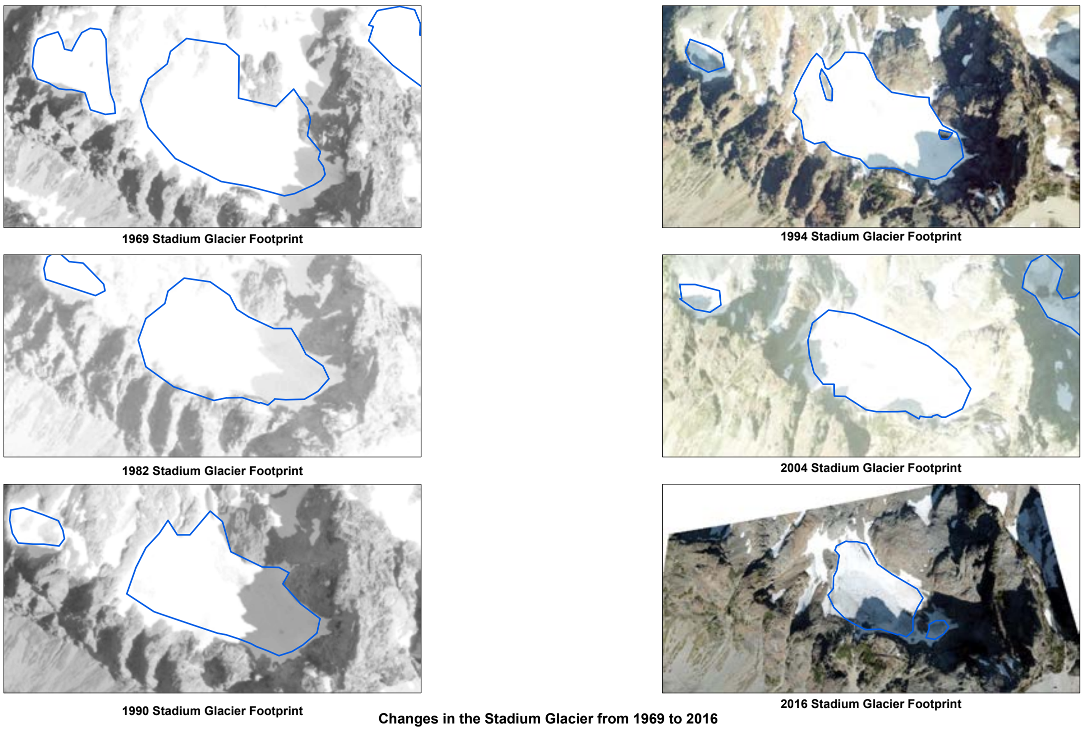
Vowell Glacier in Bugaboo Provincial Park. Photo by Scott Williamson.

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.

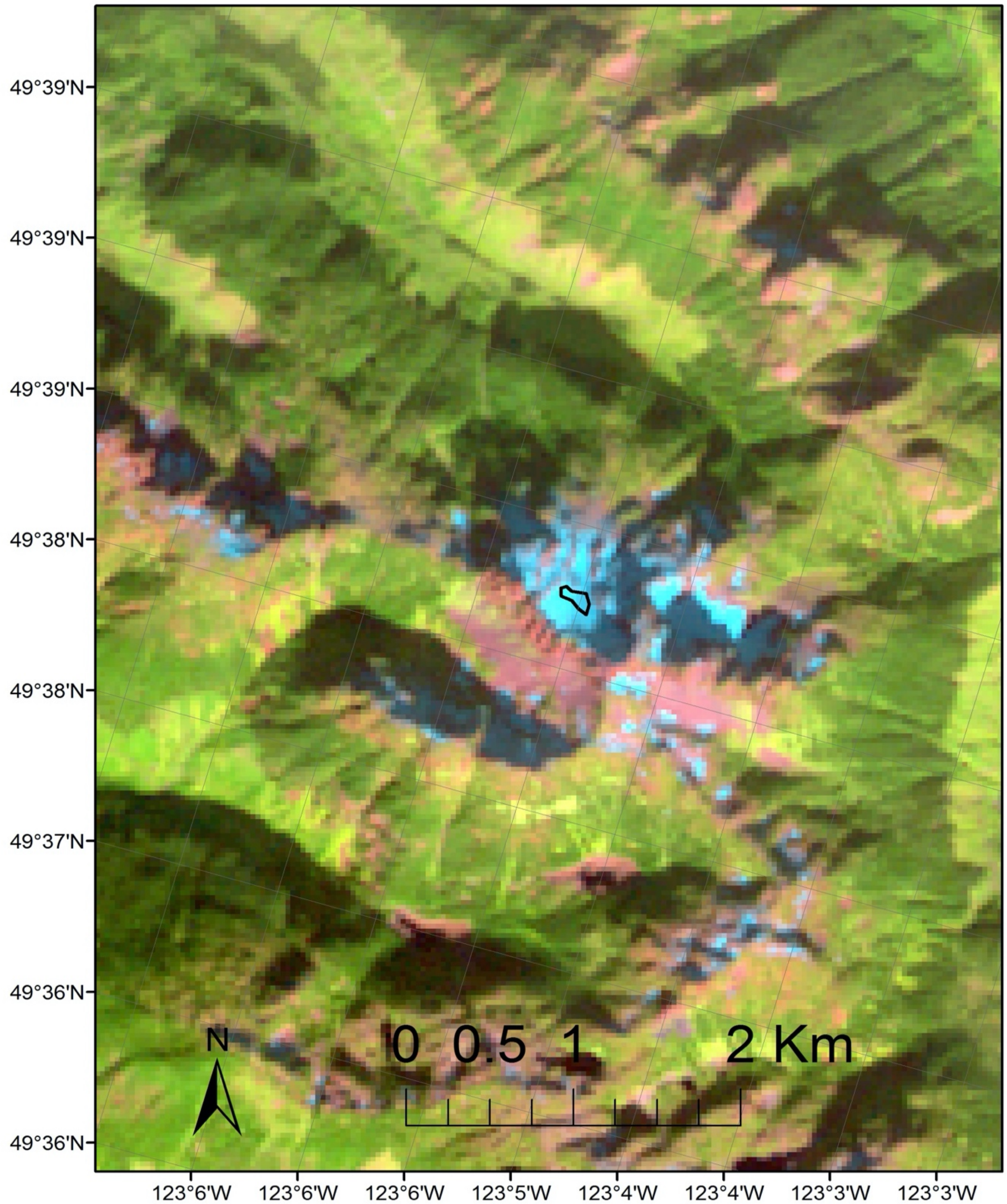


Figure by Scott Williamson.

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.

Module 4: Natural Hazards

The height, steep slopes, frequent geological instability, and extreme climates of mountainous terrain give rise to a variety of natural hazards, which may impose risks on human well-being and property.

- Floods
- Wildfires
- Mass-Movement
- Avalanches

Floods

Where weather-systems encounter mountains, they are deflected upward to higher elevations, where atmospheric pressures and temperatures are lower. Any water-vapour in these systems is then more likely to condense into liquid (or solid) form, and in due course to fall as precipitation – as rain or snow. In some situations, the air-mass may become lodged or 'stuck' against the mountains, potentially delivering large volumes of rain or snow over several days.

Steep mountain slopes with thin soils and sparse vegetation quickly channel liquid water into small upland valleys. Runoff of water from heavy rainfall is likely to travel more easily over the surface where the natural vegetation has been substantially disrupted, for example by logging or wildfires. Trees and the underlying 'duff' of decaying organic matter help to diffuse and soak-up rain, so that it is less likely to move over the. Where the vegetation has been removed, it is more likely that surface runoff will travel easily and rapidly. Wildfires, and periods of hot, dry weather, may result in a hard 'crust' being formed on the surface, again facilitating rapid runoff.

It follows that retaining land-cover with rich vegetative cover helps to reduce the risk of flooding, by slowing the rate of initial runoff. It has also been shown that the dams, ponds and channels built by beavers can help mitigate these risks (although these are less likely to be found in the high elevation 'headwaters').

Some other natural flood-mitigation approaches: https://thenarwhal.ca/topics/bc-floods-solutions/

Once the runoff generated from rainfall and/or snowmelt has flowed into rills, gullies and stream valleys, it flows rapidly to lower elevations, joining with other streams and increasing in volume and energy as it travels. As it does so, it will transport loose regolith downstream: this is likely to erode the valley further.

Wherever the rate of volume flow exceeds the capacity of the containing channel, overbank flow, a.k.a. flooding, will occur. This is most likely in broader valleys (often glacially-excavated) at lower elevations. In particular, where flows encounter shallower gradients along these larger valleys, or spill into the floodplain, the associated sudden reduction in energy results in much of their sediment-load being deposited (beginning with coarser particles through to finer material, as the energy drops).

Floods arising from glacial lake outbursts are of increasing concern as glaciers retreat. The Tsho Rolpa Glacial Lake below, for example, is one the largest glacial lakes in Nepal.

There is high risk of moraine dam breaches due to rapid glacial melt and the Tarkading Glacier calving into the lake. It is subject to hazard mitigation systems that include remote monitoring and warning sirens to protect villages downstream.

Tsho Rolpa Glacial Lake, Nepal.
Photo by Robert Plummer.

Lake Palcacocha in Peru's Cordillera Blanca is at similar risk, with threat 50,000 people below should it breach its banks and cause a flood and landslide.
Some recent Canadian examples of flooding in mountainous terrain:
Southern Alberta (Canmore, High River, Calgary), June 2013:

A low-pressure system channelling moisture from the south-east (as far as the Gulf of Mexico) became 'lodged' against the Rocky Mountains, delivering large volumes of rainfall, in turn accelerating melt of high-elevation snowpack, leading to extreme high-volume / high-energy flows and flooding in several settlements.

Upper Peace District, British Columbia, June 2016:

Similarly, a low-pressure system (again channelling moisture from the Gulf of Mexico) delivered large volumes of rainfall on the eastern flanks of the mountains. Logging (for oil and gas exploration / extraction and salvage of timber affected by mountain pine-beetle) and clearances by wildfires, together with relatively dry conditions earlier in the spring, may have exacerbated the flooding, by exposing more open ground and preventing or slowing soil recharge ('soaking-in'.)

Berg Lake, 30 June 2021:

A major storm system – possibly driven originally by pyrocumulonimbus events above intense fires in the central Interior – delivered ~215 mm rain in five hours in this area close to Mount Robson: the resultant flows drove major coarse debris transport and deposition (~3m in height in some areas), substantially damaging a trail important to the local economy
https://www.therockymountaingoat.com/2021/07/dozens-evacuated-by-air-after-berg-lake-flash-flood/
South-west British Columbia, November 2021:

Atmospheric rivers (intense bands of atmospheric moisture sourced from as far away as the Philippines) delivered large volumes of rain to the western flanks of the Coast Mountains (277.5 mm from 14 to 15 November in Hope, British Columbia.) Soils and drainage systems in the area were already saturated, so runoff was rapid and energetic, exacerbated in areas already logged or cleared by wildfire. This resulted in major disruption to transportation infrastructure – seven bridges destroyed on Hwy 5; Hwy 8 severely damaged in ~30 locations; debris / mud flows crossed Hwy 1, Hwy 7, Hwy 99, Hwy 3; flooding in Abbotsford, Princeton, and Merritt.

Wildfires

Mountain slopes are often forested and are therefore likely to accumulate high fuel-loads. South-facing unshaded slopes receive higher amounts of solar radiation, resulting in higher temperatures, and lower soil-moisture. Lightning is more likely to strike mountain peaks than lowlands, so sparking wildfires. The probability of such events is much higher during periods of hot, dry weather. Mountain landscapes may amplify these conditions: they usually occur under high atmospheric pressure, where the air is sinking – mountains may constrain its ability to spread-out near the surface, so it compresses and therefore heats further. Also, differential heating between sun-exposed and shaded areas may drive thermal winds which become stronger along narrow valleys and may fan the flames of wildfires.
Where conditions are hot and dry, fuel-loads high, and winds strong, wildfires may generate pyrocumulonimbus ‘firestorms’, which generate (usually dry) lightning. From 3 pm on 30 June 2021 to 8 am on 1 July 2021, several events of this type drove storms which yielded over 700,000 lightning pulses across a large swath of British Columbia and Alberta, over 110,000 of which hit the ground.
https://twitter.com/kyletwn/status/1410089092797243394
https://www.nesdis.noaa.gov/news/raging-wildfires-spark-lightning-over-british-columbia
https://www.vaisala.com/en/blog/2021-07/pyrocumulonimbus-event-british-columbia-canada
Mountainous regions present a range of challenges for fire-fighting. Fires generally burn up-slope but this also depends on the direction and strength of winds. Rugged terrain presents challenging conditions for ground and air operations. Dense smoke in high-pressure conditions is slow to clear from valleys – many parts of British Columbia

frequently experience extremely poor air-quality for extended periods during the wildfire season.

Climate change has demanded improved management of wildfire risk globally. New initiatives to maintain mountain forests and biodiversity from wildfire have been introduced in the South Caucusus, for example. Solutions include strengthened forecasting and communication, and new weather stations such as those in the Khosrov Forest State Reserve in Azizkend, Armenia. Drawing on available human resources, more women are now trained to fight forest fires, and there is better equipment for access to difficult mountain locations.

Mass Movements

In some situations, large volumes of rock (either previously solid, or unconsolidated regolith) may lose its 'structural coherence' in relation to its location, somehow shifting from stable and static to unstable, so that it is able to move under the force of gravity from higher to lower elevations. These 'mass-movements' may be sudden, rapid and difficult to predict, or relatively slow and steady. Where these events are large and energetic, they may be highly hazardous to people or property in their path.

One way of exploring the differences between types of mass-movement is to look at the nature of the geological material which moves:

(Initially) Solid Rock

One form of mass-movement occurs when the connections between a large volume of solid rock and the rest of that geological unit weaken: most often, this occurs along one or more structural 'joints' (planar discontinuities or cracks), or a layer of slightly different composition. If this surface of weakness slopes downwards towards the edge of an existing outer slope or cliff, then when it gives way (probably under the cumulative effects of weathering, and often with the help of lubrication through the introduction of water), the upper unit will detach and **slide**, falling down or off the outer slope to lower elevations.

Elliot Creek (central coast), November 2020: ~50 million tonnes of rock

This landslide was likely released following removal of supporting glacial ice ('debuttressing'), and a year of above-average precipitation. It was equivalent to the mass of all the 25 million cars in Canada – or 150 Empire State Buildings – travelling down a valley together at between 140 and 170 km/h.

- https://hakai.org/the-big-slide/?utm_campaign=reprint&utm_source=piquenewsmagazine
- https://www.frontiersin.org/articles/10.3389/feart.2022.916069/full
- https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2021GL096716
- https://bc.ctvnews.ca/mobile/b-c-landslide-caused-100-metre-high-tsunami-set-off-earthquake-scale-study-1.5842552?cache=/7.386407?clipId=104070

Big Bar slide (Fraser River, southern Cariboo), Early 2019: ~85,000 m³

This was a relatively small combination of rockslide and rockfall on a canyon section of the Fraser River. The rock fell directly into the river, instantly forming a new waterfall around 5.5 m in height. This presented a major obstacle to salmon of several species migrating up the river, so considerable effort was expended in finding ways to remove as much as possible of the rock as possible, while building routes along which it would be easier for the salmon to pass.

Frank Slide (Alberta, southern Rocky Mountains), April 1903: 44 million m^3 / 110 million tonnes: 70-90 fatalities

This slide was partly anthropogenic - coal-mining - but also followed a wet winter and cold snap with high groundwater saturation and sudden freezing. Oral traditions of local Indigenous peoples (Blackfoot, Ktunaxa) had referred to the peak as "the mountain that moves."

Loose or fragmented rock – including large boulders

If the volume of geological material is already fragmented to some degree, rather than being mainly solid, it is easier for it to begin to move: often this will be provoked by increased flows of water (during a storm or rapid snowmelt), the addition of new material above the deposit, or shaking from seismic activity. On near-vertical slopes, the movement may be a simple **rockfall**. On longer, somewhat less steep slopes, the looser structure allows a more chaotic, turbulent type of movement: if the rock fragments are mainly dry, they may become suspended on an air-cushion within a **rock-avalanche**: alternatively, larger proportional volumes of water may result in the development of a coarse **debris-flow**.

Meager Creek (Coast Mountains, near Pemberton British Columbia), August 2010: ~48,500,000 m^3

Several accumulations of loose rock (originally disaggregated in an alpine glacial setting, and perched high in the valley) released and fell onto another area of weak rock saturated with groundwater. These volumes of rock moved rapidly as a debris flow along the 7 km length of the Capricorn Creek valley, damming Meager Creek for 19 hours, forming a lake 1.5 km in length.

Unconsolidated regolith – smaller particle-size

Scree or talus accumulations are generally relatively stable, under ‘normal’ conditions: the smaller fragments, which are often angular, tend to fit and lodge against one another in a way which resists movement. However, this coherence may be overcome, particularly by substantial injections of water during periods of high runoff from rainstorms or rapid snowmelt, or from groundwater springs. In such cases, the volume, energy and duration of the flows are likely to dictate the violence of the flow and the distance it travels.

The widespread debris flows and mudflows experienced throughout much of south-west British Columbia in November 2022 were examples of this kind of event, when heavy rain fell over several days onto already saturated surfaces. The runoff rapidly swept large volumes of rock and smaller particles (as well as vegetation, including trees) which had accumulated in the upper reaches of uplands and mountain valleys to lower elevations, amplifying as more material and water was gathered into the flows. These flows destroyed or damaged property and transport infrastructure in their path, severely disrupting human activities in these areas for weeks to months.

In mountainous areas of British Columbia, particularly in steep-sided glacially-eroded valleys, only small amounts of relatively flat land are available. Many of these are alluvial fans – areas in which material transported by water from higher elevations has been deposited, often where the river or creek enters a lake. These settings are often thought of as being attractive locations on which to build – the idea of ‘waterfront property’ is appealing to many. However, the valleys above the fans were carved by rapid and destructive flows of this type, and they are likely to happen again – these are often dangerous settings in which to site property developments.

Soil

As the geological particles become smaller, and organic matter from decaying vegetation is added, they contribute to the formation of soil. Once again, the addition of large volumes of water within a soil layer on a slope may encourage it to slip – generally slowly (as **soil-creep**), but potentially suddenly and rapidly. The risk of this increases considerably where the binding effect of vegetation (particularly tree-roots) is removed, for example by logging. Sudden mudflows are also more likely to be generated in areas affected by wildfires.

In March 2014, following some six weeks of heavy rainfall, a relatively shallow slope on the flank of the Stillaguamish River near Oso Washington State flowed suddenly downhill and over the river, destroying 49 properties and resulting in 43 fatalities.

It may be difficult to know where and/or when any of these types of events may be likely to happen: the most useful clues are found in the surrounding landscape – understanding the geology, topography, climate, and building a picture of past events by examining the shape and structure of the terrain provides a great deal of information. The problem often seems to be that events which occur quite frequently in geological timescales – at intervals of hundreds to thousands of years – may seem unlikely from a human perspective. In the context of more extreme weather events driven by climate-change, assumptions of this nature may prove to be particularly costly.

Avalanches

A comparable form of mass-movement may occur on mountain slopes where large volumes of snow have accumulated, and at some point lose their structural coherence, resulting in rapid down-slope transport. Snow is a complex material: it may fall as flakes to granules, to form a snowpack. Depending on temperature, humidity and other factors, these tiny grains are likely to change shape (**snow metamorphosis**), in turn potentially altering the snowpack’s internal cohesive strength and stability. Many avalanches are caused where a weak layer is covered by fresh snow, so that it is buried within the snowpack. All it takes for snow overlying the weak layer to start moving is a **trigger**: this may be natural (e.g. new snowfall, wind-deposited snow, or a rapid temperature-change, driving shifts in moisture-distribution, density and the effect of gravitational forces) or human (e.g. weight added by someone on skis / snowboard / snowmobile).

Avalanche, Mount Dhaulagiri, Nepal.
Photo by Robert Plummer.

There are two main types of avalanche, involving movement of loose snow (**sluffs**) or **slabs**:

Sluff avalanches – the snow equivalent of mass-movement by loose regolith – occur in loosely-bonded snow at and near the snowpack surface. Movement begins at a single release-point: as the snow moves, it gathers more loose snow, so that the avalanche grows wider as it travels (thus typically having an inverted V-shape planform). Sluffs may be dry (in powder-snow) or wet (where the snowpack has a relatively high liquid-water content). Dry sluffs are not generally highly destructive or dangerous, although – as with any avalanche risk – it is always best to avoid them! Wet sluffs are denser and more fluid, so may move faster. They are most common in the warmer and wetter maritime climates (e.g. British Columbia Coast Mountains), and in spring, as a result either of melt driven by strong solar radiation, or rainfall. The extra speed and weight may make them more dangerous to any humans or property (as well as trees etc.) in their path.
Slab avalanches are comparable to large rockslides. They occur where a layer which was previously at the snowpack surface has physical characteristics which prevent coherence with new snow subsequently accumulated above it.

For example, where feathery **hoar crystals** have formed on a surface and persist under new accumulations of snow, they may at some point collapse. Alternatively, 'slippery' ice-crust layers may be formed by strong winds, or by some degree of thaw-freeze. Typically, a slab avalanche is triggered when the upper layers of snowpack begin to move over the

weak layer, often because of loading by yet more snow, or human activity. These tend to be the most destructive and dangerous types of avalanches.
The overlying layers forming the slab may be **hard** or **soft**, depending on the density of – and degree of granular bonding within – the snowpack. Soft slabs are less dense and more loosely bonded than hard slabs, but denser and more tightly bonded than newly fallen snow. The lines of failure along which a soft slab releases are likely to propagate over shorter distances than those in the more cohesive hard slabs and tend to break-up as they move.

A third variety is a **wet-slab** avalanche: these typically occur in spring, when meltwater or rainfall percolate through the snowpack and into a deeper weak layer – the relatively warm water breaks the bonds maintaining cohesion between the upper and lower parts of the snowpack and may also lubricate movement of the former over the latter. Wet sluffs may occur as precursors, indicating potential for imminent release of a wet-slab avalanche

Module 5: Biodiversity

The most species-rich mountain region in the world is the Northern Andes. Why are mountains known as biodiversity-hotspots? They cover just 27% of the Earth's surface, and yet contribute a disproportionate amount of biodiversity.

No one knows for sure, but there are several theories. One explanation is that mountains have many different ecosystems in a relatively small area. Ascending in altitude, the changing climate brings changing ecosystems. Therefore, it could be that microclimates play a role.

Another theory is that a link exists between mountain biodiversity, especially tropical mountains, and bedrock geology. It's been speculated that mountains originating from oceanic bedrock provide positive growing conditions for plants, so they can better adapt to challenging soils. It follows that if this impacts the plants, it also impacts the varieties of species of animals that can live off the plants and each other.

When **Charles Darwin** studied Galapagos Finches, he discovered that when bad weather affected plant growth and there were fewer seeds to eat, the finches had to eat larger seeds not normally a part of their diet to survive. Only the birds with beaks large enough to eat the larger seeds survived. These survivors had offspring with large beaks, and this inherited trait was passed on through reproduction. The species thereby evolved to have larger beaks than before, and this **adaptation** to environment is **natural selection**.

Consider the different plant and animal adaptations required for to montane, subalpine and alpine mountain areas.

The sub-alpine forest, for example, is a transition zone from dense forest below to alpine tundra above treeline. Sub-alpine areas can be buffeted by hurricane force winds, scoured by ice crystals, and weighted down by heavy snow—life can be a challenge for mountain trees. As a transition zone from dense forest below to alpine tundra above treeline, the treeline is not really a line, but rather a zone where trees gradually get smaller and more stunted until conditions are too challenging for tree growth. The plants that grow in these soils must be very hardy. One often sees the following:

- **Krummholz** = stunted or deformed vegetation in the subalpine
- **Flagging** = where you have growth on only one side of a tree due to winds
- Vegetation growing directly out of rock.

Subalpine tree growth.
Squamish, British Columbia
Photo by Martha Warren

How have animals adapted to live in the mountains?

The Red Breasted Sapsucker get their name from how they eat. These woodpeckers drill rows of holes into tree trunks and then return to those holes later to feed on the running sap and the insects attracted to it. Hummingbirds also use the Sapsucker feeding holes. The Rufous Hummingbird will follow the Sapsucker, feeding at the wells of sap that the Sapsucker keeps flowing.

Sapsucker holes, Sea to Sky Gondola, Squamish, British Columbia.
Photo by Andrea Andres.

Cougars use the thick underbrush of mountain forest for shelter and to stalk their prey. Cougars are active throughout the year and are elusive animals that prefer to avoid contact with humans.

Chipmunks live in trees and gather food on the ground in areas with underbrush, rocks, and logs, where they can hide from predators like hawks, foxes, coyotes, weasels, and snakes. They have striped bodies for camouflage, claws, and are able climbers. They feed on insects, nuts, berries, seeds, fruit, and grain which they stuff into their cheek pouches and carry to their burrow or nest to store. Chipmunks hibernate, but instead of eating a lot and fattening up before they sleep, they keep a store of nuts and seeds to eat throughout the winter. They can reduce their respiration and heart rate when food is scarce and reduce their overall body temperature. Chipmunks have litters of 2-8 pups, once or twice per year – a useful adaptation for survival of the species considering they have so many predators.

The black bear's greatest adaptation to living on the mountain is its ability to eat many different things. From fruits and nuts, grasses, twigs, and honey, to grubs, insects, fish, and small mammals. Its molars are great for grinding up foods and its large canine teeth for ripping apart fish. Bears can smell food up to 20 miles away. Their sense of smell also helps them locate other bears and detect and avoid danger. Bears have huge, strong legs to move or bend large objects like rocks or tree trunks to get to food. They have large, padded feet and strong, curved claws to climb trees easily to get to fruit. Their long and sticky tongue can reach insects in trees. They can even separate and spit out unwanted nuts or berries without using their paws.

As in circumpolar regions, mountains are experiencing faster rates of climate-change, introducing major implications for humankind and the ecosystems on which we depend. This is due to mountains extending above the surface boundary layer into the free atmosphere and being more directly exposed to major incoming weather systems. The question is which plant and animal species will adapt as our mountains change? What will happen as our mountains become warmer?

Some species will move uphill due to climate change. Mountain goats will be affected by warmer winters. If trees start growing higher up the mountainside, then there will be less of the lichens, ferns, grasses, herbs, and shrubs that goats currently eat. They will also have to go higher up the mountain in the summer to stay cool.

For caribou in the Rocky Mountains’ Jasper Park, it’s difficult to dig through the deeper snowpack further up the mountain to find food. Instead, they stand on snow to eat lichen from trees. But if a snowpack is reduced or gone completely, the caribou are unable to reach arboreal lichens. Caribou also use high-elevation snow-patches for respite from summer heat and insects.

Yaks in Nepal can't live at the elevation they used to because it's too warm now for them. They are already moving further up the mountains to reach a cooler environment, forcing them into a smaller area where it's harder to find food and water.

Vernal pools/ephemeral wetlands only contain water for part of the year. These shallow ponds of water are full in the winter and spring and dry out to become mud and soil in the summer and fall. If there are longer droughts, species like frogs and salamanders won't continue to live there.

Salamander eggs, Squamish, British Columbia. Photo by Andrea Andres.

Measuring biodiversity is important so we can see how species are adapting to global climate change. Studying the Himalayan yak, for example, may tell us a lot about how cattle and other animals will be impacted by climate change.

Climate change increases mountain exposure to hazards such as storms, landslides, and avalanches and these will impact mountain plants and animals. But it is not just warmer air temperature that's the issue. Rather, it is the increased humidity coming from warm air holding more water vapour, and warming seas and land releasing more water into the atmosphere through evaporation. The result is more heat, more storms, and increased rainfall.

Anthropogenic disturbances such as mining, farming, development, and recreational hiking can also have an adverse effect on biodiversity. The significance of mountains to people is examined in Module 6 Mountains and People.

Questions for discussion:

Where a mountain was once, say, cold and dry, but is now warmer and more humid, how will the vegetation change?
How will our water availability from glaciers and snowpacks change?

How will natural hazards be different?
How will animals and humans adapt?

Suggested case studies:

- The use of habitat corridors in mountains to increase biodiversity: Conservation corridors are being used to preserve ecological connectivity. For example, the Albertine Rift is one of the most biodiverse regions on the African continent. The Rift is located within six countries: Burundi, the Democratic Republic of the Congo, Rwanda, Tanzania, Uganda, and Zambia. 500 species are found exclusively there. Scientists predict that by the end of this century, many species there will have moved to higher elevations as the climate warms, resulting in a 75% reduction in habitat.
- The survival of animals with seasonal phonologies: Animals such as the snowshoe hare in the Rocky Mountains will be disadvantaged if snow disappears before their white winter coat sheds.
- The impact of invasive species on mountain forests: In British Columbia, the Mountain Pine Beetle was previously limited to a small area, its numbers kept down by periodic very cold temperatures in late autumn and early spring. As these cold snaps have become less frequent, the beetle was able to expand enormously, into areas where such events are even less likely. This has had widespread impact on pine-dominated forests and associated ecosystems – exacerbated by intensive ‘salvage-logging.’

Module 6: Mountains and People

What do mountains mean to you?

Mountains have always been a source of inspiration for spirituality, traditions, and the arts.

Take **Mount Olympus**. It is one of the highest peaks in Europe, and to the ancient Greeks, it was the home of the Greek Gods who lived on Mytikas Peak.

Haleakela volcano in Hawaii was considered to be *wao akua*, or “the realms of the gods,” by the Polynesians. Many religious ceremonies are still held on the rim of the summit and in the crater to this day.

Consider the arts. There are acclaimed paintings of the Group of Seven – Lawren Harris’ “Mountains in Snow,” or Norval Morrisseau’s “Riding the Great Thunderbird to the Mountain World.”

Lawren Harris’ "Mountains in Snow" by Maia C is licensed under CC BY-NC-ND 2.0.

Have you seen the movie, Avatar? Huang Shan, the mountains in China, were the inspiration for the floating mountain range in the movie – their jagged granite peaks with twisted trees growing out of them.

When you think of mountains and literature, what do you think of? It could be **Thomas Mann's The Magic Mountain** or **Li Bai's** poetry: *"We sit together, the mountain and me, until only the mountain remains."*

And what about mountains as inspiration for music? Your choice could range from **Modest Mossorgsky's "Night on Bald Mountain"** to **John Denver's "Rocky Mountain High**." Our association of mountains with music could also evoke music outdoors on mountains: the Vancouver Symphony Orchestra playing outdoors at Whistler, or the Squamish Constellation Festival.

What else are mountains to us as people? They are borders, geopolitical divides. The border between British Columbia and Alberta is in the Rocky Mountains; the boundary between France and Spain is along the Pyrenees Mountains; the boundary between Italy and France is the Alps. Historically, countries chose mountains as borders because they could defend their frontiers, defend themselves from attacks by their neighbours. And in severely rugged mountain areas, we still see that today: In the Himalayas between India and China; and in the Andes between Chile and Argentina.

But we also see efforts of international cooperation on some mountain borders. Near Testa Grigia peak, the Theodol glacier's retreat has moved a hotel on the Swiss-Italian border requiring 100 metres of border to be redrawn. (See https://bit.ly/3PHSEji)

Efforts in cross-border cooperation and collaboration such as those seen with the Hindu Kush Himalayan Monitoring and Assessment Programme, which includes India, Pakistan, China, Nepal, Afghanistan, Bangladesh, Bhutan, and Myanmar, is another example of transboundary cooperation. What do they cooperate on? One initiative is mapping human-wildlife conflict hotspots in the Eastern Himalaya. They want to enhance wildlife habitats and corridors, and like us in Canada, they have bears (Himalayan Black Bears,) and antelope (Tibetan antelope,) deer (musk deer,) gaur (Indian bison,) but also the Asian elephant, royal Bengal tiger, snow leopard, and red panda.

Another example of transboundary collaboration is the Kangchenjunga Landscape Initiative. The Southern side of Mount Kangchenjunga is shared by three countries, Bhutan, India and Nepal. They cooperate on sustainable use of resources, environmental conservation, and economic development. They map human-wildlife conflict hotspots. They've had a "Yaks Across Borders" exchange to encourage yak conservation. Yaks provide milk and meat. Their hides are used. Their dung is burned as fuel for cooking and heat. They are also used for transport. Yak herding has been important in this region for 4,500 years, but as borders were militarised between the countries, the herds couldn't mix anymore, and Yak herder communities were suffering. Under this program, Bhutan has given yak bulls to India and Nepal and it is hoped this transboundary interaction between the herders will be ongoing.

In many parts of the world, mountain economies are based on agriculture or mining, and the people living there tend to be poor. These areas have limited infrastructure, service, and opportunities. For many mountains, the issues are around farming and livestock and how to introduce best farming practices for sustainable food production. Or they are around mitigation of the impact of natural resource extraction, and the introduction of more sustainable enterprises to take its place.

Millet farming in Nepal.
Photo by Robert Plummer.

"Mountain porters (Nepal)" by Ahron de Leeuw is licensed under CC BY 2.0.

Tourism brings income and economic benefits to mountain communities, but the challenge is how to manage the environmental, social and cultural impacts of that. Recreational tourism and associated infrastructure, commercial and residential development raise the question of how to prevent damage through over-activity; and particularly, how to share benefits from tourism to local populations, including indigenous peoples. Is economic growth happening in a socially and culturally appropriate and equitable way? Locations for second homes, such as in Nainitial, Uttarakhand, in India, and in Whistler, British Columbia, in Canada, put property prices and many local services beyond the means of local populations. And when land cover changes with development, is there the infrastructure to support it in terms of transit, clean water, sewage treatment, garbage, and power? While tourism offers benefits in terms of employment opportunities and to the economy as a whole, the challenge is how to guard against over-exploitation and increasing dependence on low-wage jobs in tourism and pressure on local populations to out-migrate from the community. This is the case for Sherpas in Khumbu, Nepal, the gateway to Mount Everest, and in the Alps, and in the Rocky Mountains.

What are the solutions? Some employers provide staff housing. Will there be employer or government-paid supplements like a cost-of-living allowance you see in some expensive urban centres like London, or point of sale subsidies like to you see in remote wilderness regions like Canada’s North?

When we think of mountains and people, we should look at ethnogeology, how geological features are understood by indigenous communities. The Stawamus Chief Mountain right next to us was considered to be a longhouse turned to stone. There are traditional Quechua stories from the Andes of the most powerful spirits living on mountain summits. Mountains are often sacred sites, and many religions make pilgrimages to mountains: Wtai Shan and Emei Shan in China; Mount Sinai in Egypt; Gangotri in India; Meteora in Greece.

Legends and oral tradition are not just of cultural significance, but also of evidentiary significance. Oral histories of floods and volcanic eruptions are used by archaeologists, geographers, and geologists as corroborating evidence to piece together geological history. The Gunditjmara in Australia are an example of this. There is archaeological evidence of their occupation of 13,000 years, but they’re telling stories describing the formation of the Budj Bim volcano, a geological event from 37,000 years ago. These indigenous archives of oral tradition as geological history are of increasing importance.

The good news is there are opportunities for cooperation and collaboration to protect and preserve our mountains and mountain. There are many international organizations doing this, for example, the Adaptations at Altitude program of the Swiss Agency for Development and Cooperation, GEO Mountains led by the Mountain Research Initiative and the National Research Council of Italy, the Mountain Societies Research Institute of the University of Central Asia, the High Mountain Summit of the World Meteorological Organization, the Canadian Mountain Network, and many others.

Mountain sustainability is often defined as being where environmental sustainability, social wellbeing, and economic viability meet. So let’s end where we began. What do mountains mean to you?

Case Study: How to measure a mountain (Grades 4-6 and 7-12)

How to measure a mountain

There are many views on how to measure a mountain. Mount Everest is known as the highest mountain in the world. It's 8,848 metres and still growing. That's measuring it from sea-level to its highest peak. But if you measure mountains from their actual base, where they protrude from the earth's crust at land or sea, Mauna Kea, the volcano in Hawaii is the highest, at almost 10,000 metres. When you measure Mauna Kea from sea level, though, it's only about 4,000 metres.

What if we measured mountains from the earth's core to a mountain's peak? Then Chimborazo in Ecuador would be the highest mountain in the world. But because we measure freestanding mountains, from where sea meets land, Mount Everest is the highest.

How tall can mountains grow?

They can't get much bigger than 9,000 metres because gravity is pulling the mountain back towards the earth, and the base of the mountain has to support that pressure. If there is water around the base of the mountain, like the volcano, Mauna Kea, that will help support the weight. If it's a freestanding mountain, and there isn't sufficient support, the base of the mountain will start to liquify.

You can get much higher mountains somewhere with less gravity, like on Mars, where Olympus Mons is 25,000 metres high.

How high will Mount Everest grow? Between its plate tectonics and erosion, it's growing and shrinking at the same time. Perhaps as the erosion of the mountain and its reduced weight allows more crustal uplift. It could also be that its snow caps are protecting it from erosion by the wind and chemical reactions with the air. Nepal and China recently agreed, however, that its measurement of 8,848 metres includes the snowcap on top.

How do you think the height of a mountain should be measured?
____
____
____
____

The height of mountains can change. What are 3 different factors that you think affect the height of a mountain?

a. ____

b. ____

c. ____

Case Study: Soil Temperature (Grades 7-12)

The Dirt on Soil Temperature: 3 Studies

Soil temperature is important for many reasons. Warmer temperatures accelerate chemical weathering on mountains. Soil temperatures determine what vegetation will grow and therefore what animals will be able to live on a mountain. And on a scale not even visible to the naked eye, soil temperature impacts microorganisms that live in the soil. Soil temperature can be very different from the temperatures measured by a weather station, so scientists who want to understand what temperatures nature really feels, often have to look below ground.

We are going to look at three studies in soil temperature.

The first is remarkable for its global scale and is called SoilTemp. This global database of soil and near-surface temperature data is gathering its information from 7,538 temperature sensors in more than 70 countries around the world. Since organisms living close to the ground are so strongly influenced by soil temperatures, such so-called 'microclimate' data can help us to understand how species are experiencing climate change. As Jonas Lembrechts, scientist at the University of Antwerp in Belgium explains:

> "This is of immense importance to organisms… If we think about nature from our own 'human' perspective, we miss a lot of the details. Tiny organisms don't see or feel the world like we do. Think about a lizard on a cold and sunny day. You might be freezing cold and putting on a warm jacket, but the lizard could be basking on a stone in the sun and feeling very happy and warm indeed. As a scientist, we try to look at the world from the perspective of the organism, which is why it is so important to measure the temperatures (and other things) there where they are."

SoilTemp is an initiative from Jonas Lembrechts and Ivan Nijs at the University of Antwerp, and Jonathan Lenoir at the Université de Picardie Jules Verne, and is developed in partnership with GEO Mountains. The database is used to provide scientists across the globe with the necessary soil temperature data to understand and study nature and how it is reacting to climate change and other stressors. For more information about this study, see https://www.geomountains.org/projects-impact-stories/affiliated-projects/2869-soiltemp or www.soiltempproject.com.

The second study is an excellent example of citizens' science in action and nature-based solutions to climate change and sustainability. The "Curious Noses" project in Belgium asked 5,000 citizens to install a microclimate sensor – a 'mini weather station' sometimes called a "lawn dagger"– in their gardens. Thanks to the help of all these citizens, the researchers could learn more about protecting garden ecosystems – and people – from the impact of extreme weather events such as heatwaves, droughts or heavy rainfall. The smart sensors measure soil temperature and drought in various locations including gardens, school playgrounds, parks, and fields. Each sensor shared its data via link to the internet, so the citizens (and the whole community) could follow the impact of extreme events on their gardens. See https://curieuzeneuzen.be/home-en/.

By measuring, observing, and recording, "Curious Noses" studied whether vegetation in effect acts as an air conditioner. The results indicate that tree canopies, shade, late-afternoon sun, paved areas and asphalt, fencing and open garden borders that allow air circulation, light-coloured walls, the planting shrubs or vines next to walls – all influence this. Vegetation can also serve as a cushion to extreme precipitation, slowing the infiltration of water.

The third study illustrates what raw data from **meteorological stations** look like, and how the data can be transformed into meaningful information.

Below is a meteorological station in the southwest Yukon at ~2200 metres above sea level.

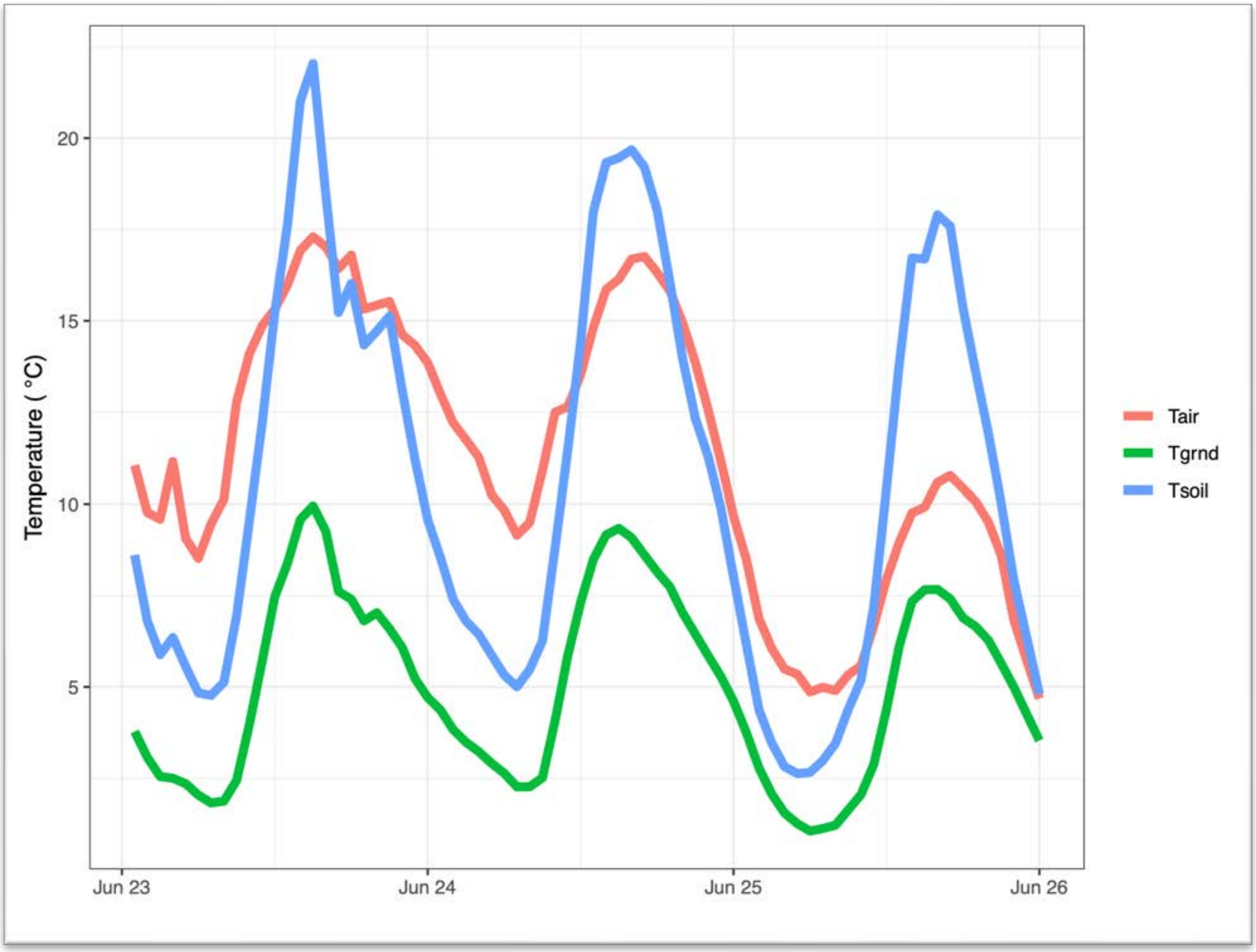
Meteorological station in the southwest Yukon at ~2200 m asl from June 2012. Photo by Scott Williamson.

The figures below are a three-day record from an adjoining station in June 2012. The weather was clear with some intermittent cloudy periods, but no rain. The air temperature was recorded at 2 m above ground, the soil temperature at 1 cm below surface in soil, and the ground temperature at 10 cm below surface.

Date	Time	Temp	Variable
2012-06-23	1:00:00	11.05	Tair
2012-06-23	2:00:00	9.77	Tair
2012-06-23	3:00:00	9.59	Tair
2012-06-23	4:00:00	11.15	Tair
2012-06-23	5:00:00	9.07	Tair
2012-06-23	6:00:00	8.52	Tair
2012-06-23	7:00:00	9.46	Tair
2012-06-23	8:00:00	10.13	Tair
2012-06-23	9:00:00	12.78	Tair

Sample data from a three-day meteorological station record from the southwest Yukon at ~2200 m asl from June 2012, measuring air, soil and ground temperature. Provided by Scott Williamson.

The station measured air, soil, and ground temperatures. See pages 108-113 for the full three-day meteorological record. When the raw data are graphed as below, the differences in temperature and their diurnal fluctuations are clear.



Air, ground and soil temperature fluctuations over a 3 day period June 2012. Data frame by Scott Williamson.

The temperature curves show that air temperature is warmer than soil temperature at night, but the opposite during the day. This is because sunlight warms the soil more than the air during the day, while at night the soil radiates more energy than the air and cools to below air temperature. Because the ground is insulated, the range between maximum and minimum temperature is much less than for soil temperature. There is no shade above the tree line where the station is located, but small variations in afternoon temperatures are caused by clouds reducing incoming sunlight. This is most noticeable on the first day.

Your study:

Mountains provide a great living laboratory. How to measure soil temperature yourself? Use a soil thermometer. Measure 5 cm below ground. Measure the surface temperature right on top of the soil. Then measure the air temperature 2 metres directly above. Take these readings in a shaded area and then in an open area.

If you are using the soil tester thermometer rather than an air temperature thermometer to measure the air temperature two metres above the soil, put a white tissue on top of the sensor. Hold the sensor so the probe that normally goes into the soil is pointed straight up and drape the tissue over it. This will prevent it from absorbing solar radiation and elevating the temperature reading above what it should be.

Doing this regularly over a period of time, one would see diurnal, seasonal, and long-term climate change temperature patterns.

Photo by Martha Warren

1. As mountains grow warmer, what changes in microbial life do you think we will see?

2. Draw a school garden that would help keep the playground cool. What does your design include to benefit from transpiration, shade, colour, and airflow?

3. If you were creating a citizen's science initiative like the "Curious Noses," what weather or climate change indicators would you want to measure and why?

Three-day meteorological station record from the southwest Yukon at ~2200 m asl from June 2012, measuring air, soil and ground temperature.

Date	Time	Temp	Variable
2012-06-23	1:00:00	11.05	Tair
2012-06-23	2:00:00	9.77	Tair
2012-06-23	3:00:00	9.59	Tair
2012-06-23	4:00:00	11.15	Tair
2012-06-23	5:00:00	9.07	Tair
2012-06-23	6:00:00	8.52	Tair
2012-06-23	7:00:00	9.46	Tair
2012-06-23	8:00:00	10.13	Tair
2012-06-23	9:00:00	12.78	Tair
2012-06-23	10:00:00	14.09	Tair
2012-06-23	11:00:00	14.86	Tair
2012-06-23	12:00:00	15.32	Tair
2012-06-23	13:00:00	15.99	Tair
2012-06-23	14:00:00	16.92	Tair
2012-06-23	15:00:00	17.3	Tair
2012-06-23	16:00:00	17.03	Tair
2012-06-23	17:00:00	16.43	Tair
2012-06-23	18:00:00	16.8	Tair
2012-06-23	19:00:00	15.32	Tair
2012-06-23	20:00:00	15.43	Tair
2012-06-23	21:00:00	15.53	Tair
2012-06-23	22:00:00	14.62	Tair
2012-06-23	23:00:00	14.33	Tair
2012-06-24	0:00:00	13.85	Tair
2012-06-24	1:00:00	13	Tair
2012-06-24	2:00:00	12.21	Tair
2012-06-24	3:00:00	11.75	Tair
2012-06-24	4:00:00	11.27	Tair
2012-06-24	5:00:00	10.26	Tair
2012-06-24	6:00:00	9.84	Tair
2012-06-24	7:00:00	9.15	Tair
2012-06-24	8:00:00	9.5	Tair
2012-06-24	9:00:00	10.91	Tair
2012-06-24	10:00:00	12.5	Tair
2012-06-24	11:00:00	12.65	Tair

2012-06-24	12:00:00	13.53	Tair
2012-06-24	13:00:00	14.82	Tair
2012-06-24	14:00:00	15.86	Tair
2012-06-24	15:00:00	16.14	Tair
2012-06-24	16:00:00	16.69	Tair
2012-06-24	17:00:00	16.76	Tair
2012-06-24	18:00:00	16.32	Tair
2012-06-24	19:00:00	15.82	Tair
2012-06-24	20:00:00	14.95	Tair
2012-06-24	21:00:00	13.86	Tair
2012-06-24	22:00:00	12.57	Tair
2012-06-24	23:00:00	11.17	Tair
2012-06-25	0:00:00	9.67	Tair
2012-06-25	1:00:00	8.49	Tair
2012-06-25	2:00:00	6.864	Tair
2012-06-25	3:00:00	6.052	Tair
2012-06-25	4:00:00	5.488	Tair
2012-06-25	5:00:00	5.349	Tair
2012-06-25	6:00:00	4.864	Tair
2012-06-25	7:00:00	4.99	Tair
2012-06-25	8:00:00	4.903	Tair
2012-06-25	9:00:00	5.333	Tair
2012-06-25	10:00:00	5.584	Tair
2012-06-25	11:00:00	6.667	Tair
2012-06-25	12:00:00	7.95	Tair
2012-06-25	13:00:00	8.95	Tair
2012-06-25	14:00:00	9.76	Tair
2012-06-25	15:00:00	9.92	Tair
2012-06-25	16:00:00	10.58	Tair
2012-06-25	17:00:00	10.77	Tair
2012-06-25	18:00:00	10.42	Tair
2012-06-25	19:00:00	10.07	Tair
2012-06-25	20:00:00	9.51	Tair
2012-06-25	21:00:00	8.6	Tair
2012-06-25	22:00:00	6.821	Tair
2012-06-25	23:00:00	5.726	Tair
2012-06-26	0:00:00	4.682	Tair
2012-06-23	1:00:00	8.61	Tsoil
2012-06-23	2:00:00	6.797	Tsoil

2012-06-23	3:00:00	5.885	Tsoil
2012-06-23	4:00:00	6.351	Tsoil
2012-06-23	5:00:00	5.562	Tsoil
2012-06-23	6:00:00	4.836	Tsoil
2012-06-23	7:00:00	4.77	Tsoil
2012-06-23	8:00:00	5.126	Tsoil
2012-06-23	9:00:00	6.938	Tsoil
2012-06-23	10:00:00	9.53	Tsoil
2012-06-23	11:00:00	12.18	Tsoil
2012-06-23	12:00:00	15.24	Tsoil
2012-06-23	13:00:00	17.64	Tsoil
2012-06-23	14:00:00	21.01	Tsoil
2012-06-23	15:00:00	22.04	Tsoil
2012-06-23	16:00:00	18.46	Tsoil
2012-06-23	17:00:00	15.23	Tsoil
2012-06-23	18:00:00	16.02	Tsoil
2012-06-23	19:00:00	14.34	Tsoil
2012-06-23	20:00:00	14.72	Tsoil
2012-06-23	21:00:00	15.13	Tsoil
2012-06-23	22:00:00	13.09	Tsoil
2012-06-23	23:00:00	11.21	Tsoil
2012-06-24	0:00:00	9.57	Tsoil
2012-06-24	1:00:00	8.54	Tsoil
2012-06-24	2:00:00	7.39	Tsoil
2012-06-24	3:00:00	6.803	Tsoil
2012-06-24	4:00:00	6.445	Tsoil
2012-06-24	5:00:00	5.876	Tsoil
2012-06-24	6:00:00	5.326	Tsoil
2012-06-24	7:00:00	5.005	Tsoil
2012-06-24	8:00:00	5.476	Tsoil
2012-06-24	9:00:00	6.258	Tsoil
2012-06-24	10:00:00	8.82	Tsoil
2012-06-24	11:00:00	11.5	Tsoil
2012-06-24	12:00:00	14.42	Tsoil
2012-06-24	13:00:00	17.99	Tsoil
2012-06-24	14:00:00	19.33	Tsoil
2012-06-24	15:00:00	19.46	Tsoil
2012-06-24	16:00:00	19.68	Tsoil
2012-06-24	17:00:00	19.21	Tsoil

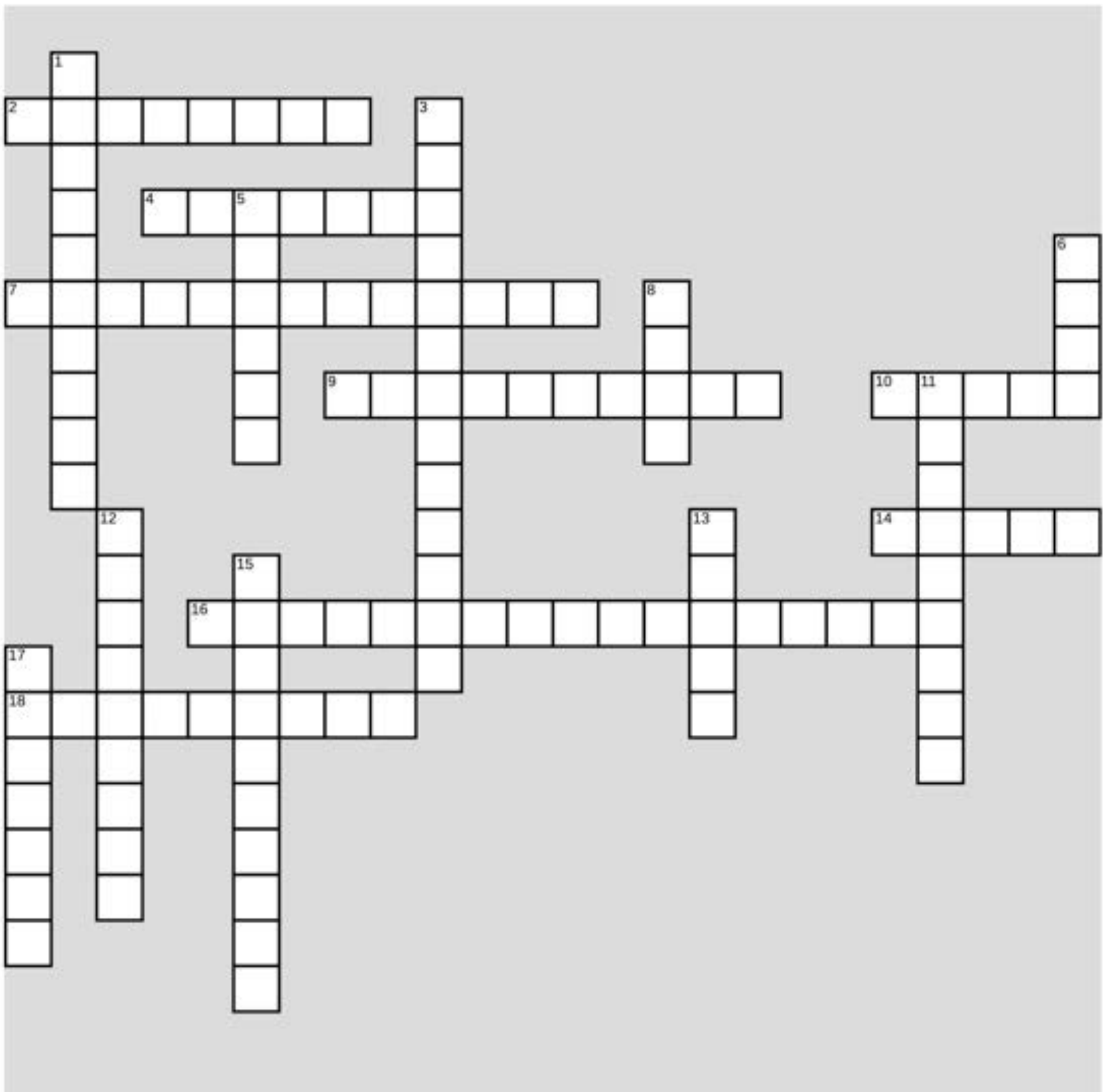
2012-06-24	18:00:00	18.03	Tsoil
2012-06-24	19:00:00	16.06	Tsoil
2012-06-24	20:00:00	13.97	Tsoil
2012-06-24	21:00:00	12.33	Tsoil
2012-06-24	22:00:00	11.29	Tsoil
2012-06-24	23:00:00	9.9	Tsoil
2012-06-25	0:00:00	8.01	Tsoil
2012-06-25	1:00:00	6.163	Tsoil
2012-06-25	2:00:00	4.364	Tsoil
2012-06-25	3:00:00	3.462	Tsoil
2012-06-25	4:00:00	2.816	Tsoil
2012-06-25	5:00:00	2.631	Tsoil
2012-06-25	6:00:00	2.661	Tsoil
2012-06-25	7:00:00	2.982	Tsoil
2012-06-25	8:00:00	3.457	Tsoil
2012-06-25	9:00:00	4.386	Tsoil
2012-06-25	10:00:00	5.191	Tsoil
2012-06-25	11:00:00	7.19	Tsoil
2012-06-25	12:00:00	10.42	Tsoil
2012-06-25	13:00:00	13.81	Tsoil
2012-06-25	14:00:00	16.72	Tsoil
2012-06-25	15:00:00	16.69	Tsoil
2012-06-25	16:00:00	17.9	Tsoil
2012-06-25	17:00:00	17.59	Tsoil
2012-06-25	18:00:00	15.36	Tsoil
2012-06-25	19:00:00	13.6	Tsoil
2012-06-25	20:00:00	11.91	Tsoil
2012-06-25	21:00:00	10.02	Tsoil
2012-06-25	22:00:00	7.91	Tsoil
2012-06-25	23:00:00	6.361	Tsoil
2012-06-26	0:00:00	4.805	Tsoil
2012-06-23	1:00:00	3.781	Tgrnd
2012-06-23	2:00:00	3.071	Tgrnd
2012-06-23	3:00:00	2.549	Tgrnd
2012-06-23	4:00:00	2.502	Tgrnd
2012-06-23	5:00:00	2.355	Tgrnd
2012-06-23	6:00:00	2.04	Tgrnd
2012-06-23	7:00:00	1.827	Tgrnd
2012-06-23	8:00:00	1.874	Tgrnd

2012-06-23	9:00:00	2.443	Tgrnd
2012-06-23	10:00:00	3.963	Tgrnd
2012-06-23	11:00:00	5.691	Tgrnd
2012-06-23	12:00:00	7.47	Tgrnd
2012-06-23	13:00:00	8.39	Tgrnd
2012-06-23	14:00:00	9.58	Tgrnd
2012-06-23	15:00:00	9.95	Tgrnd
2012-06-23	16:00:00	9.26	Tgrnd
2012-06-23	17:00:00	7.61	Tgrnd
2012-06-23	18:00:00	7.4	Tgrnd
2012-06-23	19:00:00	6.809	Tgrnd
2012-06-23	20:00:00	7.03	Tgrnd
2012-06-23	21:00:00	6.592	Tgrnd
2012-06-23	22:00:00	6.079	Tgrnd
2012-06-23	23:00:00	5.231	Tgrnd
2012-06-24	0:00:00	4.709	Tgrnd
2012-06-24	1:00:00	4.368	Tgrnd
2012-06-24	2:00:00	3.83	Tgrnd
2012-06-24	3:00:00	3.488	Tgrnd
2012-06-24	4:00:00	3.232	Tgrnd
2012-06-24	5:00:00	2.915	Tgrnd
2012-06-24	6:00:00	2.639	Tgrnd
2012-06-24	7:00:00	2.267	Tgrnd
2012-06-24	8:00:00	2.268	Tgrnd
2012-06-24	9:00:00	2.515	Tgrnd
2012-06-24	10:00:00	4.086	Tgrnd
2012-06-24	11:00:00	5.872	Tgrnd
2012-06-24	12:00:00	7.31	Tgrnd
2012-06-24	13:00:00	8.49	Tgrnd
2012-06-24	14:00:00	9.16	Tgrnd
2012-06-24	15:00:00	9.34	Tgrnd
2012-06-24	16:00:00	9.08	Tgrnd
2012-06-24	17:00:00	8.61	Tgrnd
2012-06-24	18:00:00	8.15	Tgrnd
2012-06-24	19:00:00	7.74	Tgrnd
2012-06-24	20:00:00	7.03	Tgrnd
2012-06-24	21:00:00	6.446	Tgrnd
2012-06-24	22:00:00	5.856	Tgrnd
2012-06-24	23:00:00	5.289	Tgrnd

2012-06-25	0:00:00	4.607	Tgrnd
2012-06-25	1:00:00	3.751	Tgrnd
2012-06-25	2:00:00	2.778	Tgrnd
2012-06-25	3:00:00	2.07	Tgrnd
2012-06-25	4:00:00	1.55	Tgrnd
2012-06-25	5:00:00	1.26	Tgrnd
2012-06-25	6:00:00	1.057	Tgrnd
2012-06-25	7:00:00	1.125	Tgrnd
2012-06-25	8:00:00	1.218	Tgrnd
2012-06-25	9:00:00	1.637	Tgrnd
2012-06-25	10:00:00	2.056	Tgrnd
2012-06-25	11:00:00	2.877	Tgrnd
2012-06-25	12:00:00	4.38	Tgrnd
2012-06-25	13:00:00	6.115	Tgrnd
2012-06-25	14:00:00	7.34	Tgrnd
2012-06-25	15:00:00	7.66	Tgrnd
2012-06-25	16:00:00	7.67	Tgrnd
2012-06-25	17:00:00	7.41	Tgrnd
2012-06-25	18:00:00	6.89	Tgrnd
2012-06-25	19:00:00	6.652	Tgrnd
2012-06-25	20:00:00	6.278	Tgrnd
2012-06-25	21:00:00	5.645	Tgrnd
2012-06-25	22:00:00	4.99	Tgrnd
2012-06-25	23:00:00	4.258	Tgrnd
2012-06-26	0:00:00	3.533	Tgrnd

Meteorological station record provided by Scott Williamson.

Mountain Hazards



SEA TO SKY GONDOLA
ADVENTURE BY NATURE

Across

2 May be exacerbated by thermal winds and hot, dry weather.

4 Avalanche type that typically occurs in the Spring.

7 Increases the risk of natural hazards but can be mitigated by sustainable land practices and ecosystem restoration.

9 The shaking of the earth's surface caused by a sudden release of energy in the earth's crust that creates seismic waves.

10 Molten rock beneath the earth's surface.

14 By slowing the rate of initial runoff, this risk is reduced by retaining land-cover with rich vegetative cover.

16 When lava and gas are released from a volcano.

18 A mass of solid rocks moving quickly downslope.

Down

1 Forest fires can be caused by _______________.

3 Landslide released after removal of supporting glacial ice.

5 Minor seismic shaking.

6 Molten rock that breaks through the earth's surface.

8 Type of avalanche triggered when the upper layers of snowpack begin to move over a weak layer.

11 Mass movement of snow.

12 Changes in ___________ impact mountain slope stability and the frequency and severity of natural hazards.

13 Type of avalanche triggered when the week layer of a snowpack is on the top.

15 Movement of a soil layer on a slope due to water and gravity.

17 Natural or human, causing avalanche.

Mountains

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F P B O A F D T J V
J I S U A B P K O A Q I E T H E
Y O U N D T K S F R E Z Y S M J A G P S
W J Z O K O D B S F K Z X V S O M Y L N N E
S A J Y W E E E T I T A W T O L R A Z U K W X G D G
V G X K L A Y Z K C F N T R E E L I N E V S Q F P T N Q
B Y H F I A J D T I I U S J K D R Y S K I X B I K C V B A O
Z A S F N Y E M Z E R A R D T Q G G Z M X T P O Q N C M H D P D
R O T E L C R C K E M R S N I A T N U O M Y K C O R E H T R A R
A Q D W Q J V R Y N W M T L H T M O U N T K E N Y A G J V Z Q I J E
E U S Z G G O U S I E D F Z Z O J K E S Q S F B D E O A J F P M U H Q A
C U S K D F O I T S U S A C U A C H T U O S Y W M O M I L A H Q M A B T
D T K B P T T A R I H Y X P J L W C Q M N T V A D F F Z D N C O O D A C T X
C N M N Q N Z E G U V U W E D B F O M G R Q U S J J X O L I Q U H V D O T J
M O V S O P B F K B M T K Y D Y V A L L E Y S L Y O Y Y R L N F Q E I D G M
T O E R C W L V T H I R D P O L E X K V Y O T Z I I R K I B T L K A Z R Z X Z N
I V A G A A H C I R B A H T N U O M M I K T O J S R F T Z E I Y D R H C Y S B L
J T C C X J L Z J Q E W C L N O P J D H S B H O W R T J V B W K O I U D U R S B
F A C Z O D N I S N T Z T M H Q G M L I P G X E U N P E V E M H N U K X E E Y E
B T A W K S X A I B G V E B W B M N B J Z H N B U H R D D Q T D C Y S T N W V F
K I Q G Z L W P M A H U O K Y R B T W P U Z T O O E E A U H U K E M U V G O C Y
U B B J Q X B T H I O Y B I P B W R X Z O V M V S M I D J K S Z Z I A D U T N Q
I A R B G C S B J Z L R X R O X Z C E R B N F T L B A N U J E T S F B V N R I W
W H S Y U U X U Q V H I Q E X C L H I Q Z R L C S N W S X R S Z S Z M V B E O M
R G F N Q H Q J S K M V K C Q Y G M Z Z K L S M Z M H J G J A V Y Q U V M T A E
F H S S A P X V T R F D T T J O B E V D U S R D H J N H F B M Q U S Q T A B
F P R I A N V I F A Q S O N U W L L P J V S X I Z R B K S I T U E K V A W J
Q A J G W B R E I F I W X N U T H X Q U U U M C K S Q Y V O K X T R V K D K
W T V R R E P Q M K N T I F O M K K A T A R F R B T G C D M G O D M C K
X E F G Q Q Z V K U A A L T T M T D X L G K E N X K A G I J B F N R H B
Q M L T F K H E I Q X B Y E O C L A K B Y O V J G W Z V C M Q Z V E
P C C O K S Z N G W L S I Q Y W Y Y S Q S D X R D B U E H M M Y T P
H D A U X S D T C F M B L P A P R V C E G F F Z D D R N G O R I
K R X S U U W P A C E C I A Y A C C L E U Q K L I S C G Z R
Y R R R X O J A R S A G T C V P R O N K Q H M G I E V L
S Q A W W P B Q K M W G Y S N S R E I C A L G T U Q
H K K V U E O F H B L B R X A R L A G T S M Y K
Q V S E A S X F Y C Y X R T X M T I E V
K B K K P Y J U V K F M U S H J
S F W F W R Q M D S
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BASE	MOUNT EVEREST	QUELCCAYA ICE CAP	THIRD POLE
BIODIVERSITY	MOUNT HABRICH	RWENZORI MOUNTAINS	TREELINE
CONTOUR	MOUNT KENYA	SNOWLINE	VALLEYS
GLACIERS	MOUNT KILIMANJARO	SOUTH CAUCASUS	WATERTOWERS
HABITAT	MOUNT TIRICH MIR	SUMMIT	


WORLD'S LARGEST MOUNTAIN RANGES
THE BROOKS RANGE
THE ROCKIES
THE APPALACHIANS
THE ANDES
THE PYENEES
THE ALPS
THE ATLAS
THE URALS
THE TIEN SHEN
THE KUEN LUN
THE ZARGOS
THE HINDU KUSH
THE HIMALAYAS
THE KOLYMA
THE GREAT DIVIDING RANGE
SEA TO SKY GONDOLA
ADVENTURE BY NATURE