Edexcel Geography A-Level

Glaciated Landscapes and Change

Detailed Notes

Glacial & Interglacial Periods

The earth has experienced many periods in which temperatures were **much colder** than they are currently. Aside from an ice age around 300 million years ago, the most recent major **ice age** occured in the **Pleistocene era**. The period spanned from around 2.5 million years ago to 11,700 years ago.

During this ice age, there were many **fluctuations** in global temperatures:

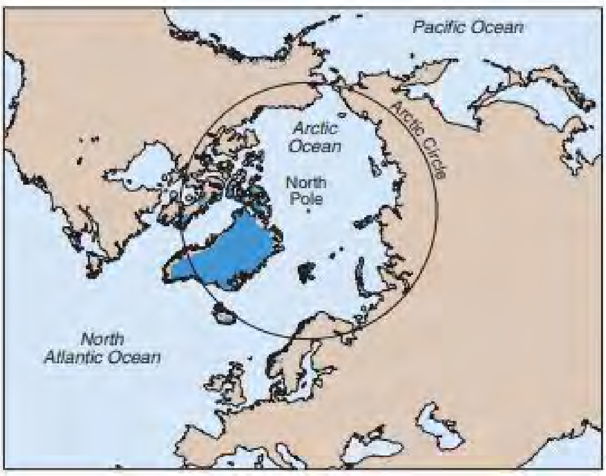
- **Glacial** period: **colder** temperatures, causing glacial **advances** and sea levels to fall.
- **Interglacial** period: **warmer** temperatures, causing glacial **retreats** and sea levels to rise.

The most recent period of glacial advance (**Last Glacial Maximum**) was around **21,000 years ago**, and the present distribution of cold environments is much more isolated in comparison to this period.

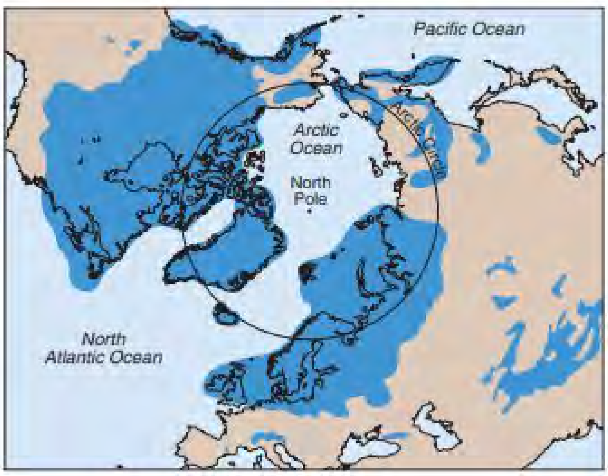
This interactive timeline outlines global temperature trends since the last **glacial maximum**. (https://www.iflscience.com/environment/this-temperature-timeline-of-earth-shows-exactly-how-nonsensical-climatechange-deniers-really-are/)

A much larger area of the northern hemisphere was completely covered by ice, including the majority of the UK.

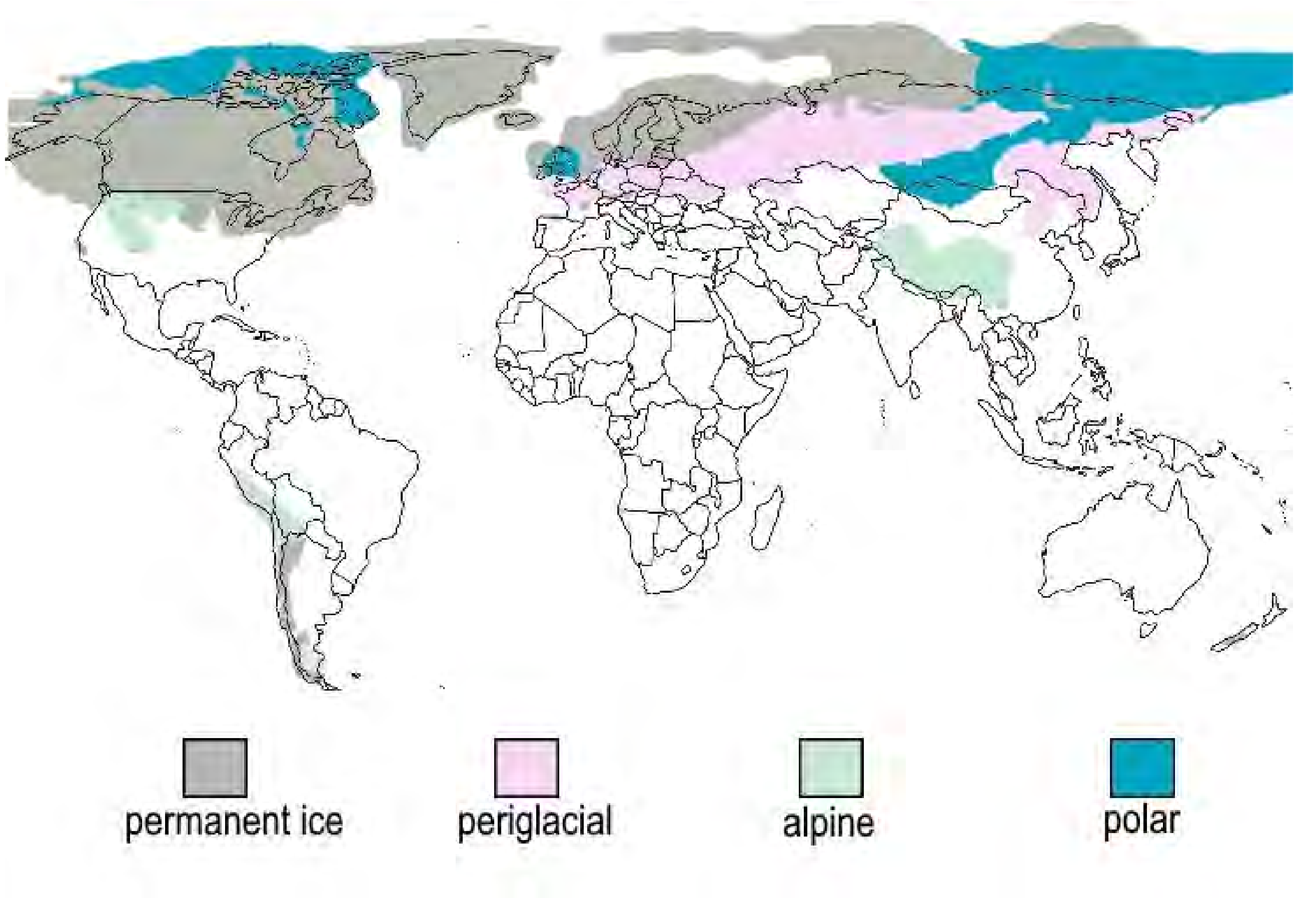
Present distribution of ice sheets.



Last glacial maximum distribution of ice sheets.



Source: http://www.open.edu/openlearn/ocw/pluginfile.php/614637/mod_resource/content/1/e500_11_sci_sk1_05t.pdf

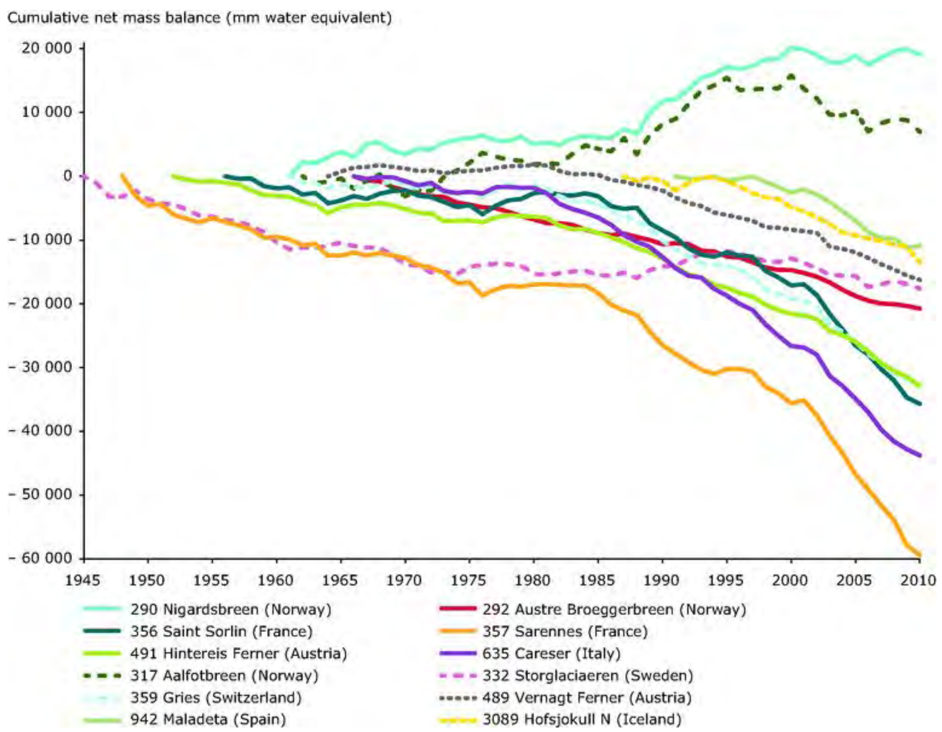


The world is currently in an **interglacial period**, meaning temperatures are higher and the majority of our glaciers are retreating.

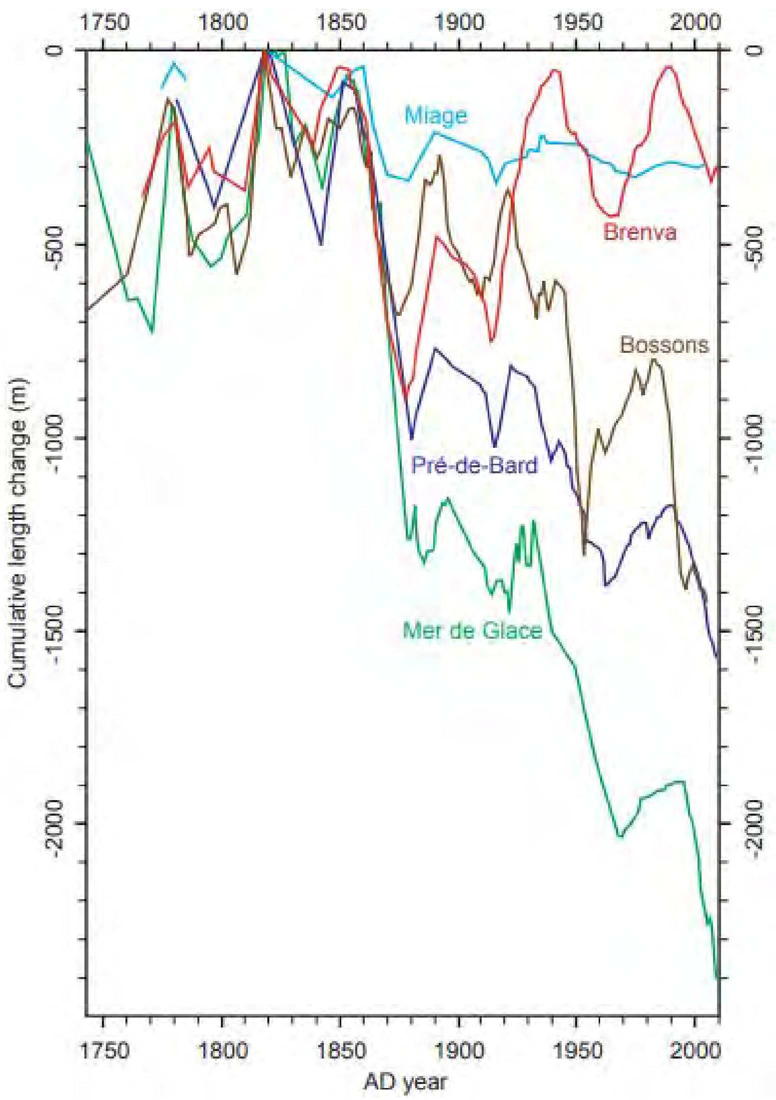
Historical Periods of Glacial Advance and Retreat

Glaciers have advanced and retreated in **correlation** with the world's glacial and interglacial periods. Currently, the **majority** of glaciers are thought to be **retreating** due to **increased temperatures**.

(Source:http://www.antarcticglaciers.org/modern-glaciers/introduction-glacier-mass-balance/)



Historically, global temperatures have been increasing since Last Glacial Maximum. However, there have been **smaller global coolings** in recent history that have affected the mass balance of glaciers. The '**Little Ice Age**' - between 1300 and 1870 has been the most significant global cooling in recent history. The graph shows the length change in 5 different glaciers in Mont Blanc in history. The period from 1818-1821 (during the Little Ice Age) shows that all glaciers were at their largest point at this time.
(Source: https://archive-ouverte.unige.ch/)



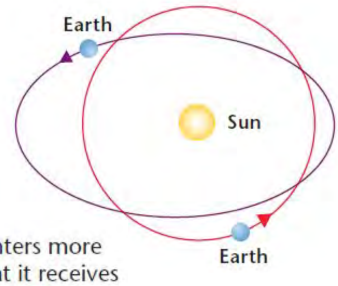
Glacial advance in the Alps was a very prevalent issue during the Little Ice Age. **Heavy snowfall and avalanches** were common and posed a risk to life.

"Between 1627 and 1633 Chamonix lost a third if its land through avalanches, snow, glaciers and flooding, and the remaining hectares were under constant threat."
(Source: Fagan, 2010. 'The Little Ice Age')

Long Term Causes of Glacial Periods

One piece of evidence to explain **long term climate change** is the Earth's **Milankovitch Cycles**. Milankovitch's theory of **astronomical climate forcing** states that when **global energy alters**, the consequent **variations in the earth's orbit** force **global changes**. These changes involve:

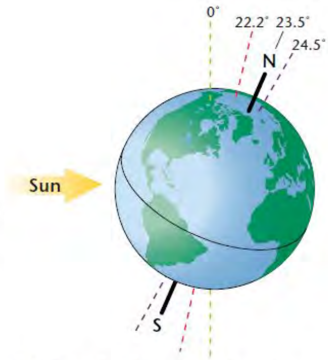
a) **Stretch/Eccentricity**: The earth's orbit changes from **circular to eclipse** every 96000 years, which changes the distance between the earth and the sun. Therefore, the Earth will be closer to/ further away from the sun at certain points during different orbital shapes, affecting the **climate** (e.g. if the Earth is closer to the sun, the Earth will receive more solar radiation and therefore be warmer).

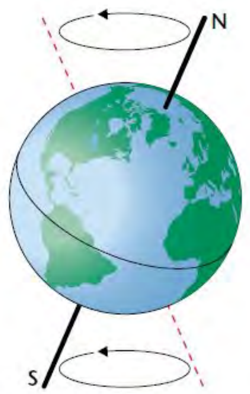


Eccentricity Earth encounters more variation in the energy that it receives from the sun when Earth's orbit is elongated than it does when Earth's orbit is more circular.

b) **Tilt**: The Earth's **tilt** changes between 21.8 degrees and 24.4 degrees every 41000 years. If the tilt is greater, tropics receive more energy and thus become larger.

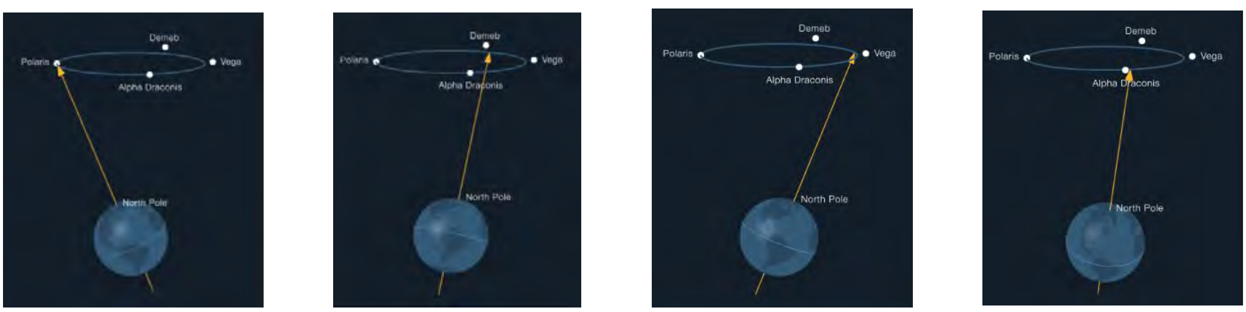
Tilt The tilt of Earth's axis varies between 22.2° and 24.5°. The greater the tilt angle is, the more solar energy the poles receive.





c) **Wobble/Axial Precession**: Over time, the **direction in which the axis tilts** changes (in the same way that a spinning top moves). In 22000 years, the axial tilt spins one whole time around. This does not affect how much sun the Earth receives overall, only where the solar radiation is distributed (i.e. which hemisphere).

Precession A gradual change, or "wobble," in the orientation of Earth's axis affects the relationship between Earth's tilt and eccentricity.



(Source: grahamhancock.com; https://i.stack.imgur.com/D93Lk.gif)

Short Term Causes of Glacial Periods

Short Term causes of Climate Change involve:

- **Variations in Solar Output**: **Energy output of the sun** is not constant. **Sunspots** occur by magnetic storms, forming dark areas on the sun which increase solar output. The number of sunspots increase/decrease in an 11 year cycle. Sunspots aren't regular and can vary; during the Medieval warming period, there were high numbers of sunspots but during the Maunder Minimum, there were few sunspots.
- **Volcanic Eruptions**: For instance, Mount Tambora in Indonesia erupted in 1815 and lowered global temperature by 0.5 degrees Celsius. Initially, scientists thought that the ash produced would block some solar radiation, hence cooling the Earth. However, it is actually sulfur dioxide, a potent greenhouse gas, which is released during an eruption and reflects radiation for several years.

Holocene Epoch

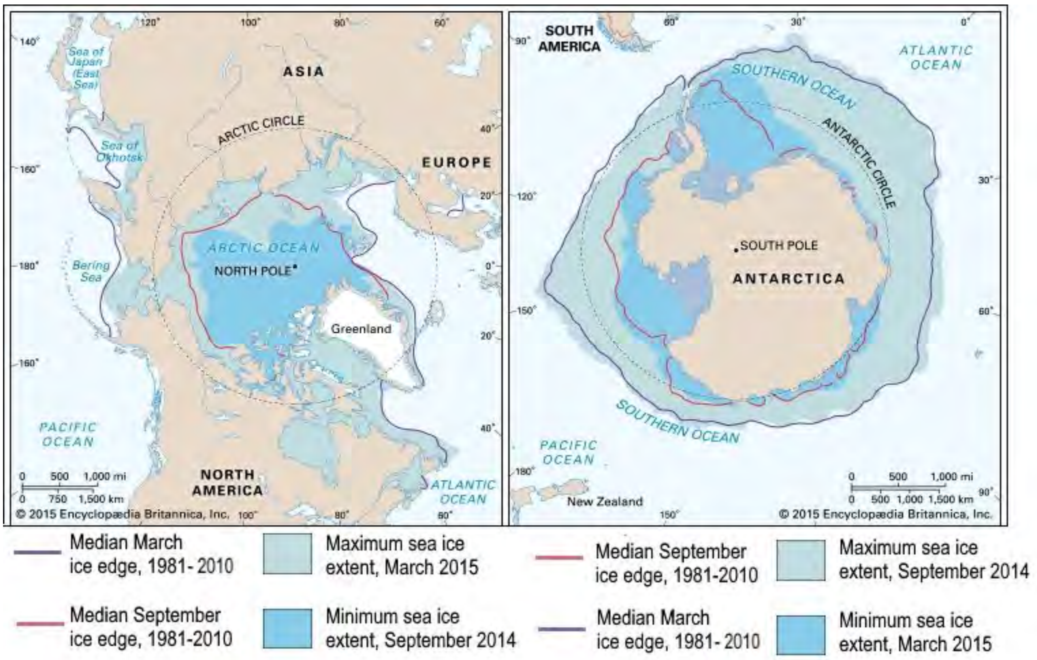
We are currently in a **Holocene epoch**, which is an era of limited ice cover lasting over 10,000 years. The last glacial and ice covers exist in **polar, alpine and periglacial** regions.

Polar Environments

Current Distribution

Polar environments are located at the **poles** (high **latitudes**) of the Earth within the **Arctic Circle (66°N)** and the **Antarctic Circle (66°S)**. These environments can also be described as being within the **10°C isotherm**, which means in the hottest month, the average temperature stays below 10°C. However, the first definition is the most common.

In polar regions, the maximum extent of ice sheets occurs within the **coldest, winter months**. The Arctic Winter (northern hemisphere) occurs from December - March, and the Antarctic Winter (southern hemisphere) occurs from March - October.



Source: National Snow and Ice Data Center (NSIDC)

Characteristics - Climate

Due to the **consistently below freezing temperatures** with **little rainfall**, polar environments have **slow nutrient cycles**, meaning the soil is usually **deprived of nutrients**. The climate causes little wildlife to thrive, especially decomposers.Winter temperatures average **-40°C** in some polar regions and precipitation almost never exceeds **100mm per year**.

Characteristics - Vegetation and Soils

The cold, harsh climate with little rainfall also means only **highly adapted vegetation can grow**, such as mosses and lichen.These plants rarely decompose as there are a lack of decomposers. When plants eventually decompose, the cold temperatures cause this process to be extremely **slow**.

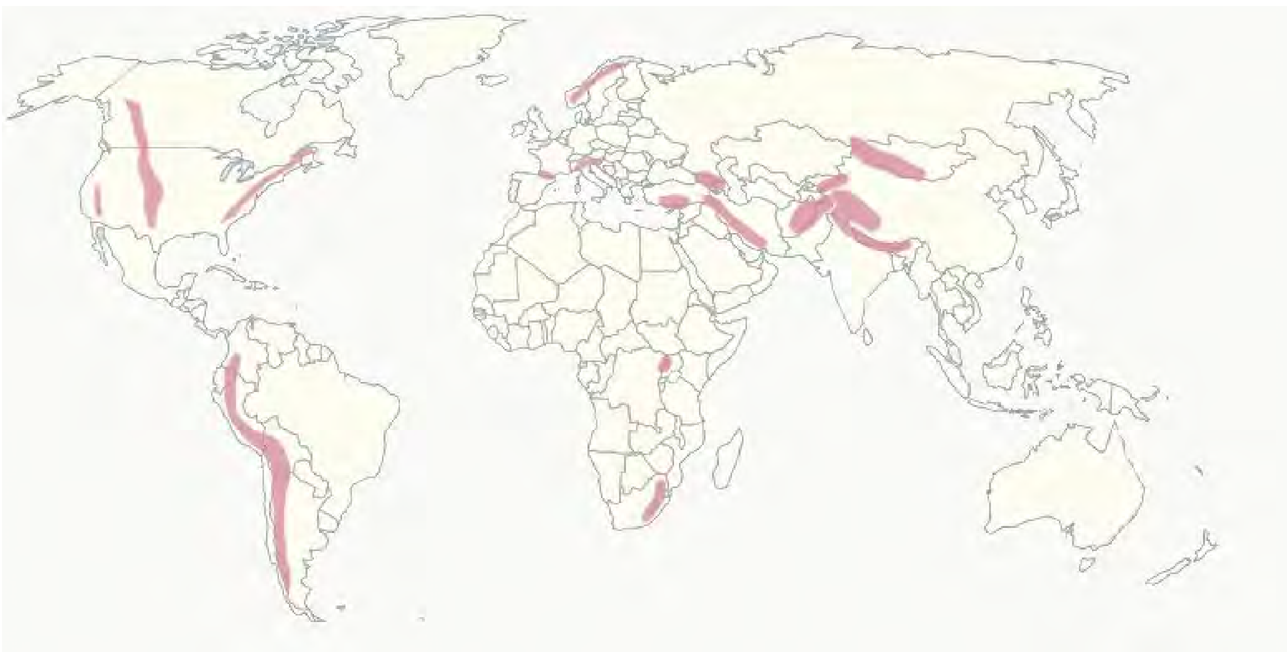
This **lack of nutrient rich vegetation** from the harsh climate causes the **soil to be low in nutrients**. The nutrient deprived, frozen soil further limits nutrient rich **plant growth**. This creates a cycle where poor vegetation causes poor soil, and poor soil causes poor vegetation.

The Antarctic especially demonstrates the harsh living conditions of polar regions. Aside from marine animals such as seals and penguins, the largest land animal in Antarctica is a **wingless midge** less than 1.5cm long. The environment makes it almost impossible for anything to survive other than highly adapted species that can withstand the conditions.

Alpine Environments

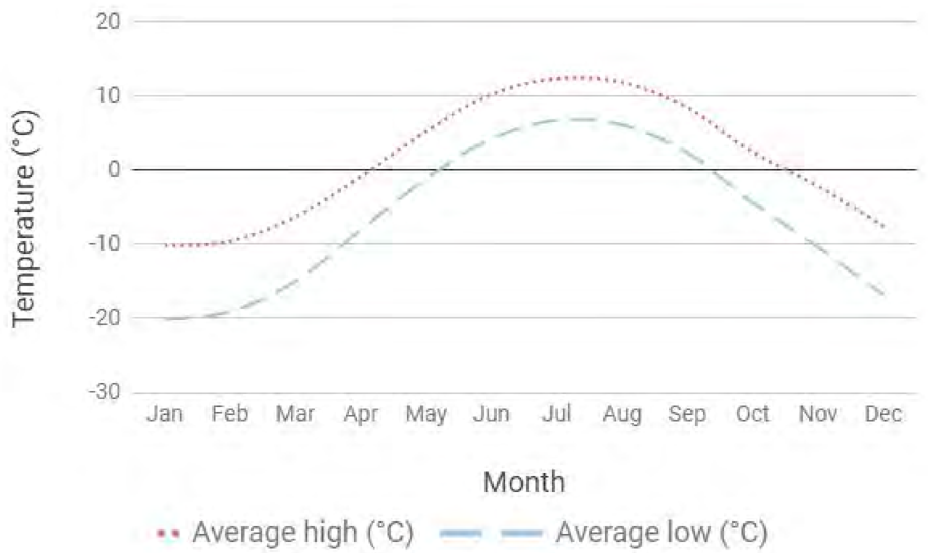
Current Distribution

Alpine environments are areas of low temperatures in high **altitude**, **mountainous** regions, found at any latitudes. These environments are found **above the tree line**.



Characteristics - Climate

Temperatures in alpine areas **fluctuate annually**, and alpine summers are frequently above 0°C. An example of an alpine environment is Mount Washington, The White Mountains. As seen in the graph below, there is a large amount of fluctuation between seasonal temperatures.



Characteristics - Vegetation and Soils

In the winter, alpine environments receive **heavy snowfall**, more than in polar environments in most cases. In summer, milder temperatures can lead to sometimes **heavy rainfall** and a lot of **meltwater** from the melting of snow and ice. The climate allows adapted **animals** to move to higher altitudes. The milder temperatures also stimulate plant growth, thawing, and decomposition.

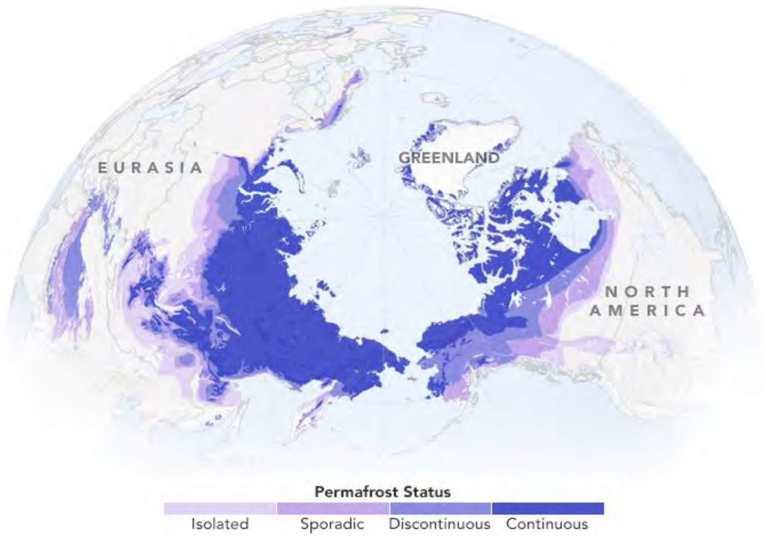
Vegetation that is adapted to the alpine climate **thrives** in milder alpine summers, and usually dies back in winter. The climate (and consequent wildlife) allows for a **quicker nutrient cycle**, as the wildlife use vegetation for **food** and the warmer climate encourages **decomposing**. Alpine vegetation is **decomposed more quickly** than in a polar climate, and **grows quicker** too due to soil fertility and climate.

Higher temperatures allow soils (usually at lower altitudes) to **thaw**, increasing the **area that vegetation can grow in**. The nutrient rich vegetation allows a more **fertile soil** to develop when it decomposes, as the nutrients are **transferred** into the soil. This fertile soil allows more **nutrient rich plants to grow**. Soils usually **freeze** in winter, meaning less plants can grow in the colder conditions.

Periglacial Landscapes

Current Distribution

Periglacial environments are areas found on the **edge** of colder environments like polar and alpine environments.These areas are consistently cold enough that the ground is permanently frozen (**permafrost**). Permafrost can be **continuous**, **discontinuous**, **sporadic** or **isolated**, which indicates the extent of permafrost cover. Although permafrost is also found on the fringes of glacial and alpine environments, the majority of permafrost is located at **high latitudes** within the **northern hemisphere**.



Source: https://earthobservatory.nasa.gov/images/87794/picturing-arctic-permafrost

Characteristics - Climate, Vegetation and Soils

Similar to polar environments, **precipitation is low** (but still occurs in summer months). Temperatures are **consistently below freezing**. The latitude of some permafrost regions also assists in the consistently cold temperatures, as **winters** in higher latitudes **last longer** with less daylight hours, making them colder.

Vegetation is **more prevalent** than in **polar** regions, but only highly adapted plants can survive in the cold temperatures with little rainfall. The temperatures and poor soil leads to a **slow nutrient cycle**.The lack of nutrient rich plants contributes to the **soil infertility**. The permafrost makes it especially hard for plants to grow as plants cannot infiltrate the soil.

The cold climate causes the lower ground to be **frozen all year around**. However, slightly warmer summer temperatures causes the **thawing** of upper soil called the **active layer**. Soil is usually extremely **waterlogged** in summer due to thawing, which means plants become deoxygenated within the soil and cannot survive, and any nutrients are often **leached** out.

Periglacial Processes:

- **Nivation:** Common in periglacial environments due to the **fluctuating** temperatures. Nivation is a collective term for processes involving **snow and ice** that cause erosion (the prefix *niv-* is Latin for **snow**). **Nivation hollows** are created by nivation processes, which is where snow gathers in a small depression and eventually this erodes into a hollow full of snow. Nivation hollows are the beginnings of **corries**.

- **Active Layer:** The top layer of permafrost that **thaws in the summer**.

- **Frost Heave:** Water underneath rocks or ground freezes, **expands**, and thus forces the mass **upwards**.

- **Solifluction:** Mass movement of soil that becomes **waterlogged** when water is trapped between the active layer and the frozen permafrost. Waterlogged soil **flows** easily when gravity acts upon it (usually on a gradient).

Glacial Systems and Processes

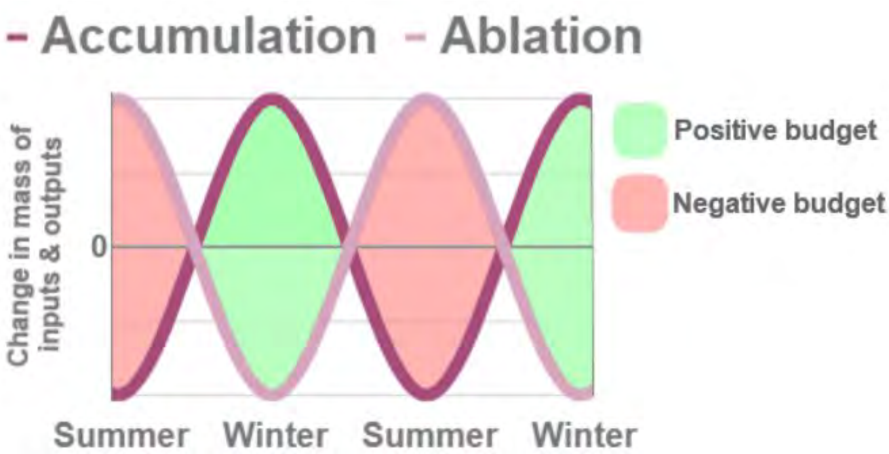
Accumulation: The **addition of mass** (precipitation, usually snow) to the glacier. Mainly occurs at higher altitudes at the source of the glacier.

Ablation: The **loss of mass** from the glacier. This includes meltwater, avalanches, sublimation, evaporation, and other processes.

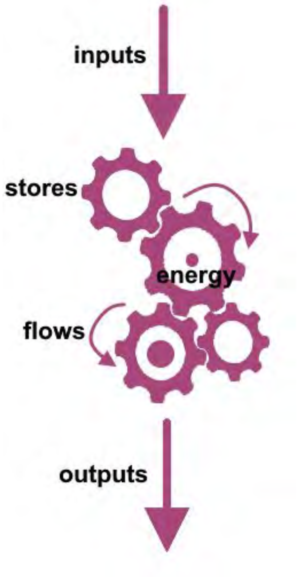
Glacial budget: The **mass balance** of a glacier, i.e the **difference between accumulation and ablation**.

- A **positive** glacial budget shows **accumulation exceeds ablation**, so the glacier is **advancing**.
- A **negative** glacial budget shows **ablation exceeds accumulation**, to the glacier is **retreating**.

Glacial budgets fluctuate yearly, with more ablation in the summer months and more accumulation in winter months.



System features



Glaciers are **natural systems**, meaning there are specific interactions within their development and sustaining that allow glaciers to work.

In the concept of a natural system, something **enters** the system which allows for **processes** to occur, eventually leading to something **leaving** the system.

In an **open system**, there are inputs from **outside** the system's set area.

In a **closed system**, all of the inputs and processes occur **within** the system's set area (think of it as if you were to put a box around the system - it would still be able to occur as all of the necessary aspects are within the system already).
The aspects of a system apply to the natural system of a glacier:

Inputs: **Additions** to the glacier (**accumulation**). Precipitation such as snow or hail are inputs to the glacier, as well as avalanches from other areas entering the system. **Debris** that has been eroded can also fall into a glacier's system and consequently can be transported and deposited elsewhere.

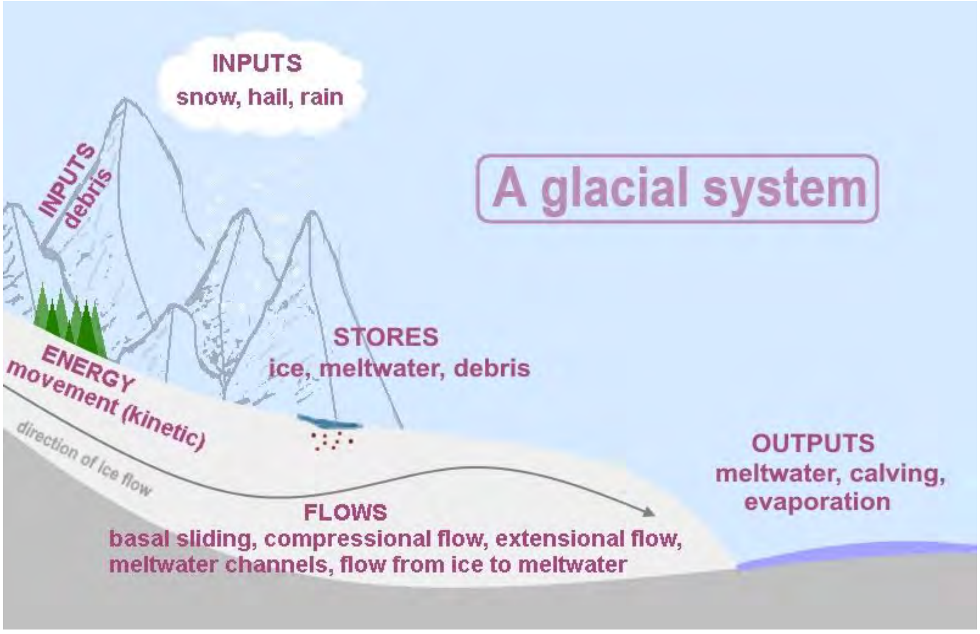
Outputs: Things that **leave** the glacier system, usually in the form of meltwater. All **ablation** processes are outputs. **Calving** is also a common output, in which large pieces of glacier break off at the **snout** (the end).

Energy: Glaciers all have varying amounts of energy dependent on their **mass**, their **environment**, their **composition** and other factors. For example, a glacier with more meltwater underneath it would move faster, giving it more energy. Glacial energy is usually in the form of **kinetic** energy as the glacier moves. This energy allows erosion to occur. **Gravity** allows the glacier to have energy, as it forces the glacier downhill.

Stores: Also known as components. Stores are the **mass** that glaciers **hold**. The majority of stores within the glacier are ice, but sediment from erosion and meltwater lakes/channels also contribute to stores. There are 3 types of glacial stores: **subglacial** (underneath the glacier), **englacial** (within the glacier), and **supraglacial** (on top of the glacier).

Flows: Flows occur in glaciers through the **transfer** of **mass** or **energy**. There are flows in mass and energy from ice on the glacier to meltwater leaving the glacier. The glacier also moves through flows, such as **compressional flow**.

Dynamic Equilibrium: Equilibrium refers to a **state of balance**. This balance is **dynamic** when the processes causing the balance are **continual** (always occuring). For example, even if the glacier is constantly gaining inputs and losing outputs, if the amount of these are the same, the mass of the glacier does not change **annually** and the glacier is at dynamic equilibrium. The area where **mass gain = mass loss** on a glacier is called the **equilibrium line**.



Feedback Loops: A feedback loop is a type of **chain reaction**, where one process leads to another process, leading to another process, and so on. There are two types of feedback loops: positive and negative.

In positive feedback, a process occurs, which causes another process to occur, which starts a chain reaction that **heightens** the first process.

Temperatures rise → Permafrost melts → CO2 released → Greenhouse effect → Temperatures rise

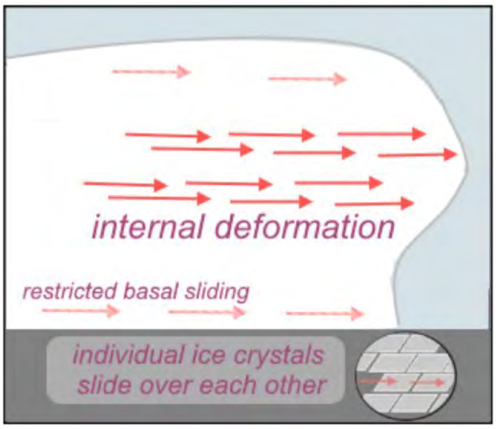
In negative feedback, the process that occurs is **counteracted** by an opposing process, causing the effects to cancel each other out and **nothing to change**.

Temperatures rise → Permafrost melts → More plants to take in CO2 → Greenhouse effect lessens → Temperatures fall

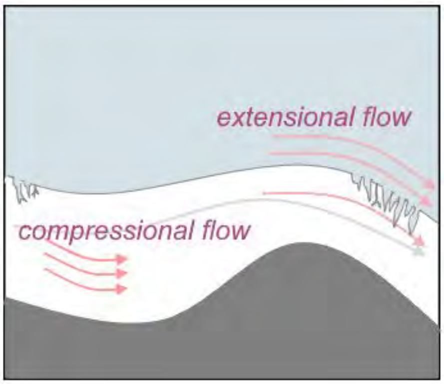
Ice Movement

Glaciers move under their own weight, which - with gravity - forces the ice to flow. There are different ways in which a glacier moves.

- **Internal Deformation:** The deformation of **layers of ice** or **individual ice crystals** caused by the pressure from the weight of the ice. This causes **some layers** to move **faster** than others, so different parts of the glacier can be further advanced.



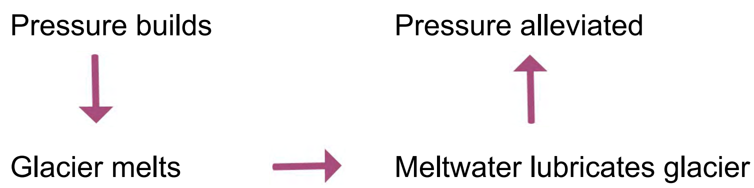
- **Compressional Flow:** When ice hits a shallower gradient, friction causes the ice to slow down, **build up** and compress. This causes ice to get thicker.
- **Extensional Flow:** When ice meets a steep downhill gradient (usually when going over a hill), gravity forces the ice to **increase in velocity**. Friction causes the ice to thin out and extend, causing deep cracks called **crevasses**.



- **Rotational Slip:** Compressed ice becomes **trapped** in a hollow, but **gravity** causes it to continue to move **downwards**. Meltwater assists in moving the glacier in a rotational movement, causing it to continually **erode** the hollow.
- **Basal Sliding:** Glacier sliding over the bedrock. This is due to **meltwater** providing **lubrication** for the glacier to move.

The velocity and power of these movements is heightened by the composition of the glacier and surrounding landscape. More powerful movements cause more erosion, creating characteristic glaciated landscapes:

- **Temperature** of glacial environment - warmer temperatures would lead to more **meltwater**, causing more basal sliding to occur. **Erosional processes** would thus be heightened. So colder glaciers move more slowly.
- **Mass** of glacier - heavier glaciers move more under the **force of gravity**, and more **pressure** is created due to the weight. In itself, this pressure causes erosional processes, but also encourages **meltwater** which assists in erosion.
- **Relief** - a steeper relief heightens the **effects of gravity** on a glacier. A warm based glacier would have a higher **velocity** as meltwater assists lubrication. A cold based glacier would struggle to move, building pressure and again causing more erosional processes. This could be classed as a **negative feedback loop**.
- The **size of obstacles** that a glacier must travel around affects the motion of the glacier. **Creep** occurs when a glacier travels around a large obstacle (greater than 1m) by **plastically deformation**. Alternatively, if the obstacle is smaller than 1m, the glacier will melt under increased pressure and so the glacier accelerates due to **basal slip**. The glacier will refreeze on the leeside of the obstacle, which is known as **regelation**.



Glacial Environments

A glacial environment is an area where temperatures are consistently cold enough to sustain **glaciers** or **ice sheets**. Glacial environments are in both **polar** and **alpine areas** (and sometimes periglacial however temperatures are usually not cold enough). The climate, soil, and vegetation is dependent on the region in which the glacier develops, but the temperatures must be **below freezing** for long enough in the year that the glacier does not melt entirely.

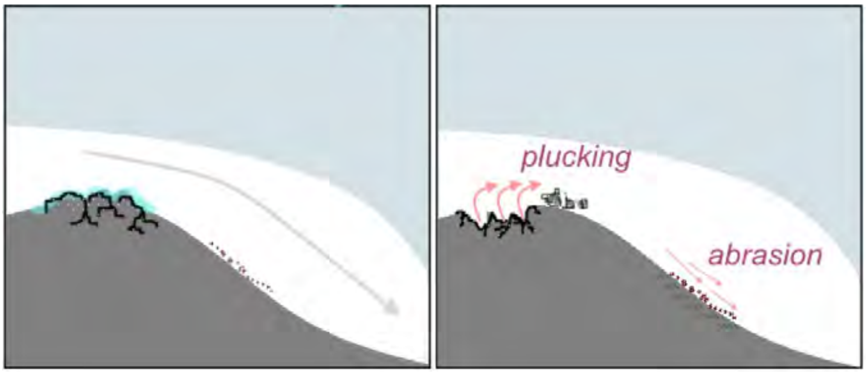
Development of Glaciated Landscapes

Glaciated landscapes are shaped by processes that create landforms. The three main type of processes that create landforms are **geomorphological** (topography/rocks), **periglacial**, and **fluvioglacial** (water). These processes create glaciated, periglacial, and fluvioglacial landscapes.

Erosion

- **Plucking:** Rocks attached to bedrock or sides become **frozen** to the glacier. When the glacier moves, the rocks are pulled (**plucked**) from the landscape, leaving a jagged surface.
- **Abrasion:** A **sandpapering** effect caused by small rocks embedded within the glacier rubbing on bedrock. Usually leaves a smooth surface with scratches called **striations**.

- **Crushing:** For weak bedrock, the weight of the glacier causes **fracturing** in the bedrock. Glacial crushing tends to produce large, angular blocks of rock.
- **Basal ice melting**: The weight of the temperate glacier will cause basal ice melting. The large volume of water produced causes **fluvial erosion** - hydraulic action, attrition, corrosion - which will erode the base of the glacier over time.



Development of Landforms

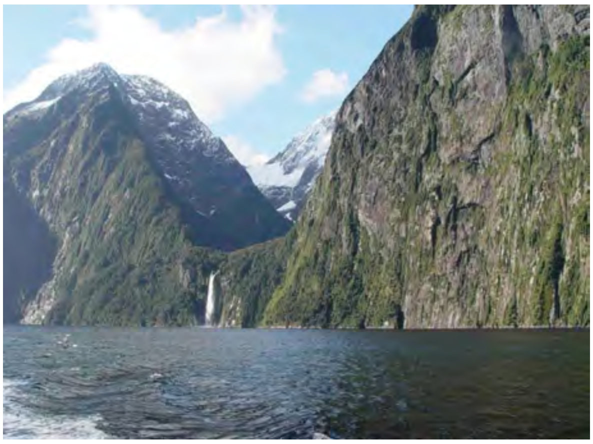
Different landforms are created in certain cold environments. The table below shows which landforms arise from different environments.

LANDFORM	PROCESS			
	Geomorphological		**Fluvioglacial**	**Periglacial**
	Erosion	Corries	Meltwater channels	Patterned ground
	Erosion	Arêtes	Kames	Ice wedges
	Erosion	Glacial troughs	Eskers	Pingos
	Erosion	Hanging valleys	Outwash plains	Blockfields
	Erosion	Truncated spurs		Solifluction lobes
	Erosion	Roches moutonnées		Terracettes
	Deposition	Drumlins		Thermokarst
	Deposition	Erratics		
	Deposition	Moraines		
	Deposition	Till plains		

Geomorphological Landforms and Glaciated Landscapes

Erosional

Corries	Arêtes
	
Red Tarn, The Lake District (Source:http://www.living-art.org.uk/Members/Daz_Hill/Helvellyn,_Swirral_Edge_&_Red_Tarn/)	**Striding Edge (Helvellyn), The Lake District** (Source:https://where2walk.co.uk/lake_district/classic_circuits/helvellyn-by-the-edges/#jp-carousel-31175)
Corries form when **snow** continues to **build up** in a depression or nivation hollow, eventually compacting to form a **glacier**. The glacier becomes trapped within the hollow, meaning the only way it can move is through **rotational slip**. The back wall is eroded through plucking and frost shattering, and the hollow is deepened through rotational abrasion. Water can fill corries to make **tarns** (lakes).	A **knife-edged ridge** formed between two corries (when the two steep back walls meet). If three meet, they create a point called a **pyramidal peak**.
As corries are eroded rocks, they last a **long time** and are minimally affected by erosion. This is why corries have lasted thousands of years.	Similar to corries, arêtes last a **long time**.

Glacial Troughs	Hanging Valleys
	
Glen Geusachan, The Cairngorms (Source:https://www.flickr.com/photos/28183399@N03/3720916604)	**Fiordland National Park, New Zealand** (Source:http://www.lobster.co.nz/the-source/gallery/image-22/)
A **u-shaped valley** formed by a glacier **bulldozing** and eroding through a river (v-shaped) valley. The glacier has enough force to erode away a river's **interlocking spurs**. This leaves smooth but steep **truncated spurs** on the valley sides and a wide, flat valley floor. The river that originally flowed through the valley will continue to flow, giving it the name **misfit stream** due to its small size in comparison to the surroundings.	A smaller **u-shaped valley** caused by a **tributary glacier**. The smaller glacier does not have enough **energy** to erode to the valley floor, leaving a hanging valley. **Waterfalls** often form here.
U shaped valleys last for a **long amount of time**.	Hanging valleys last for a **long time** as they are an erosional feature, however **waterfalls can erode away a hanging valley** over time.

Roches moutonnées

Myot Hill, Falkirk, Scotland (Source:https://www.geograph.org.uk/photo/164736)

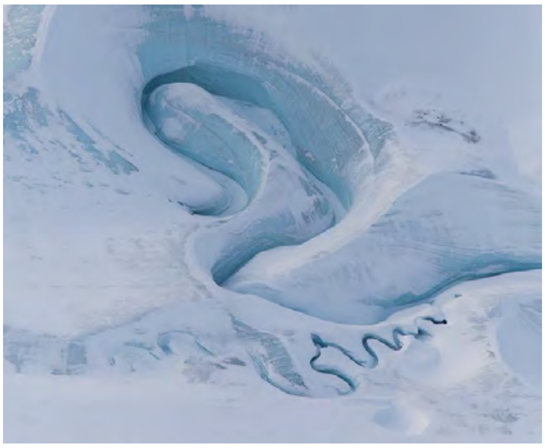
A mound of rock shaped by a glacier flowing over it and eroding it. The glacier would be moving right (**stoss side**) to left (**lee side**) in the picture. ● The glacier hits an **obstacle** that is too large and hard to pluck, it must move over it. ● The glacier hitting the obstacle increases **friction and pressure**, therefore increasing melting as the lower ice can reach the **pressure melting point**. ● This meltwater allows the glacier to slide over the rock, and smaller rocks will **abrade** the stoss side ● When the glacier reaches the top of the obstacle, **friction and pressure drop** ● Meltwater **refreezes** ● Frozen rocks are **plucked** from the lee side.
These landforms last a **long time** as they are made of rock.

Depositional

Till Plains	Erratics
	
Saskatchewan Glacier, Alberta (Source:http://www.albertawow.com/hikes/Saskatchewan_Glacier/Saskatchewan_Glacier.htm)	**Norber Erratics, Yorkshire Dales** (Source:https://www.tripadvisor.co.uk/Attraction_Review-g503988-d4932501-Reviews-Norber_Erratics)
Till is **unsorted** glacial material formed through **erosion** and **weathering**. Till plains form when an ice sheet detaches from the main glacier and melts, causing all of the till **on top of** and **within** the glacier to **deposit** on the valley floor.	A large **boulder** that is of a **different rock type** to surrounding rock. This boulder would have been **broken off** by weathering and erosion, then **transported** by a glacier and **deposited** when it has been moved to a different location. The glacier deposits when it **loses energy**.
Till plains last a **medium-long** amount of time. They can be disrupted through meltwater, periglacial processes and weathering. However, due to their vast nature, till plains will usually be noticeable.	Depending on the size of the erratic, these can last a **long time** as they are too big to be displaced by weathering alone.

Moraines	Drumlins
	
Wrangell-St. Elias, Alaska (Source:https://www.nps.gov/articles/lateralmedialmoraines.htm)	**Eureka Drumlin Field, Montana** (Source:http://jupiter.plymouth.edu/~sci_ed/Turski/Courses/Earth_Science/Images/4.drumlin.jpg)
Deposits of eroded material that are transported with the glacier. There are different types of moraine: **Lateral:** material deposited on the **sides** of a glacier, leaving a ridge when the ice melts. **Medial:** formed from two lateral moraines meeting in the **middle** of a glacier and depositing material. **Ground:** carried **under the glacier** and abraded between the glacier and valley floor. Ground moraine is the only **sorted** moraine as all of it is abraded underneath the glacier, whereas all other types of moraine is unsorted. **Recessional:** Forms at the end of a glacier when a **retreating** glacier stays stationary for a sufficient time. Usually shows smaller, seasonal retreats. **Terminal:** Material deposited at the snout of a glacier on the valley floor.	When a glacier hits an **obstacle** that cannot be eroded, deposition from underneath the glacier **builds up** behind the obstacle. The glacier moves over the large mound and then drags excess deposition over the other side. This causes a **tear drop** shape with a long, **tapered** edge. The blunt end is the stoss side, whereas the tapered end is the lee side. Drumlins can be around 1500m long and 100m high. Drumlins are usually found in groups called 'swarms'.
Moraine can be classed as lasting a **medium amount of time**. Although moraine is still present thousands of years after glaciers have retreated, it can be displaced through meltwater during retreat or weathering.	Drumlins last a **long time**, but can sometimes be disguised as they are depositional, meaning greenery can grow in the sediment.

Fluvioglacial Landforms and Fluvioglacial Landscapes

Meltwater Channels	Kames
	
Ellesmere Island, Canada (Source:https://earthobservatory.nasa.gov/images/90004/meltwater-channels-on-ellesmere-island)	**Kirriemuir,Scotland** (Source:https://upload.wikimedia.org/wikipedia/commons/6/62/Kame_below_Wester_Pearsie_-_geograph.org.uk_-_605724.jpg)
Streams of meltwater (melted glacier) formed by higher temperatures. Channels can flow within, in front of, and around the glacier. Due to the pressure from the glacier, they are **highly erosive**. If meltwater channels lose energy, they **deposit** sorted material in small islands, creating **braided channels**.	Meltwater transports and deposits eroded material on a retreating glacier. Material collects **within a depression** on top of the glacier. When the glacier melts completely, the material is left on the valley floor. This leaves a mound of (usually fine) material. Kames are **sorted**, meaning the heaviest load will be deposited first and finer sediments will be on top.
Meltwater channels last a **short amount of time** because they will only last during periods of higher temperatures that will allow for liquid water. However, the eroded landscapes can last a long time.	Kames last a **medium amount of time** as they can be eroded and weathered due to their composition.

Eskers	Outwash Plains
	
The Kippet Hills Esker, Aberdeenshire (Source:http://earthwise.bgs.ac.uk/images/3/30/P219697.jpg)	**Rendu Glacier, Alaska** (Source:http://www.geo.mtu.edu/KeweenawGeoheritage/Glaciers/Outwash.html)
A long, winding **ridge** of glacial deposition. An esker is a mould of glacial **meltwater channels**. Material is deposited when the subglacial meltwater channel loses energy. Due to the high **hydrostatic pressure**, the mound builds up and retains its shape.	When a glacier recedes, a large amount of meltwater is released due to the higher temperatures melting the ice. The meltwater loses energy as it is under less pressure, so it **deposits** the material in front of the glacier. Material is deposited into **sorted** layers - gravel and rocks are deposited first and the finer sediment is deposited on top. The deposits can create **alluvial fans**, which is where the meltwater channels separate into smaller, fanned out sections in order to take the fastest route through the deposited material.
Eskers last a **medium-long amount of time**. Due to their size, an esker is difficult to erode and weather, however it is not as strong as erosional, rock-composed features.	These plains last a **short amount of time** as they are only sediment, meaning they are easily eroded and weathered. In alpine regions especially, outwash plains are only seasonal.

Periglacial Landforms and Periglacial Landscapes

Patterned Ground	Ice Wedges
	
'Stone Rings', Svalbard (Source:https://commons.wikimedia.org/wiki/File:Permafrost_stone-rings_hg.jpg)	**Banks Island, Canada** (Source:https://www.researchgate.net/publication/286392120_Ice-wedge_growth_and_casting_in_a_Late_Pleistocene)
Patterned ground is formed through the **frost heave** of stones in and underneath the active layer. • **Ice lenses** exist within permafrost, and they grow through repeated freezing and thawing. **Capillary action** draws more water to the ice lens, causing it to grow more. • When the ice lens expands, stones around the ice lens are **shunted** upwards. • **Larger stones roll down** due to their weight. • **Fine sediment fills the space** to stop larger rocks. • **Polygons** appear on **flat** surfaces, or **stripes** on **steeper inclines** where the rocks roll downhill.	Water infiltrates small cracks in the permafrost and expands on freezing (**frost action**). Water then fills the expanded ground. The process repeats and leaves a large ice wedge.
This landform lasts a **medium amount of time** as they can be disrupted when periglacial landscapes become warmer, disrupting the ice lenses.	The ice wedge is likely to last a **medium amount of time** as temperatures must consistently stay cool enough for the ice wedge to grow.

Pingos

Pingo National Landmark, Canada
(Source:http://www-personal.umich.edu/~kpetaine/visuals/album/NLand/Pingo/)

Ground is forced upwards through **frost heave** of an **ice lens**, leaving a mound. The mound can be an **open** or **closed** pingo.
Open pingo formation (**discontinuous permafrost**)

- Water moves through **unfrozen ground** between areas of permafrost
- Due to capillary action, the **water groups together**
- Water freezes and creates an ice lens
- The **ice lens continues to grow** and pushes the unfrozen ground upwards

Closed pingo formation (**continuous permafrost**)

- Under a lake, **permafrost is insulated** and melts.
- The lake will eventually dry up or freeze, leaving the **unfrozen ground**.
- An **ice lens will develop** through capillary action when temperatures drop and the water groups together
- When temperatures drop, **permafrost advances** and **frost heaves** the unfrozen ground upwards, creating a mound.

Pingos last a **medium amount of time**, as cracks in the ground let in water which melts the ice lens, and warmer temperatures also melt the ice lens.

Terracettes

Kingston near Lewes, The South Downs
(Source:http://www.geograph.org.uk/photo/1822067)

.The formation of terracettes is not wholly known or agreed upon in geographical study. There are a few theories as to how they arise, however the most common theory involved the intervention of vegetation. **Frost heave** pushes particles of soil upwards, which would usually fall downhill through the process of **creep**. However, vegetation blocks the soil from falling, meaning it stays behind in a step shape. The shape of terracettes can be described as **terraces**.

Terracettes last a **short-medium amount of time** as thawing of the soil would disrupt the process of frost heave.However, the extent of the landform means the area is unlikely to be cleared completely in the short-term through weathering.

Solifluction Lobes

Seward Peninsula, Alaska
(Source:http://www.adfg.alaska.gov/index.cfm?adfg=viewinglocations.nomecouncil34to53)

When the active layer thaws and **solifluction** occurs, tongue-shaped lobes of soil fall down a slope.

Solifluction lobes last a **short-medium amount of time**, as the soil cannot retain the stretched structure for long, and when temperatures rise the soil moisture content will decrease.

Blockfields

Broad Crag, The Lake District
(Source:http://www.summiteer.co.uk/2013/Aug13/ScafellP22/SP22.html

A rock-strewn landscape caused by extensive **frost action** of the landscape

Blockfields will last a **medium-long amount of time** as loose rocks can be displaced through weathering.

Thermokarst

Hudson Bay Lowlands, Canada (Source:http://www.ougseurope.org/index.php?id=39)

Marshy, **boggy** wetlands caused when **permafrost melts**. Any ice lenses within the ground originally, or landforms such as pingos would **melt and collapse**. This can leave holes in the ground, which will also fill with meltwater.

Thermokarst landscapes last a **short-medium amount of time** as they will dry up when temperatures rise and permafrost retreats.

Value of Glaciated Landscapes

Both relict and active glaciated landscapes have **value**. They are of **economic, environmental** or **cultural** significance:

- **Polar scientific research**, especially in the Arctic and Antarctic, is significant. Since these environments have had **minimal human influence**, they provide perfect measurements of the Earth's past environments. **Rare wildlife** is also monitored and researched.

- There is some **spiritual associations** with glacial landscapes. Indigenous communities such as **Alaska's Tlingit people** and **America's First Nations** base much of their culture on the **snake-like being** of glaciers.

However, this environment is under **threat**.

Environmental Fragility: The concept of an environment being **vulnerable and at risk**, as it lacks the **ability to be resilient** and **adapt** to **changes**.

Fragile cold environments

Cold environments are classed as environmentally fragile due to a number of reasons, causing small changes to have large and destructive impacts.

- **Highly adapted ecosystem -** plants and animals must be highly adapted to the **extreme weather conditions** around them in order to survive. Especially in polar regions, plants and animals have adaptations that allow them to **survive in the cold temperatures**. Therefore, when something in the ecosystem changes, e.g. the temperature becomes higher, these highly adapted species find it more **difficult to cope with the changes**.

- **Slow nutrient cycle -** due to the **cold temperatures** and **nutrient deprived environment**, cold environments' nutrient cycles are slow. This means that things will take **longer to break down**, and longer to restore if they are damaged. Plants **cannot regenerate as quickly** as in other environments, which can limit their growth indefinitely. This also means that if litter or other **foreign objects** are placed in the environment, they will take a **long time to decompose** which can affect plant and animal behaviour.

- **Lack of biodiversity -** due to the cold and unforgiving climate, only certain plants and animals thrive, meaning **food chains are limited and species depend on each other**. If a species is removed or damaged, this can spread throughout the **entire** food chain, affecting every aspect of the ecosystem. For example, species of krill is declining in the Antarctic, which is causing penguins to migrate to different areas, affecting seal populations.

Human Impacts

A major threat to cold environments is the effects that humans have on them. Humans affect cold environments through **direct intervention** or through a **passive contribution**. Humans can affect cold environments directly at the local scale, e.g. dropping litter in an alpine environment. However, they can also contribute at regional and global scales through pollution and oil usage.

Tourism

Tourism is a **recent** but present problem in cold environments. **Alpine tourism** is the most prevalent and oldest form of cold environment tourism due to mountainous regions being used as ski slopes.

120 MILLION TOURISTS VISIT THE ALPS EVERY YEAR

- The development of ski resorts increases **urbanisation** and **construction**, **displacing** wildlife and the ecosystem
- Humans in alpine areas disrupt the ecosystem by destroying plants in **snow sports** and **scaring wildlife away** (e.g. the environmental damage caused by ski runs is likely to be irreparable -plants will not recover during thawing season)
- Any litter dropped will **stay in the nutrient cycle for a long time**, as decomposition is slow

Tourism in other cold environments is also a growing industry, especially in Antarctica due to a recent rise in '**extreme tourism**'. Antarctica is arguably even more fragile than alpine environments, meaning any foreign object entering the ecosystem is likely to have catastrophic effects on the pristine and untouched environment. **Sea ice destruction** and **cruise ship crashes** are also contributors to environmental destruction as tourist numbers increase. For example, the MS Explorer crash in 2007.

Resource Exploitation

Polar and periglacial environments especially have an abundance of natural resources, such as minerals and oil. These regions have therefore become at **risk of overexploitation** and habitat destruction.

- **Oil exploitation** disrupts the habitat through the infrastructure that comes with it, e.g. drilling and pipelines.
- **Oil spills** also cause catastrophic damage to periglacial and polar regions, as the fragile ecosystem cannot remove the oil quickly, affecting the ecosystem. (One of many examples: https://www.independent.co.uk/environment/burst-oil-pipeline-causes-catastrophe-in-alaska-351121.html)
- **Metal and mineral exploitation** damages the environment through mining and quarrying, scaring away wildlife and causing damage beyond repair. Currently, Antarctica is protected from this exploitation, but this is not to say it will be in the future.

Fishing and Whaling

Polar regions especially are under threat from **unsustainable fishing** in these areas, which disrupts the **food chain** of these fragile environments. Sealing and whaling began as far back as the 18th century, and although there are currently bans on **almost** all whaling, whale populations still stay at reduced and endangered levels from the damage previously done in the past.

Other fishing has increased in the 20th and 21st century, and there are still reports of **illegal, unreported, and unregulated (IUU) fishing**. This fishing is unsustainable and causes **wide scale marine habitat damage**. Overfishing also removes vital animals in the food chain, such as overfishing of krill which removes other marine animal food sources.

Pollution

Pollution is the largest **scale** problem impacting cold environments. There is local pollution issues associated with leaving litter etc. in alpine environments and polluting an area with oil. However, pollution is also a global issue due to the combustion of fossil fuels.

Global Warming

Furthermore, **Global Warming** is also threatening these glaciated landscapes. The combustion of fossil fuels causes a variety of issues for cold environments, often setting up **positive feedback loops** in which an impact can quickly spiral into a worse impact. Global warming is a major issue for cold environments.

Warmer temperatures cause **melting**, which is clearly bad for all cold environments.

- Permafrost melts
- Glaciers retreat
- Alpine environments thaw for longer summers

This melting causes further issues:

- Local **floods** near glaciers
- Regional floods if rivers etc.carry water elsewhere
- Global floods if major ice sheets and glaciers melt, causing sea level rises
- Disruption to flora and fauna that are adapted to the environment
- **CO_2** is released into the atmosphere that is **stored** in ice sheets and permafrost
- **Albedo effect** is lessened due to less ice sheets (this is the idea that white surfaces - ice - reflect solar radiation back into the atmosphere, meaning more heat is absorbed into oceans)

Positive feedback loops caused by melting

↗ **Permafrost melts** ↘

Greenhouse effect ← **CO_2 released**

↗ **Ice sheets melt** ↘

Sea temperatures rise ← **Ocean absorbs more heat (lowered albedo effect)**

Higher regional temperatures affect cold environments in other ways

- **Invasive species** that are adapted to higher temperatures have grown and caused the colonisation of some cold environments
- **Migration patterns** of certain animals have been disrupted by the higher temperatures. For example, the strandings of polar bears migrating to lower latitudes in winter
  - **Food chains** are disrupted by migration changes and invasive species

Management

As cold environments are so fragile and in need of **protecting**, there are current strategies put in place to conserve these regions. It must also be considered how cold environments should be managed in the future, especially due to future worries into climate change.

Current management of cold environments

Tourism

Sustainable tourism is becoming a growing industry, helping to reduce the effects humans have on their trips to fragile cold environments. Charities such as WWF are promoting sustainable alpine tourism in order to protect these areas. Visit their website for examples of 'green tourism' in alpine environments (http://wwf.panda.org/knowledge_hub/where_we_work/alps/our_solutions22222/tourism/)

Polar extreme tourism in most cases encourages a positive management of these cold environments. Visitors are **limited** so only smaller cruise ships can land (100 people at a time). Cruise ships must also have a permit and **regulations are very tight**. For example, shoes must be checked for foreign objects so they do not enter the ecosystem. Tourists are also encouraged to become **aware** of the risks to cold environments and **contribute to charities**.

Cold environments are also **protected by law** in some areas, such as areas of permafrost in Alaska that restrict access and construction.

Exploitation

Many cold environments are protected by law so that any **natural resources cannot be over exploited**. For example, the Antarctic Treaty and Madrid Protocol have banned mining in Antarctica. There are also **extensive fishing quotas** and **monitoring systems** in polar environments as to protect the ecosystem, as well as a ban on all military activity.

Climate Change

There is little that can be done directly to stop the effects of climate change on cold environments. Globally, though, there are strategies in place to **mitigate** climate change so that it may not have such catastrophic effects. International agreements and conventions are attempting global cooperation.