GEOLOGY, NATURE, CLIMATE

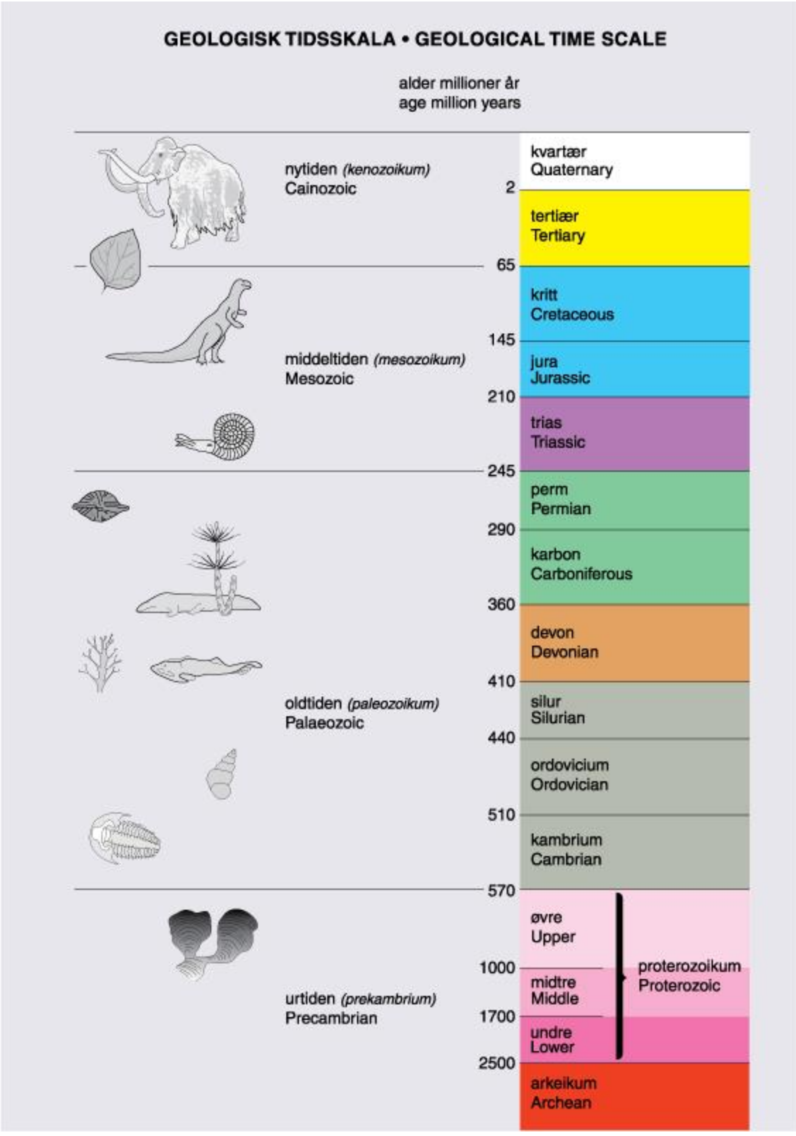
Content

Svalbard's geological developement

https://cruise-handbook.npolar.no/en/svalbard/geological-development.html

By Winfried Dallmann

For more than a hundred years, Svalbard has fascinated people with a special interest in the geological history of the Earth. Many who have visited Svalbard have been taken with the stark wilderness of the archipelago and its stunning mountains. The diverse geology of Svalbard has resulted in a wide range of landscapes. Hornsund, for example, is surrounded by jagged mountain ridges; the east coast of southern Spitsbergen is characterized by flat-topped nunataks, whereas the landscape around Woodfjorden is distinguished by gentler slopes with distinctive, reddish colours.



No other place in northern Europe displays such diversity in geological formations and no other place has so many geological eras exposed in outcrops. Since many areas lack significant amounts of soil and vegetation, the bedrock exposures can be studied unimpeded over large distances. All of these factors make Svalbard a unique place for studying geological processes – or for being captivated by the beauty of the land.

Evolution through the ages

The often heard statement that Svalbard once was located near the Equator is only partly correct. In Svalbard – as in Norway and the rest of the world – there are rocks that were formed in other climate zones, for instance in the tropical zone during the Devonian. Continental displacement (driven by convection currents in the lower part of the Earth's mantle) and displacements of the Earth's surface with respect to its rotational axis (and consequently the North and South Pole) are the most important factors that explain the present-day occurrence of these rocks in the Arctic.

However, Svalbard was not Svalbard at that time. When Svalbard's Devonian rocks were deposited, about 410-360 million years ago, much of Svalbard's bedrock was not yet there. The other part of what can be seen at the surface today was deeply buried below the surface. It would therefore be misleading to say that Svalbard has moved through the climate zones. Even though the deeper parts of the bedrock basement have been the same since the Devonian, tectonic processes like subsidence and uplift, deposition and erosion, have significantly altered the geographical conditions. (This refers, for instance, to the distribution of land and sea, topography and relief.) At some times during Svalbard's geological history its rocks were part of an enormous landmass; at other times they were below the bottom of the sea.

The history prior to the Devonian is even more complicated, because the basement consists of several blocks of the Earth's crust, which are derived from places thousands of kilometres apart. These were thrust together during a number of orogeneses (episodes of mountain chain formation) through the Precambrian and the lower Palaeozoic.

Svalbard's geological succession is usually subdivided into three main units: the old basement (Precambrian and lower Palaeozoic); unaltered sedimentary rocks (late Palaeozoic to Tertiary); and young unconsolidated deposits (Quaternary).

Basement rocks (Precambrian and Palaeozoic up to Silurian)

Folded granitic gneisses and amphibolites of Palaeoproterozoic age in the basement rocks of Ny-Friesland. *(Image: Winfried Dallmann / The Norwegian Polar Institute)*

Sedimentary rocks (Devonian to Tertiary)

Red Devonian sandstone by Woodfjorden. These are the molasse deposits of the Caledonian mountain chain. Miocene (late Tertiary) basalt lava flows cover the mountain tops. *(Image: Winfried Dallmann / The Norwegian Polar Institute)*

Flat-lying shelf deposits of the Carboniferous and Permian by Billefjorden. Gypsum and anhydrite layers are visible as greyish horizontal bands in the middle part of the mountain side. *(Image: Winfried Dallmann / The Norwegian Polar Institute)*

The Hyrnefjellet Anticline in Hornsund, with sedimentary rocks of the Carboniferous to Triassic periods, folded during the early Tertiary tectonic phase. *(Image: Winfried Dallmann / The Norwegian Polar Institute)*

The lower Tertiary layers close to Longyearbyen with the entrance of an abandoned coal mine. *(Image: Winfried Dallmann / The Norwegian Polar Institute)*

A fossilized leaf of a gingkotre from tertiary sandstone in central Spitsbergen. *(Image: Winfrid Dallmann / Norwegian Polar Institute)*

Unconsolidated deposits (Quaternary)

Halvdanpiggen by Woodfjorden, the ruin of a Quaternary volcanic pipe within red Devonian sandstones. *(Image: Winfried Dallmann / The Norwegian Polar Institute)*

Permafrost is responsible for typical Arctic landforms:

- **Rock glaciers** are masses of rocks, gravel and sand which are derived from the weathering of mountainsides. They are saturated with water, which is frozen all year. These glaciers move slowly down-hill on many of Svalbard’s valley sides and coastal mountains. They can be recognized by their typical curved shapes.
- **Patterned ground** is often found in flat areas in the form of hexagonal stone circles or earth cracks. They are formed through alternating thawing and freezing of the upper ground layer.
- **Pingos** are mounds of earth-covered ice that occur due to the interaction of permafrost and springs, mainly at the bottom of valleys. They look like gravel hills, sometimes with a small pond on the top, or with a periodically active spring.
- **Thermokarst** are systems of channels in the permafrost through which water circulates. Unconsolidated mass is washed away, forming holes or depressions at the surface, where ponds or lakes can form. The most prominent example occurs on Vardeborgsletta close to Isfjorden.

During a period of the Quaternary there was active volcanism in north-western Spitsbergen. The most prominent volcano, Sverrefjellet, is between 100 000 and 250 000 years old. The thermal springs by Bockfjorden indicate that the geothermal gradient – the downward temperature increase – is still high in the area in the aftermath of this volcanic activity.

Isfjorden's geology and landscape

https://cruise-handbook.npolar.no/en/isfjorden/geology-and-landscape.html

By Jørn Henriksen, Winfried Dallmann

Isfjorden is one of the largest fjords in Svalbard – second only to Wijdefjorden in length – and it leads out to many smaller fjords. The furthest point of Billefjorden, one of these smaller fjords, is a stone's throw away from the furthest point of Wijdefjorden, extending down from the north. The characteristics of the mountains change as one travels from west to east in Isfjorden. In the west, bedrocks from the Caledonian mountain range, which was formed some 400 million years ago (Silurian/Devonian), can be found. The most prominent example of carbonate rock in this area is Alkehornet, a landmark close to the mouth of Isfjorden. Just below Alkhornet there is a level plain, much like the ones found all along the west coast of Spitsbergen. Parts of this plain have been formed by considerably younger marine depositions. These are less than two million years old.

Karst topography at Kapp Ekholm in Billefjorden, one of the fjords branching off Isfjorden. The ponds (sinkholes) are formed as a result of dissolution of the underlying bedrock, which consists of gypsum and anhydrite. The mountain Pyramiden can be seen on the other side of the fjord. *(Image: Odd Harald Hansen / The Norwegian Polar Institute)*

The cliff of Festningen is situated by the mouth of Grønfjorden, to the south of Isfjorden. A profile of different kinds of rock – all on a slant – is seen here, as is also the case on the island of Akseløya and the peninsula Ahlstrandhalvøya in Billesund. Between the point of Lewinodden and Festningen large parts of Svalbard's geological history are readily available for viewing. The youngest rocks (from the Tertiary period) can be found along the beach in the east, while old bedrock can be found in the west. In 1960, the first evidence of the existence of dinosaurs in Svalbard was found, in the form of fossils discovered at Festningen. These were footprints from an iguanodon-like herbivorous dinosaur, which is estimated to have lived 125-130 million years ago, that is, early in the Cretaceous period. The mountain wall on which these footprints were found has since collapsed onto the beach. Several other footprints have later been discovered, although less distinct than the first ones. In latter years, fossils of other animals have been found in inner areas of Isfjorden. In 2006 a sensational discovery was made by scientists from the Museum of Natural History in Oslo. They found a fossilized pliosaur, one of the largest carnivorous marine reptiles ever to have existed on Earth.

Tourists taking in the grand folds of Sylfjellet, to the west of Bohemanflya. The layered effect is the same as Festningen's profile. *(Image: Jørn Henriksen)*

The profile of rocks that can be seen from Festningen and westwards continues across Isfjorden and also emerges in various northern areas of the fjord.

Prior to the discovery of the pliosaur described in the boxed text, plesiosaurs and ichthyosaurs had been found, both also prehistoric marine reptiles. Discoveries such as these make Svalbard important for palaeontological research. A relative scarcity of vegetation makes fossils easy to find, although the Arctic climate (in which the ground freezes and thaws regularly) means they are found in a porous and vulnerable state. Securing the findings has been difficult and time consuming, and due to a fear of losing something, several emergency digs have had to be carried out. Large fossils are a part of Svalbard's history and the archipelago's environmental protection laws are being re-examined with an aim to preserve these findings in the best way possible.

The eastern parts of Isfjorden are characterized by plateau-shaped mountains made up of horizontal layers of sedimentary rocks. Large talus slopes are frequently formed at the base of steep cliffs. When weathering accentuates differences in rocks, spectacular landforms may form. Weathering of more resistant sandstone and limestone layers may result in ridges or pinnacles. Basalt cliffs are present at several places in Isfjorden, for example at Diabasodden. Molten rock of basaltic composition has been injected into fractures in the sedimentary layers and crystallized into hard diabase. Today, the basalt cliffs provide nesting sites for colonies of Brunnich's guillemot and Atlantic puffins.

Some of the broadest U-shaped valleys in Svalbard are found in the Isfjorden area: Sassendalen and Adventdalen. During the last Ice Age, these valleys were outlets for large masses of ice that moved down-valley from east to west. Both valleys are long and flat and meltwater from the glaciers flows in a braided pattern. These rivers transport eroded rock material (particles of gravel, sand and clay) into the fjord. The sediments are deposited in fan-shaped deltas, which in time will turn into stratified sedimentary rocks.

Some landforms are recent. An example is Coraholmen in Ekmanfjorden. In 1896 the glacier Sefströmbreen advanced dramatically fast. Such events of extremely rapid movements are called surges in glaciological terminology. The glacier front advanced rapidly forwards and ploughed the bottom bed of Ekmanfjorden. The debris was thrust up and deposited on Coraholmen. Today the landscape is characterized by hummocky and pitted moraine and abundant small lakes.

The hummocky moraine is partly ice-cored and the lakes form as buried ice melts. Abundant shells are present in the deposits on Coraholmen. Deposits from this surge are also found on Flintholmen.

Glaciers on Spitsbergen

https://www.unis.no/wp-content/uploads/2014/08/1.-Glaciers-on-svalbard.pdf
By UNIS

What is a glacier?

- A glacier consists of ice and snow.
- It has survived at least 2 melting seasons.
- It deforms under its own weight, the ice flows!

How do glaciers form?

Glaciers form where:

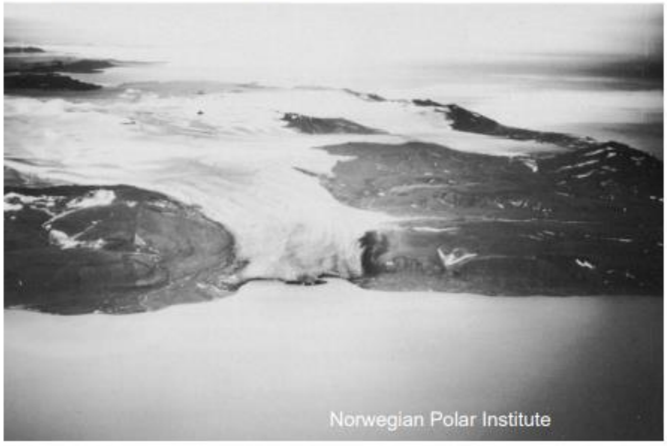
- Summer temperatures are not high enough to melt all the snow accumulated during the previous winter.
- In winter fresh snow accumulates, year after year, on top of the snow that survived summer.
- When the ice gets 10s of meters thick it begins to flow out- and downwards to areas with higher temperature. Here the ice melts or calves into the sea.

What is a surge?

- A response to an imbalance in the glacier geometry caused by insufficient mass transport from accumulation to ablation area (In Svalbard probably linked to permafrost).
- A sudden increase in speed (often from 10s of meters/year to 1000s of meters/year)

- The buildup period between surges in Spitsbergen is typically 50-500 years
- The surge typically lasts from 2 to 10 years
- Often, but not always, the terminus (tip) of the glacier advances several kilometers.
- The surface of the glacier becomes heavily crevassed (fractured) as a result of the increased speed.
- It takes from 10-20 years for the newly formed crevasses to close up.
- Estimates of Svalbard glaciers that surge lie between 30% and 90%

Example of surge - Freemannbreen



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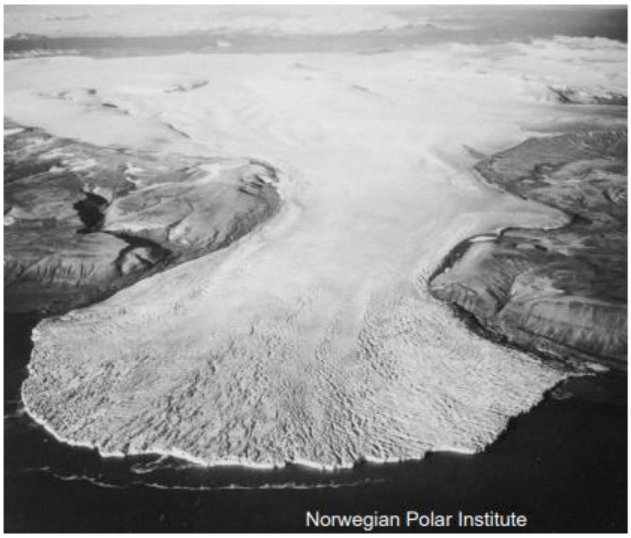

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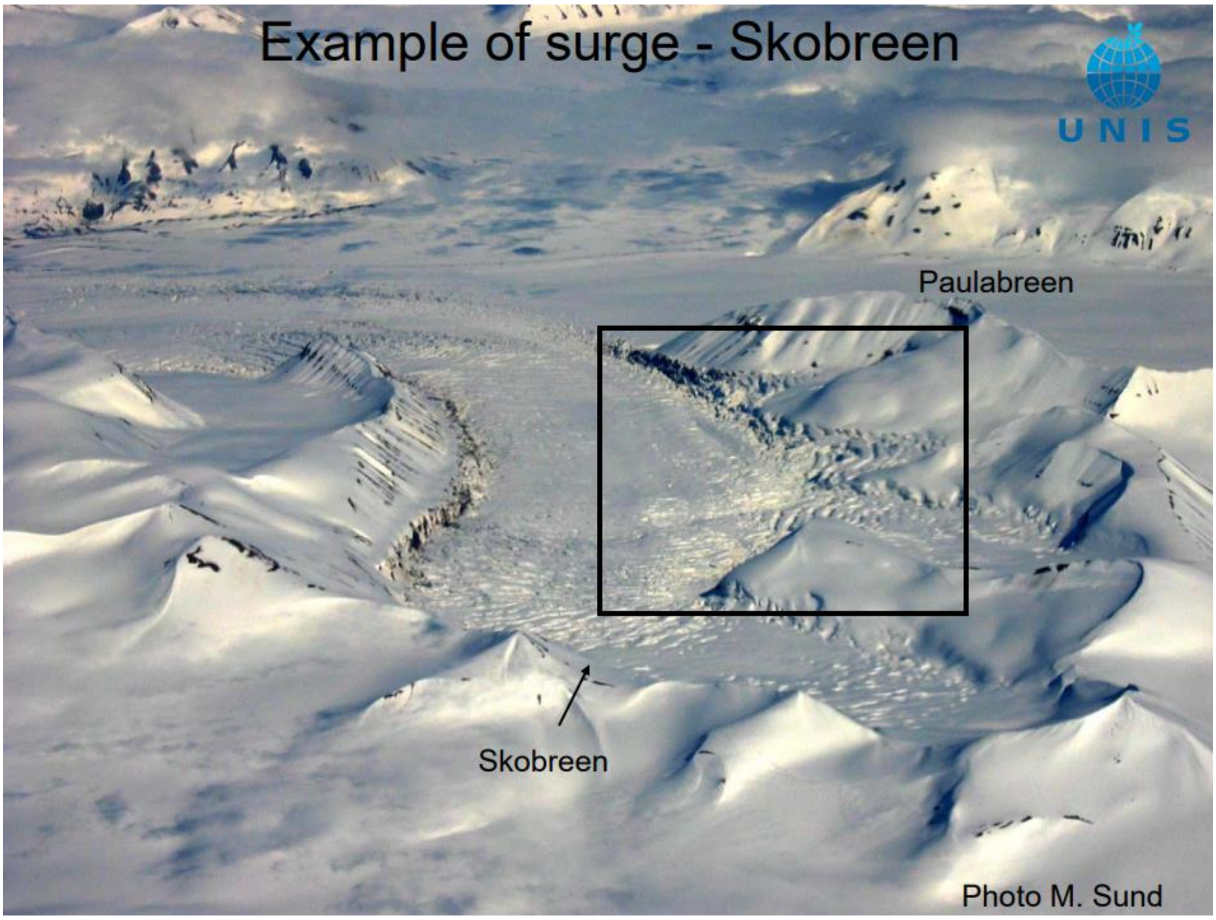
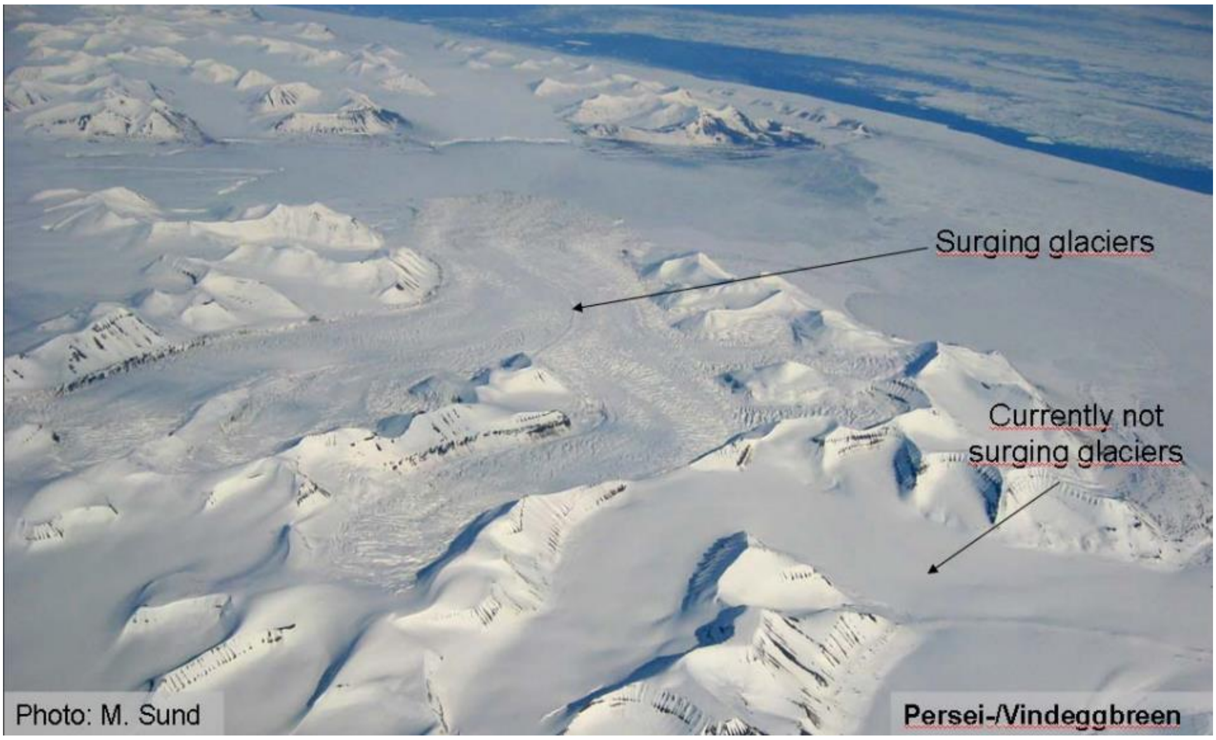




Glaciers in Svalbard - Today

- 60% of Spitsbergen is covered by glaciers
- Austfonna; The worlds 3. biggest ice cube

- The largest glaciers are on the east coast and in the northern parts due to more precipitation
- Longyearbyen: 300 mm/year, an arctic desert
- Mean annual temperature -5°C
- For glaciers the summer temperature is more important than the winter temperature

Glaciers in Svalbard - Past

- 18.000 BC: Ice age, most of Spitsbergen covered by ice.
- 10.000 BC: Holocene optimum. Relatively warm with few glaciers.
- 5500 BC: Colder again, climate similar to today.
- 1000 BC: Milder than today, Vikings were growing grain on Greenland
- 500 BC: Little Ice Age begins. The mean annual temperature sinks considerably and the glaciers are growing.
- 1920 -1925 Little Ice Age ends on Spitsbergen Mean annual temperature rises several degrees.
- 1925-2000: Mean annual temperature -5C. The glaciers are to large for todays climate and are therefore shrinking.

Glaciers on Spitsbergen - Future

- Glaciers will return to their pre little ice age size.
- If temperatures rise, models indicate that the precipitation might increase as well.
- The surge frequency for glaciers might change.
- The velocity and calving rates might change as well.

Climate in Svalbard

https://www.npolar.no/en/themes/climate-processes-and-drivers/
By Norwegian Polar Institute

Climate: processes and drivers

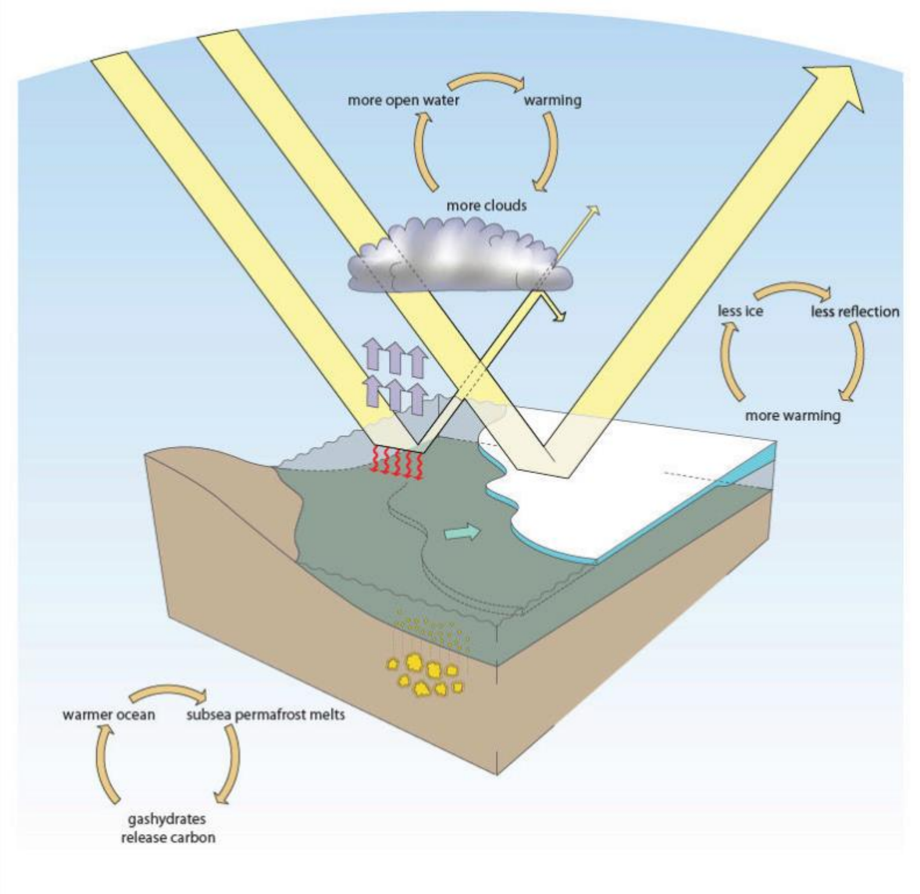
What happens in the global climate is mainly determined by a few fundamental processes: incoming solar radiation, characteristics of the earth's surface, the atmosphere's ability to retain heat, and the reflectivity of the atmosphere and the earth's surface. Various mechanisms serve to enhance or weaken the effects of these processes on climate.

Global processes

The energy that radiates from the sun creates the basis for weather and climate on earth. The radiation absorbed makes the earth warmer. Unless an equal amount of energy is lost to outer space, the temperature on earth would increase.
Earth loses energy to space by radiating infrared light from the surface and the atmosphere. Averaged over the entire globe, the earth loses the same amount of energy in the form of infrared radiation as it takes up from the sun.

Radiation

All surfaces radiate energy, often in the form of light. How much and what type of light (infrared, visible, ultraviolet) depends on the surface's temperature. Surfaces with temperatures common on earth radiate infrared light, whereas the sun is hot enough to radiate visible and ultraviolet light. The warmer the surface, the greater the radiation.



Albedo effect at sea. A light surface (snow and ice) reflects almost 80% of the incoming energy back to the atmosphere, whereas the dark ocean absorbs heat and reflects only about 10%.
Illustration: Audun Igesund / Norwegian Polar Institute

Greenhouse gases

For celestial bodies without an atmosphere, such as the moon or Mercury, it is easy to calculate surface temperature based simply on their distance from the sun, their size and how much sunlight they reflect. If the same formula is applied to the earth, the calculated average surface temperature is about -17°C. However, the gases in the atmosphere take up much of the infrared radiation emitted from the surface of the earth, which means that the atmosphere grows warmer. The warm atmosphere subsequently emits infrared radiation both out toward space and back to the surface. The infrared light emitted down toward earth warms the surface. This process is called the greenhouse effect, and explains why the earth has an average temperature closer to +14°C than to -17°C. Water vapour is the most important greenhouse gas, followed by carbon dioxide (CO_2) and methane (CH_4).

Climate can change as a result of natural processes or human activities. The most important process behind the ongoing climate change is an increased concentration of CO_2 and other greenhouse gases in the atmosphere, which enhance the greenhouse effect. The latest IPCC report summarising available knowledge and evidence shows that the concentration of CO_2 in the atmosphere has increased by about 40% since the beginning of the industrial revolution. There are clear indications that human activities have caused this increase. The current atmospheric concentration of CO_2 is far higher than any level attained through natural variation over the past 800 000 years, as demonstrated by ice cores, and it is quite certain that the increase in atmospheric CO_2 levels seen in the last 100 years has been more rapid than any other increase over the last 22 000 years. Read more about the greenhouse effect and changing concentrations of greenhouse gases at miljøstatus.no.

Aerosols

Aerosols (tiny particles of soot or sulphates) in the atmosphere can have a cooling effect owing to their ability to refract and absorb incoming solar radiation. The aerosols can also have an indirect effect: they function as condensation nuclei and contribute to formation of clouds. Increased cloud cover increases the earth's ability to reflect sunlight and thus cools the earth. However, soot in aerosol form also has a warming effect. Read more about soot as a driver of climate at miljøstatus.no.

Human activities release many aerosols. The IPCC[?] estimates that overall, man-made aerosols have a cooling effect; in other words, aerosols have lessened the warming we would otherwise have experienced from the increased concentrations of greenhouse gases.

The earth's orbit around the sun

Many other natural processes also influence climate. These processes have led to major climate changes in the past. In the past few million years, the earth has experienced several ice ages, when ice sheets like those that now cover Greenland and Antarctica covered large parts of North America and Europe. These changes were mainly caused by gradual changes in the earth's orbit around the sun.

Solar radiation

Solar radiation varies over an 11-year cycle, and also over longer time scales. The latest IPCC summary of available knowledge and evidence shows that changes in solar radiation have probably contributed very little to the overall changes in climate since the beginning of the industrial era. A few studies show that changes in solar radiation may have contributed to increased global average temperatures during the first half of the 20th century, but have probably played a very minor role in the last half of the century.

Global ocean circulation and atmospheric circulation

The global climate system is also regulated by the energy balance in the oceans and the atmosphere. Global ocean circulation and atmospheric circulation are driven by forces that strive to even out differences in temperature between high and low latitudes. Heat exchange between ocean and atmosphere is an important factor in regional climate patterns. Conditions that influence this balance – such as changes in air and sea temperatures, or cloud and sea ice cover – will thus influence how the climate evolves. On a geological time scale, changes in the shape and location of continents can have strong effects on circulation and heat balance and thus also on global climate. However, given that the continents have been in approximately the same place for the past 500 000 years, this is not a factor of any importance for ongoing climate change.
On geological time scales, the concentrations of greenhouse gases – especially CO_2 – change through natural processes. Volcanos emit CO_2 to the atmosphere. This release is balanced by processes that capture CO_2 in the seabed, and it can be demonstrated in several ways that the increase in atmospheric CO_2 levels since the industrial revolution has been caused by human activities.

Processes at the poles

Distinctly polar processes in both north and south, on land (snow, glaciers, and permafrost) and at sea (sea ice, ocean circulation, bottom water formation)), play a crucial role in the global climate system, acting through complex interactions and feedback mechanisms.

Sea Ice

Sea ice is an important factor in maintaining radiative balance in the global climate system through the albedo effect[?].

Snow-covered sea ice reflects about 80% of incoming solar radiation, in contrast to open seas, which absorb more than 90% of incoming solar radiation and reflect only 10% back to the atmosphere. Because of this, changes in the proportion of sea ice and open water have a strong impact on the climate in this region. Record low amounts of sea ice are now being observed repeatedly in Arctic, whereas the extent of sea ice around Antarctica is relatively stable or increasing slightly. Studies suggest that the changes in ice cover in the north over the past decades have contributed to warmer temperatures in the Arctic through much of the year. They also suggest that most of the recent temperature increase in the Arctic can be attributed to reduced sea ice coverage, which in turn influences the formation of sea ice. A study from 2010 concluded that the changes in Arctic sea ice extent in the past few years have had less impact on temperature trends outside the region, that is south of 60°N.

Altered ice dynamics and structure, combined with uptake of heat in ice-free seas help enhance the warming of the Arctic and the loss of sea ice. When the heat stored in this reservoir returns to the atmosphere in the autumn and winter, the warmth does not stay in the lower layers of the atmosphere, but rises to higher altitudes, where it influences Arctic wind systems, particularly air exchange between north and south. This is probably a contributing factor in the record low temperatures and record heavy snowfall in southern Europe, along with unusually high temperatures in the Arctic in the winter of 2009-2010.

At the poles, cold, dense water is formed, which flows along the depths of the oceans toward the equator; to compensate, other currents form and flow at the ocean surface toward the poles. This is the motor in the ocean circulation system, which in turn regulates global climate. New bottom water forms in only a few areas of the world's oceans. Global warming can perturb bottom water formation by warming the surface water and increasing the influx of fresh water, both of which decrease the density of the surface water. A considerable proportion of the fresh water in the Arctic Ocean leaves the Arctic with the East Greenland Current through Fram Strait and ends up in the Greenland and Labrador seas, where it can influence the crucial bottom water formation. The Norwegian Polar Institute has been monitoring the fresh water current in Fram Strait since 1997, through permanently deployed instruments and annual research cruises across the current. The Institute reports these monitoring results in MOSJ.

Snow

Snow cover, like sea ice cover, is an important factor in maintenance of radiation balance in the global climate system through the albedo effect[?]. On average, about 46 million square kilometres of the earth's surface is covered with snow every year. But the total area of this snow cover is decreasing, and the period when there is snow cover is getting shorter.
The latest IPPC report shows that over the last decades, the area covered by snow has decreased by about 1.6% per decade, and the spring snowmelt is occurring earlier and earlier. Studies imply that the changes in surface temperature that result from changes in snow cover are smaller than those caused by altered sea ice coverage, but are more extensive and prominent in autumn and spring.

Permafrost

Permafrost lies under much of the land in the Arctic, and under the seabed in some places. Permafrost is important for global climate developments because huge amounts of greenhouse gases (mainly methane) lie "locked" inside the frozen ground and could be set free if the permafrost were to disappear. Permafrost is thawing at several locations in the Arctic, and its temperature is now 2°C warmer than it was 20-30 years ago. A monitoring series reported through MOSJ, shows thawing also in Svalbard. So far, however, it has been difficult to calculate the potential magnitude of greenhouse gas emissions from thawing permafrost, because many of the interlinked consequences of such thawing remain poorly understood. The most recent IPCC summary of available knowledge and evidence shows that the best estimate for 2100 is between 50 and 250 gigatonnes of carbon, depending on how global temperature evolves

Glaciers and ice sheets

Glaciers and ice sheets in polar regions influence the climate system in several ways. They too affect radiation balance through the albedo effect[?], just as sea ice and snow do, but they also have impact on influx of fresh water to the world's oceans, and thus affect ocean circulation. Almost all the glaciers and ice caps in the Arctic have decreased in volume over the last century; Alaska and northern Canada are the regions that have seen the greatest loss of glacier mass in the past decade. Parallel with this, reduced seawater salinity and density have been observed. It has been estimated that the influx of fresh water (from all sources) has increased by 7700 km^3 over the past few years. If this trend continues, there is a risk of changes in major ocean currents, which would in turn have impact on global climate.

Weather in Svalbard

https://www.unis.no/wp-content/uploads/2014/08/safety_weather.pdf
By Anna Anna Sjöblom, Department of Arctic Geophysics

The weather is an important factor to take into account when planning field activities on Svalbard
There have been more or less continuous meteorological measurements since 1912 on Svalbard. Most meteorological measurements are performed on the west side of Svalbard, where people live. This means there are vast areas where the weather conditions have not been investigated thoroughly, which must be kept in mind when climatic conditions on Svalbard are discussed.

The most characteristic feature about the weather on Svalbard is that it is determined both by large scale factors as well as local factors. The weather can vary a lot over a short distance, and it is important to understand why it is so for safety reasons when travelling in the field.

Most important things to remember about weather on Svalbard:

- The weather can change very fast.
- Weather forecasts are often uncertain and should be dealt with accordingly.
- The weather is influenced by many local factors, and even if the weather is fine in Longyearbyen, it does not have to be so a few kilometres away.
- It is usually not the low temperature itself that is dangerous on Svalbard, but the combination with strong wind and dry air.

What to think about when reading forecasts

Many of the forecasts are computer generated and not quality checked by a meteorologist (for example meteograms). A few tips:

- The wind speed given is often too low.
- The wind direction given is the large scale wind direction which will then be steered locally by topography.
- A small mistake in the localisation of a weather system can give a large change in weather.
- The timing of weather systems can be wrong. Weather systems can come earlier or later.
- The weather can change very fast.

- Local factors will in the end determine the actual weather.

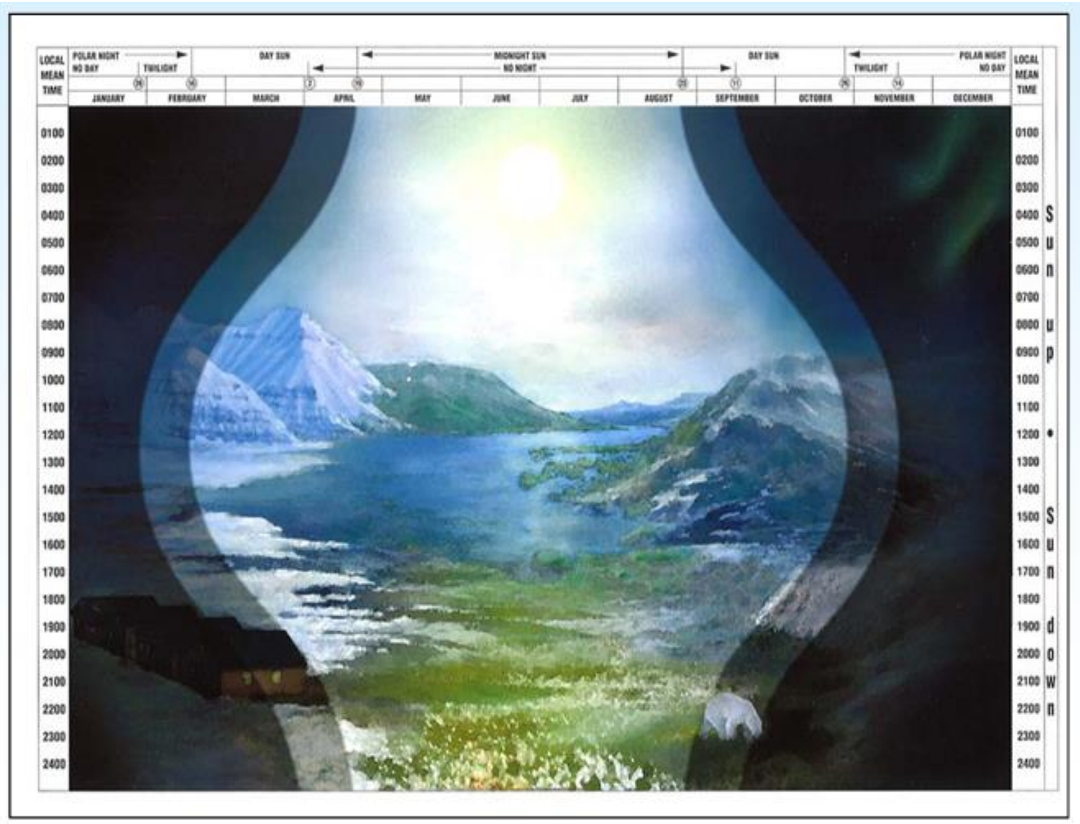
Why are the forecasts uncertain?

Forecast models use a description of the atmosphere and its physical phenomena when calculating the weather forecast. These descriptions are based on processes on lower latitudes, simply because more research has been done there than in the Arctic. In order to improve the weather forecast for the Arctic more measurements are needed to understand what is different here. This involves for example processes during the long polar night and local phenomena typical for the Arctic. Understanding these phenomena is also important to decrease the uncertainty in global climate prediction models.

Midnight sun and polar night

Svalbard has midnight sun and polar night for a large part of the year, which influences the weather. Even if the sun is shining for several months it never gets really warm on Svalbard since the sun is at a low angle above the horizon, even when it is at its highest.

The long polar night cools the surface effectively and this cooling is only interrupted by brief episodes of slightly warmer air which can be transported to Svalbard from the south.



Some useful weather links on the internet:

- UNIS has several weather stations on-line: http://www.unis.no
- Yr.no gives weather forecasts and climatic data for many places around the world: http://www.yr.no/
- The Norwegian meteorological institute has a lot of useful information: http://met.no/index.shtml
- Climatic data can be found on: http://eklima.met.no

- A lot of meteorlogical information can be found on http://www.wetterzentrale.de/
- Satellite images: http://www.sat.dundee.ac.uk/
- Current weather around the Arctic: http://www.athropolis.com/map2.htm