Antarctica - a world of ice

The ice of Antarctica

Almost 90% of the planet's fresh water, is locked up in the snow and ice of Antarctica. There is so much ice it covers an area twice that of Australia and produces an ice cap that is the single largest solid object on the surface of Earth - so heavy it deforms the crust beneath.

This huge volume of ice is not constant, but grows during ice ages and shrinks between them. Every year new snow accumulates on the surface of the continent, but due to the persistent cold does not melt, instead it is compressed by the weight of new snow and becomes ice. This ice preserves a rich and detailed climate record spanning more than a million years, giving us a detailed view of Earth's history, even before modern humans walked its surface.

From the centre of Antarctica 'glacial conveyor belts' transport 200 billion tonnes of ice each year, to ice shelves at the edge of the continent. These ice shelves then travel across the surface of the ocean before breaking apart to create a flotilla of icebergs which drift northwards into the currents of the Southern Ocean.

In this way the volume of fresh water released from Antarctica is a delicate balance between snowfall and the loss of ice to the Southern Ocean - a process that plays a major role in controlling the world's climate, as well as all its physical and biological systems.

Ice sheet 'mass balance'

How much ice is gained or lost over time is known as an ice sheet's *mass balance*. If there is no gain nor loss the ice sheet is said to be *in equilibrium*.

The mass balance of a single glacier can be estimated but trying to do this for a whole continent is very difficult, as each glacier may behave differently. However since the 1960's man-made satellites have allowed the height, temperature and flow rates of large areas of ice to be measured - with some satellites now accurate to the nearest centimetre.

Snow and ice formation

Snow is formed when moisture evaporates from open water, cools and condenses on tiny particles such as dust. These frozen particles gather more water around them and form snowflakes, that eventually fall and settle.

Since moisture and cold are essential for snow, coastal areas are regularly battered by snow storms, which can bring more than two metres of snow per year.These coastal storms rarely penetrate inland - instead tiny granules of ice, known as *diamond dus*t drift down through the atmosphere and settle on the surface of the ice sheet. Each granule of diamond dust is so much smaller than a snow flake that at the South Pole only 2 - 5cm of snow accumulates each year - equivalent to the rainfall of the Sahara desert.

- As snow is compressed air is expelled, making the snow flakes rounder and forming *firn* snow.
- As firn is compressed the crystals are compressed further sealing air into individual pockets or pores and forming *bubbly snow*. This air makes up a tenth of the volume of bubbly snow and is an important sample of the atmosphere on the day the snow fell.

The ice cap of Antarctica is the largest solid object on Earth. Image Stephen Hudson, Wikicommons

Ice cores

By drilling into buried ice and extracting air samples, scientists can build a record of past climates. Some of these cores are over three kilometres deep, and provide a continuous Antarctic record dating back 800,000 years - allowing us to better understand how the current rate of global warming compares to past events and cycles.

One chemical tool used to examine ice cores counts the different forms (isotopes) of oxygen and hydrogen. Since the ratio of these isotopes is determined by air temperature, the trapped air records the temperature the day the snow fell.

By making numerous measurements climate changes can be found, such as that showing how Earth naturally experiences cycles of increasing and decreasing greenhouse gases. This data also indicates that today's greenhouse gas concentrations are the highest in 420,000 years - possibly through the burning of fossil fuels.

PROXIES

Proxies are clues or indirect evidence about an event. They are especially useful when real evidence, such as temperature, cannot be preserved. Using proxies enables Antarctic scientists to:

- identify seasonal and annual snowfalls.
- get accurate dates or 'time stamps' by chemically examining layers of volcanic ash.
- date layers by measuring levels of radioactivity.
- estimate ancient sea ice cover, photosynthesis and pollution by measuring trace elements and dust levels.

Dust and climate

Dust levels in an ice core are an important clue about past climates. This is because during cold (glacial) times, more fresh water is locked up in ice caps and glaciers, so that the remaining land is drier and desert like. At such times winds also tend to be stronger, due to the greater temperature difference between the equator and the poles, so more dust appears in the ice core records. During warmer periods the opposite happens and the ice is often cleaner.

Antarctic Drainage

Ice flows outwards from the centre of Antarctica from nearly 4000m above sea level in the middle of the East Antarctic Ice Sheet - rather than from the South Pole as many imagine.

Despite the scale and speed of its movement the flow is actually controlled by the underlying rock formations and at a microscopic level by the way individual ice crystals slide past each other. The ice moves fastest at the surface, and more slowly near the bedrock due to friction and shearing. For this reason, horizontal layers in the ice sheet move past each other at different rates - rates which vary from a few metres to several hundred metres a year.

There are five major drainage systems in Antarctica, with each made up of ice streams, glaciers and sub-glacial water flow. These systems mostly flows into the ice shelves which fringe the continent, although some glaciers flow directly into the sea.

1. Ice streams

Ice streams are giant rivers of ice and the first were discovered only when satellite images of Earth became available in 1972. These images showed ice streams cutting through the Antarctic ice sheet and being fringed by wide zones of crevasses - a feature which indicated they were flowing ten to a hundred times faster than the surrounding ice. Like a river, ice streams flow fastest in the centre and more slowly at the edges. These fast flow rates were difficult to explain so glaciologists drilled bore holes into the ice, sending cameras and instruments to the bedrock below. Here they found a water-filled, glacial sediment called *till*, which lubricated the ice stream's movement. Despite the cold, water flows beneath the ice stream due to *pressure melting*, which can also be seen if you squeeze a snowball in your hand.

The conditions beneath the ice are important in controlling ice streams and therefore the whole stability of Antarctica, especially since ice streams stop and start very quickly. Of special concern are the ice streams of the Amundsen Sea Coast (West Antarctica), as they are strongly out of balance with the rest of the ice sheet, resulting in ice accelerating, thinning and showing rapid loss across some of the largest glaciers in the region. Considering these glaciers have grounding lines close to the ocean they are particularly vulnerable to rapid melting.

The discovery of ice streams and understanding their behaviour has been one of the greatest glaciological advances in the history of Antarctic science.

2. Glaciers

There are three main types of Antarctic glacier.

Outlet Glaciers

Unlike ice streams, which cut a path through an ice sheet, outlet glaciers flow through mountain ranges following the shape of the valleys beneath. The outlet glaciers of Antarctica provided routes which the early explorers used to cross the Trans Antarctic Mountains as they headed to the South Pole.

Dry Valley glaciers

The 'Dry Valleys' of Antarctica are so named because they are ice free. Although such glaciers are rare in Antarctica they create of its most striking features, for instance the McMurdo Dry Valleys have numerous such glaciers which drape the valley walls and terminate in near-vertical ice cliffs. This spectacular appearance is made possible because they lack water at their base, but instead are frozen to the bedrock. As a consequence Dry Valley glaciers move very slowly, contain very old ice and are rich in sediment at their base.

The Peltier Channel. Recent spectacular collapses of ice shelves around the AP, may cause a 'runaway' release of ice from the continent. Image: Serge Ouachée, Wikicommons

Antarctica Peninsula glaciers

The shape and action of glaciers on the Antarctic Peninsula are controlled by the mountains down which they flow, making them more like glaciers on other continents, complete with ice filled valleys and cirques. Most Antarctic Peninsula glaciers have been retreating rapidly in recent decades, in response to rising temperatures in the area.

3. Ice shelves

Ice shelves are floating rafts of ice, formed when glaciers reach the coast. Almost half of Antarctica. is fringed by ice shelves, which although appearing flat, featureless and unmoving, are often fast moving, reaching speeds of several kilometres a year.

The largest ice shelves are the Ross, the Ronne-Filchner and the Amery, but there are also many other smaller ice shelves around the coast of Antarctica. All are fed by the flow of inland ice, but also gain ice by seawater freezing on to their base and from snowfall above. Ice shelves loose mass mainly by shedding icebergs off their seaward edge into the ocean, in a process known as *calving*, which creates vertical cliffs of ice. Around the Ross Ice Shelf calving has produced impenetrable cliffs that rise 50 metres from the sea, which prompted early explorers to name it 'The Barrier'.

Ice shelves flow from the land and slide over the sea floor until the water is deep enough to allow them to float. The line where an ice shelf floats, no longer touching the sea floor, is called the *grounding line*. The thickest ice is generally found at the grounding line, as the ice thins as it spreads out over the ocean. With a warming climate only ice inland of the grounding line will contribute to sea level rise, as ice that is seaward of the grounding line is already floating. The position of the grounding line is very sensitive to climate change;

- in cold climates when the ice sheet expands, the grounding line will move further into the ocean.
- in warming climates the grounding line retreats

4. Icebergs

Icebergs are fragments of ice shelves that form when the ice breaks along lines of weakness, caused by ocean currents and waves. As ice bergs are pushed by wind and currents they all travel west around the continent before moving north to be caught in the easterly flow (West Wind Drift). By the time icebergs have moved far enough north to reach the Antarctic Convergence they have usually disintegrated, but on rare occasions icebergs have travelled as far north as 35 degrees into the Indian and South Atlantic Oceans.

Some of the largest icebergs known have originated from the ice shelves of the Ross Sea. The largest recorded is B-15, which calved off the Ross Ice Shelf in 2000 and had an area of over 11,000 km² (larger than Jamaica). This giant prevented ocean currents and winds from breaking up the summer sea ice, and even caused a decline in penguin populations due to the extra distances that parents had to cover to reach their chicks from open water.

5. Sea ice

In winter, the area covered by ice in Antarctica approximately doubles, as the surface of the ocean freezes. This extra ice extends up to 1000 km from the coast and covers an area of 20 million square kilometres. The annual growth and loss of Antarctic sea ice follows a seasonal pattern:

- during May and June, the sea ice front advances by up to 4 km a day. As it reaches outward it also thickens due to snowfall and freezing of the seawater beneath.
- during September - October the extent of sea ice is at a maximum, reaching 3-4 metres.
- by the end of February Antarctic sea ice has melted back to the edge of the continent.

The seasonal effects of sea ice

The change from dark open ocean to solid, white ice (and back) has enormous effects on Antarctica - for example:

- in winter the sea ice acts as a 'blanket' over the ocean and prevents the evaporation of moisture into the atmosphere. This is one of the main reasons Antarctica is so dry.
- in spring, when the sun returns to Antarctica the brightness of the sea ice reflects much of the sun's energy into the atmosphere, slowing the rate at which the continent warms.
- in summer, when the sea ice has retreated, the atmosphere around Antarctica is more humid, and coastal regions receive more snow. The increase in open water also allows more light to penetrate into the sea, which increases the rate of photosynthesis and allows food chains to flourish.

Types of Sea Ice

Sea ice varies but there are three important forms:

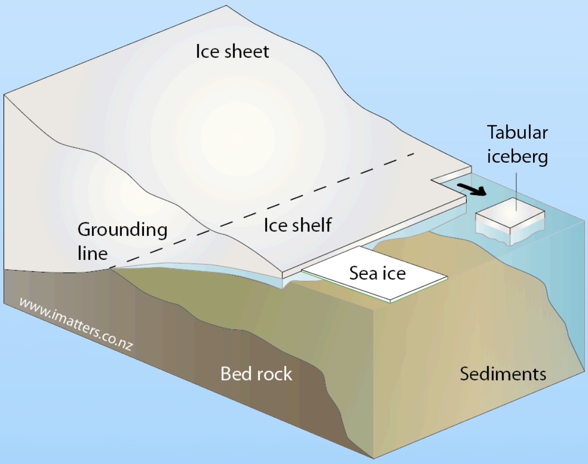
1. ***Frazil ice*** is the first to form and begins as small needles, these then become a delicate layer of tiny ice plates. As frazil ice thickens it forms an icy sludge known as *grease ice*. If conditions are calm grease ice can grow rapidly into solid sheets called *nilas*, but in stormy seas it may be rammed together into *pancake ice*. If pancake ice thickens further it forms *floes*, which eventually grow into *first year sea ice*.

When the seas congeal into frozen sea ice, the size of the Antarctic almost doubles and the continent becomes almost inaccessible. Image: Ville Miettinen, Wikicommons.

2. ***First year sea ice*** is initially salty but with time the salty brine drains down through the ice. If this ice is frozen to the continent, it is known as *fast ice*, but if it rests on open ocean it is known as *pack ice*
3. ***Multi-year ice*** is ice that has survived more than one winter so is the least salty. It is also the least dense because of the empty holes (brine pockets) near its surface.

6. Ice floes

Sea ice is not a single uniform sheet of ice, but is grouped into floes. These floes move with wind and currents, and may join together forming 'pressure ridges' where they meet.The areas of open water between floes are known as *polynyas*. Polynyas usually last a long time and occur in the same place, due to ocean currents and water upwelling from below. These islands of open water are crucial for some organisms to survive the cold winter months.



There are many different types of ice in Antarctica.

Adapted from material by *Kate SInclair, GNS*.
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See following page for practical ideas.

Practical activity: Making sea ice

Introduction

Sea ice forms differently from other forms of ice mainly because it:

- cools by loosing heat from the upper surface, into the atmosphere
- thickens by the continual formation of new ice on the underside of sea ice
- contains salt, which is lost from beneath the ice as it freezes

What to do

1. Cut the top of a large plastic bottle.
2. Add 1 litre of tap water and 35 grams (2 Tps) of table salt.
3. Stir until all the salt is dissolved.
4. Wrap the bottle's sides and base with an insulating layer (eg old towels, clothing, newspaper), but leave the top surface of the salty water exposed.
5. Place the bottle and insulation in a freezer, for about two to four hours.

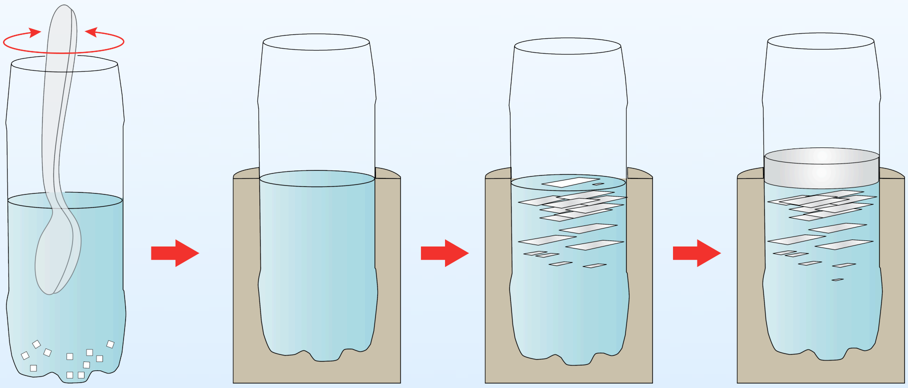

Image: iMatters

How it works

As the water in the sea freezes it forms flat sheets of *platelet ice,* which float upwards.
As cooling continues the platelets join to form a solid mass of ice.
As the water freezes the salt is excluded and sinks downwards.

Note:
The ice becomes less salty, while the solution (sea) below becomes more salty. This can be easily be tested by tasting the saltiness of a small sample of these three

- the salty water at the start
- the water from beneath the ice.
- the ice

Relevance

- Sea ice forms due to loss of heat from the sea into the colder atmosphere above.
- Sea ice forms on the sea surface, insulating the water below and preventing whole oceans freezing.
- Salt sinking beneath sea ice helps to drive the circulation of ocean currents around the world.

Practical activity: Make an ice flow model

For details visit :

www.gns.cri.nz/Home/Learning/Science-Topics/Ice-Snow/Lesson-Plans

Practical activity: Make an model of Antarctic ice

Using the materials below, make a model which shows features in the diagram.

- plastic container
- rocks (as bedrock)
- sediment (sand or gravel)
- fresh and salty water

Note: Your model will have to be made in stages, rather than in one step.