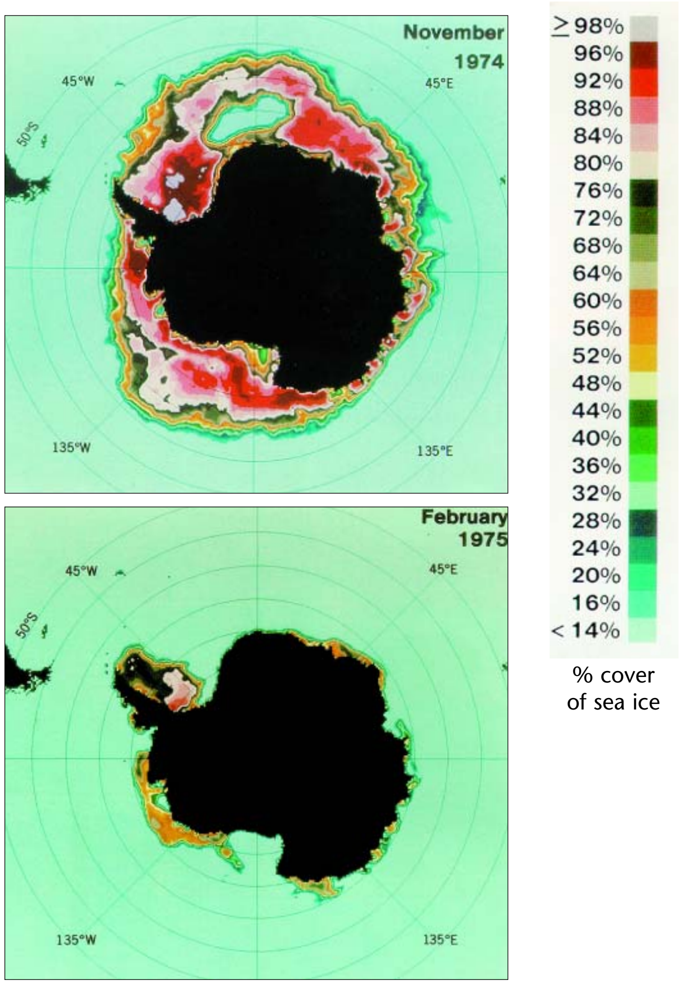
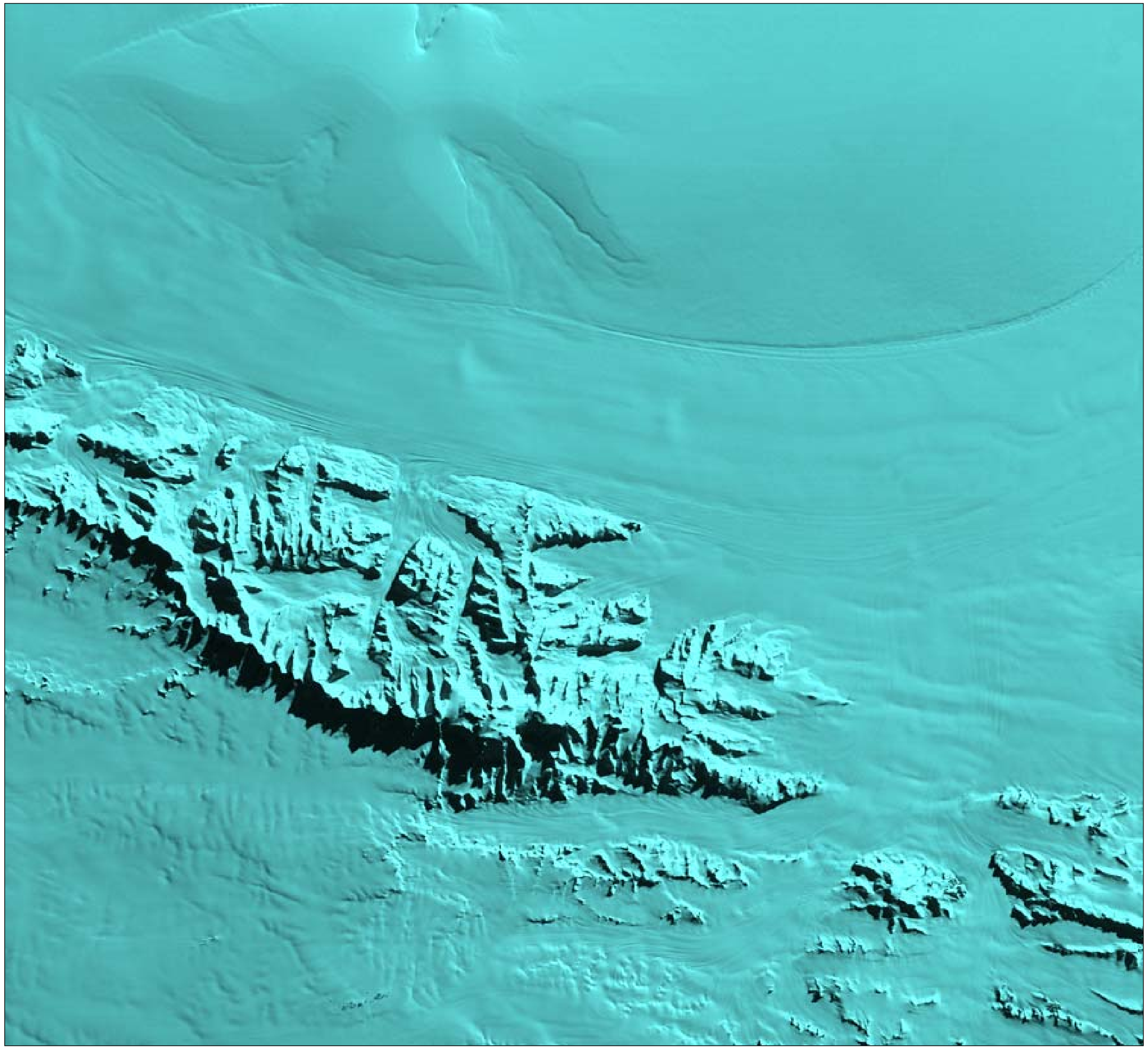
Sea ice and ice streams

Resource ICE1



NASA satellite images of sea ice extent in November 1974 and February 1975. The hole in the sea ice in the November image is a polynya and was a semi-permanent feature in the 1970s. However, it has not reappeared since then.

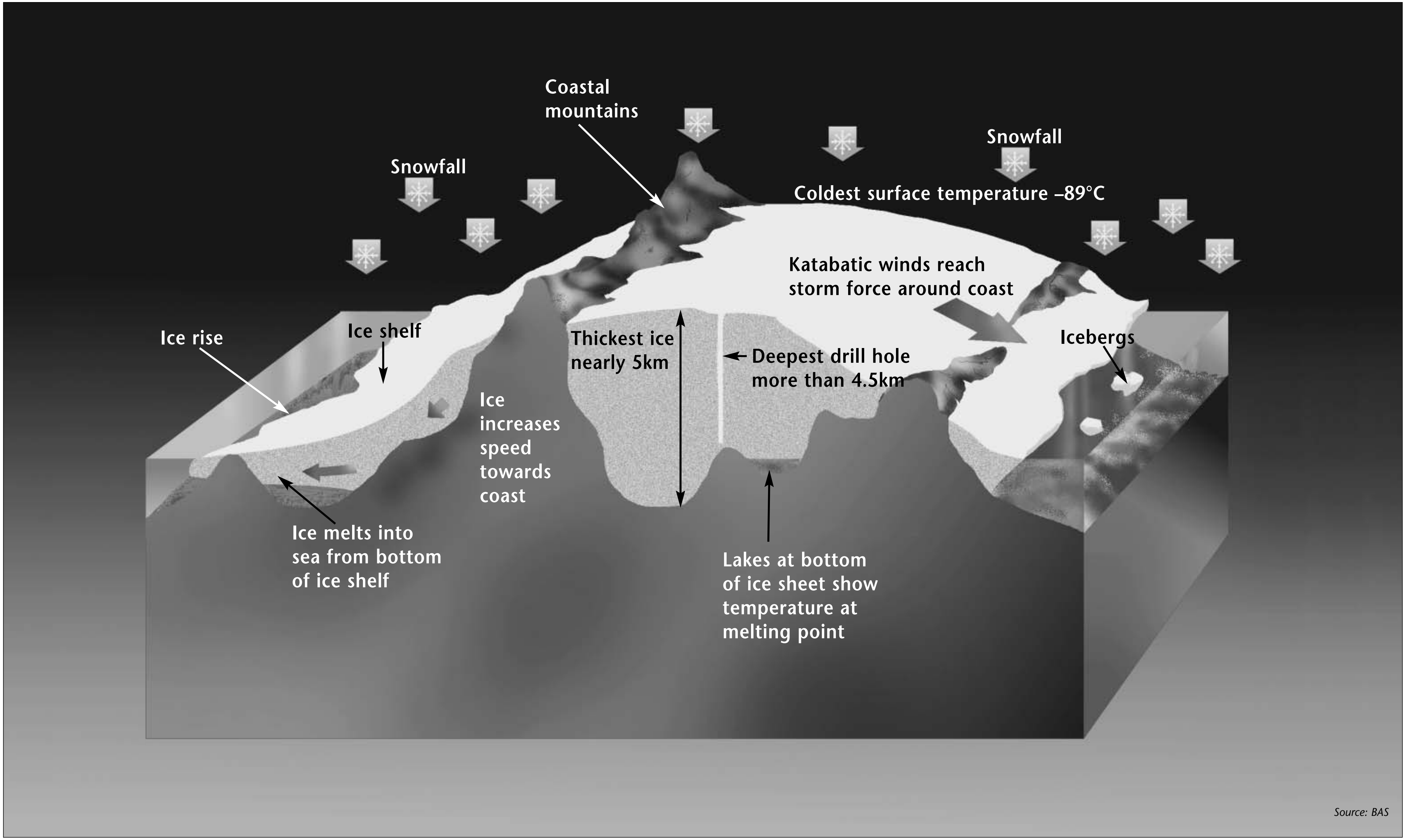
NASA



BAS/Eosat Ltd

Landsat satellite image of the Rutford Ice Stream

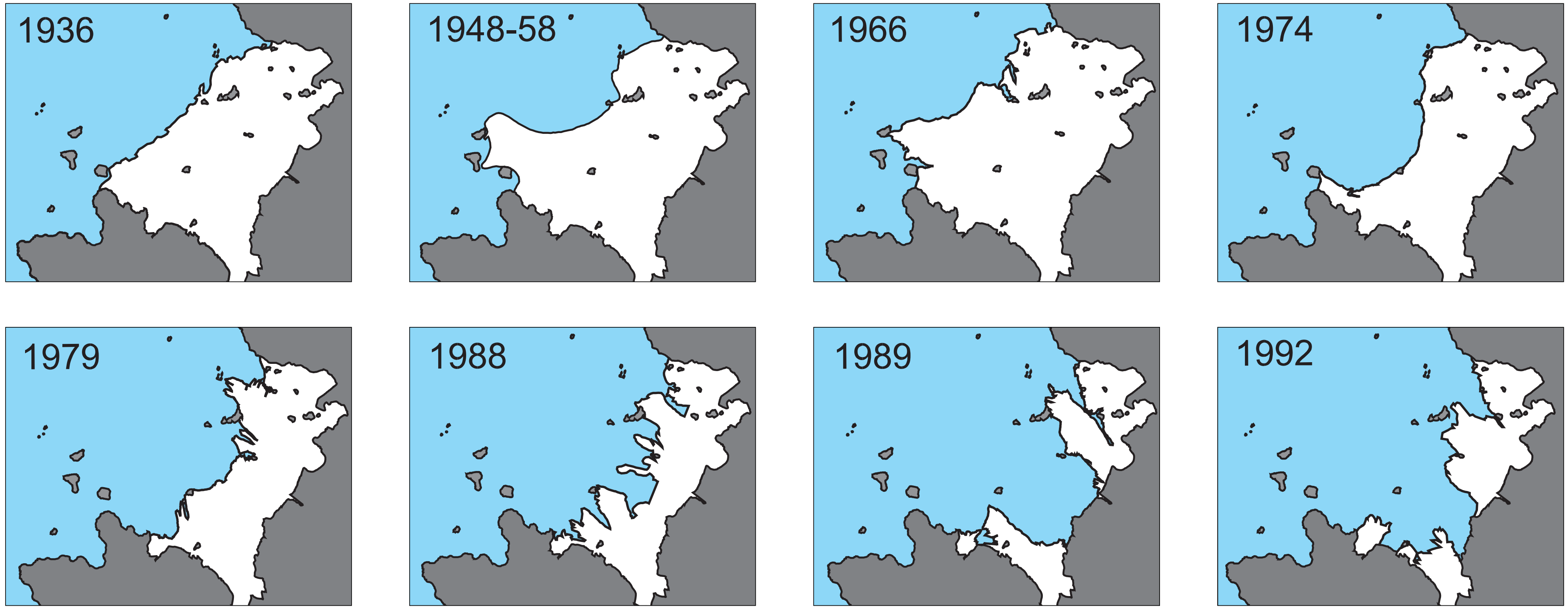
A block diagram of the Antarctic ice sheets



Source: BAS

The retreat of Wordie Ice Shelf

Resource ICE3

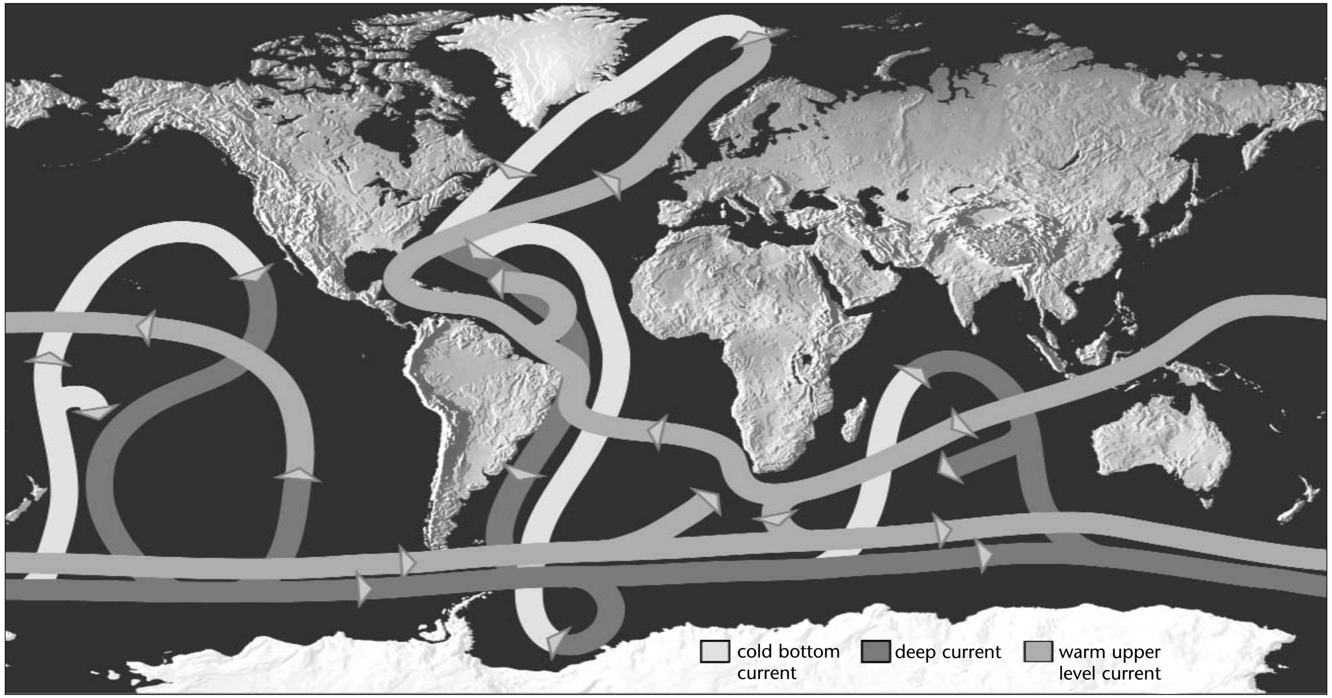


The extent of the Wordie Ice Shelf from 1936–92. This series of maps was compiled from expedition reports, aerial photography and satellite images.

Source: BAS

The thermohaline circulation (THC)

Climate and weather patterns are controlled partly by the transport of heat over the planet. Water has a greater heat capacity than air, so the oceans dominate heat movement between the tropics and the poles.



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The thermohaline circulation in the Antarctic

The largest part of the heat transport system is known as the 'thermohaline circulation' (THC). Differences in seawater density in different parts of the world cause flow from 'high pressure' (e.g. high density) to 'low pressure' (e.g. low density) regions, as in the atmosphere. These density changes are caused by changes in salinity (saltiness) and temperature.

The THC consists of several currents which form a continuous 'Conveyor Belt', linking the major ocean basins. Flow close to the surface in one direction is balanced by flow in the opposite direction close to the sea floor (see diagram). Input of very dense water into the deep ocean to drive the deep water currents is a very important component of the THC. Cold, salty water is produced near the surface, and then sinks because of its high density. There are two regions where this occurs:

- where water from the Arctic Ocean enters the North Atlantic Ocean; and
- at a few locations around Antarctica.

The production of this especially dense water in the Southern Ocean is linked to the formation of sea ice close to floating ice shelves. The largest volume is produced in the Weddell Sea, off the Filchner Ronne Ice Shelf, close to the South Atlantic Ocean.

The climate in north-western Europe is influenced strongly by the transport of heat by the THC. Countries such as the UK and France enjoy relatively mild winter climates because of it. Mean January temperatures in Brittany, for example, are around 4°C. The average temperatures for the same month in Eastern Canada, at a roughly comparable latitude, are around -5°C. This contrast happens because heat is carried from the tropics to western Europe by the Gulf Stream/North Atlantic Drift.

A major change in the THC could have massive impact on north-western Europe, making its climate similar to that of the eastern seaboard of North America. Rapid cooling events happened in the British Isles at the end of the last Ice Age. The pattern of those events suggest that the North Atlantic Drift did not reach so far north, thus switching off the oceanic 'central heating'.

Some climatologists are now using complex computer models to examine whether future climate change could also affect the THC. They suspect that a warmer world could change the amount of sea ice, and possibly also change the ice shelves. Such changes could alter the amount of dense water supplied to the deep ocean currents.

The implications of changes in the North Atlantic Drift for the UK and north-western Europe would be immense. Ironically, it contradicts the expected consequences of global warming. While most people anticipate a warmer climate in the UK the opposite could be the case, at least in winter.

These predictions are highly speculative, although the evidence for past changes is strong. This issue highlights the complexity of atmospheric and oceanic systems and the difficulties attached to predicting change. It also illustrates the interconnectedness of the planet's systems. Changes in sea ice in Antarctica could influence the climates of countries thousands of kilometres away.

Response of the ice sheets to climate change

Resource ICE5

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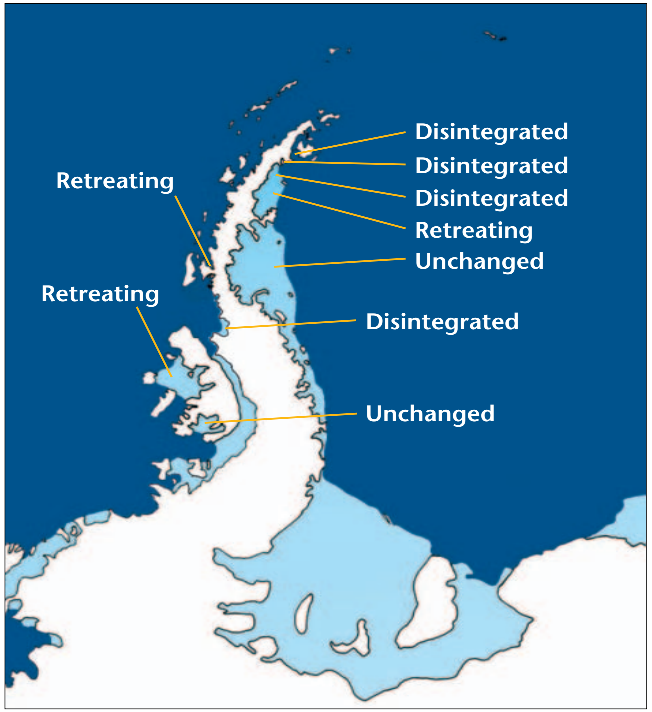
Break-up of the Larsen B Ice Shelf

Ice sheets are only one of several factors controlling world sea level. The majority of recent sea level rise resulted from thermal expansion of the oceans and melting of non-polar glaciers. Ice sheets are, however, important and we know that the most rapid periods of sea level rise coincided with ice sheet retreat. To plan for the future we must urgently address the question: what will be the contribution of ice sheets to changing sea level?

Ice sheet balance

Every year the Antarctic ice sheet accumulates mass from falling snow and frost. It loses mass through icebergs, melting from the base of ice shelves and a small amount of surface melting. Measuring imbalance between yearly accumulation and loss would allow us to estimate the change in the mass of the ice sheet. Although a change in floating ice has no impact on sea level (it already displaces its own mass of water) any change in the grounded ice sheet will affect sea level directly. Two methods are used to determine the mass balance of the ice sheet. We can estimate both the mass accumulated and mass lost, and subtract them to give the imbalance. This method is prone to large uncertainties. Alternatively, we can use modern remote sensing techniques to measure directly whether the ice sheet is getting thicker or thinner. One such recent study used a satellite altimeter. It showed that at present most of the ice sheet is close to balance. The problem with this method is that we have only a few years of data and not all of the ice sheet has been measured.

Predicting the future of the ice sheet requires us to investigate and understand past and present changes in the ice sheet and what caused them. We must then use our understanding to build models that predict the fate of the ice sheet reliably.



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Changing ice shelves in the Antarctic Peninsula. Ice shelves are shown as they were in 1990.

Ice shelf retreat

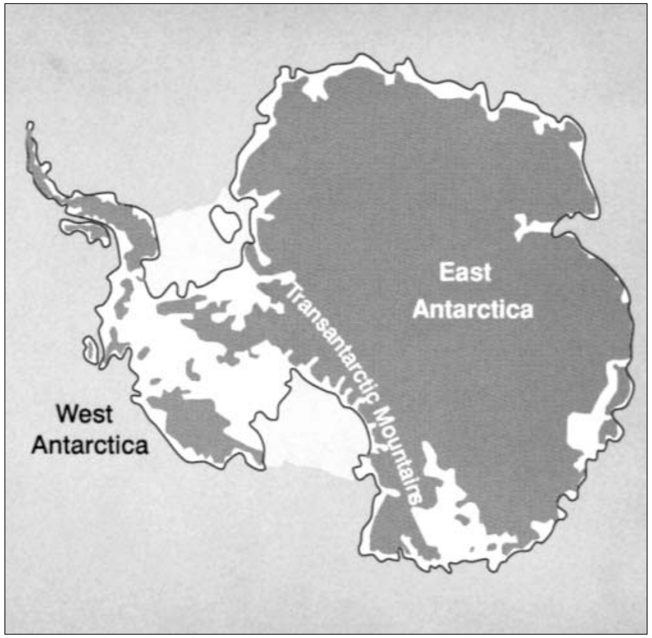
Floating ice shelves fringe much of the Antarctic ice sheet (only a few small ice shelves exist in the Arctic). Recently considerable research has been devoted to looking at what controls their size. It is now clear that while the calving of icebergs as large as small countries (e.g. from the Ronne-Filchner and Ross ice shelves in the 1980s) may be part of the normal life-cycle of an ice shelf, the progressive retreat of smaller ice shelves on the Antarctic Peninsula may well be linked to changing climate.

The extent of ice shelves around the Antarctic Peninsula have been mapped using various data: reports from expeditions, aerial photographs and satellite images. Around 8000 km^2 has been lost since the 1950s. In the same period meteorological stations on the Antarctic Peninsula measured an increase in the air temperature of about 2°C. The two observations can be linked because there exists a climatic limit of viability for ice shelves related to summer temperatures. Warming has pushed the limit south and all the ice shelves that are now to the north have retreated, including: Wordie Ice Shelf, the ice shelf that occupied Prince Gustav Channel; and Larsen Ice Shelf A. The final stages of the loss of Larsen Ice Shelf A in 1995 were particularly spectacular; in 50 days an area of ice shelf the size of Surrey broke up into thousands of football pitch-sized icebergs and floated away.

What caused the warming which attacked the ice shelves is not yet clear. It is possible the climate in this region is subject to natural cycles or that the warming could be related to global climate change. If the warming continues more ice shelves may be threatened.

The stability of the West Antarctic ice sheet

While ice shelves are not a direct influence on sea level because they are already floating, it has been argued that the Ross and Ronne-Filchner ice shelves help to stabilise the ice sheet in West Antarctica and so indirectly help to control sea level. Scientists are still unsure if the ice sheet would collapse if these ice shelves retreated. Total loss of the West Antarctic ice sheet would raise global sea level by around 6 m. Fortunately, these ice shelves are a long way south where it is much colder than on the Antarctic Peninsula, and they are unlikely to be threatened by warming in the next 200 years. The Intergovernmental Panel on Climate Change (IPCC) gives us the most authoritative view on the subject, saying ‘the likelihood of a major sea level rise by the year 2100 due to a collapse of the West Antarctic Ice Sheet (WAIS) is considered low’. For planning purposes, however, the low probability of ice sheet collapse must be balanced against the severity of its impact.



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The land remaining (shaded dark grey) if all the Antarctic ice sheet were removed

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A BAS glaciologist surveying the Antarctic ice sheet

Thickening ice sheet?

Ironically, there is an opposing effect that scientists are more confident in predicting. If the southern hemisphere climate warms, warmer air will transport more moisture to Antarctica. This will give more precipitation and affect the mass balance of the Antarctic ice sheet. The ice sheet will respond by thickening. So over the next century changes in Antarctica may oppose sea level rise, although they are unlikely to be sufficient to completely counteract the thermal expansion of the oceans and melting of non-polar glaciers.

Conclusion

Global sea level is a difficult thing to measure but there is good evidence that over the last 100 years it has risen by between 10 and 25 cm. For the next 100 years there is no single reliable prediction. In 1995, the IPCC predicted a rise of between 13 and 94 cm but noted that the behaviour of the polar ice sheets remains a major source of uncertainty. The lack of certainty justifies the need for extensive research into both climate change and the dynamic behaviour of ice sheets.

Antarctic ice

Worksheet 7

The Antarctic ice sheet covers more than 99% of the continent and is up to 4700 m thick. Many textbooks discuss ice sheets in terms of geomorphology, the study of the features they leave on the landscape, but this worksheet concentrates on how ice sheets influence the rest of the world, through climate and sea level. First we describe the features of the ice sheet and surrounding sea ice.

Ice sheets

The Antarctic ice sheet is the largest single mass of ice on Earth. It covers an area of almost 14 million km^2 and contains 30 million km^3 of ice. Around 90% of the fresh water on the Earth's surface is held in the ice sheet, an amount equivalent to 70 m of water in the world's oceans. In East Antarctica the ice sheet rests on a major landmass, but in West Antarctica the bed is in places more than 2500 m below sea level. It would be seabed if the ice sheet were not there. Even in summer, Antarctic temperatures are below 0°C and so frost and snow crystals that gather on the surface of the ice sheet do not melt but accumulate year-by-year. As these crystals are buried the weight of the crystals above presses them together. Eventually, they are transformed into dense and impermeable glacial ice.


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The wind forms rough shapes on the surface of the ice


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A large tabular iceberg

Glacial ice seems solid but under the tremendous pressures it experiences in the ice sheet, it will flow like a viscous liquid. This means that the ice sheet does not continue to get thicker as new snow falls but, under the action of gravity, flows over and around obstacles toward the sea. The ice sheet acts like a conveyor belt, taking snow from the atmosphere and delivering ice back to the sea. Whether the mass of ice entering balances the amount leaving is the subject of considerable scientific research.

Although the surface is cold, the base of the ice sheet is generally warmer, in places it melts and the melt-water lubricates the ice sheet so that it flows more rapidly. This process produces fast-flowing channels in the ice sheet – these are called ice streams.

Ice streams

Although they account for only 10% of the volume of the ice sheet, ice streams are sizeable features, up to 50 km wide, 2000 m thick and hundreds of km long. Some flow at speeds of over 1000 m per year and most of the ice leaving the ice sheet passes though them.

Ice streams generally form where basal water is present, but other factors also control their velocity, in particular whether the ice stream rests on hard rock or soft, deformable sediments. At the edges of ice streams deformation causes ice to recrystallise making it softer and concentrating the deformation into narrow bands or shear margins. Crevasses, cracks in the ice, result from rapid deformation and are common in shear margins.

Ice streams and glaciers are effective at eroding rock and their presence can leave lasting marks on the landscape (e.g. truncated spurs).

Task 1 Resource ICE1 shows a Landsat satellite image of the Rutford Ice Stream, bounded by the Ellsworth Mountains in the lower part and Fletcher Promontory near the top. Trace the image, or draw a sketch map, and mark the following features:

- Ellsworth Mountains
- Fletcher Promontory
- Rutford Ice Stream
- shear margins
- tributary glaciers
- possible corries or cwms
- truncated spurs
- the direction of flow (how can you tell?).

Task 2 Resource ICE2 shows a block diagram of the ice sheet. Draw a vertical cross-section of this and annotate it using the information given in this worksheet.

Ice shelves

Ice is less dense than water. Near the coast ice sheets generally rest on a bed below sea level, but there comes a point where it begins to float. It floats in hydrostatic equilibrium and either it stays attached to the ice sheet as an ice shelf, or breaks away as an iceberg. Being afloat, ice

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The mountainous, glaciated coastline of the Antarctic Peninsula

shelves experience no friction under them, so they tend to flow even more rapidly than ice streams, up to 3 km per year. Much of Antarctica is fringed by ice shelves. The Ross and Ronne-Filchner ice shelves each have areas greater than the British Isles.

Across the base of ice shelves sea water and ice come into contact. Where this sea water is warm enough, the ice shelf will melt, adding cold fresh water to the sea. This diluted seawater eventually helps to form a water mass called Antarctic Bottom Water which is present in many of the deepest parts of the world's oceans. Eventually ice breaks off the ice shelves to form icebergs.

Sea ice

Beyond the ice shelves is the sea. When the sea freezes it forms a salty type of ice – sea ice. The area covered by sea ice varies with the seasons from around 3 million km^2 in February, to around 20 million km^2 in October. Satellite images of sea ice extent are shown in Resource ICE2.

Task 3 Trace over the coastline of Antarctica shown on the maps in Resource ICE2. Draw on your map the extent of the sea ice in November and February. Estimate the difference in area (millions of km^2). What factors discussed in the text make this exercise difficult.

Although only a few metres thick, sea ice insulates the sea and limits the amount of sunlight reaching it. Lack of light limits growth of phytoplankton in the sea, though algae do multiply in the sea ice itself, sometimes turning it brown. The insulation effect reduces heat transfer between ocean and atmosphere, keeping the air cold and dry. Finally, as sea ice melts it cools both ocean and atmosphere. Because it limits energy transfer, the extent of sea ice is critical to the climate of the Southern Ocean.

Is climate change altering the ice sheet?

Glaciologists study the ice sheet using a variety of modern techniques (for example, ice-penetrating radar, satellite remote sensing and field surveying). They measure ice thickness, the rate of accumulation and loss, and they image flow structures within the ice.

Most glaciologists agree that the Antarctic ice sheet has existed continuously for at least 3 million years. However, there is evidence that local changes are under way. Sea ice extent appears to be decreasing, and some ice shelves are breaking up. The most spectacular of these attracted considerable publicity, particularly the collapse of part of Larsen Ice Shelf in 1995. Resources ICE3–6 focus on climate change and draw your attention to the loss of ice cover. Resource ICE3 shows the retreat of Wordie Ice Shelf from 1936 to 1992, compiled from expedition reports, aerial photographs and satellite images.

Task 4 Produce a map of the Wordie Ice Shelf as it was in 1936 using Resource ICE3. Using one or more overlays plot the retreat of the ice shelf until 1992. Using graph paper or another technique calculate the area of ice lost. What do you think caused the ice shelf break-up?

Future changes in the Antarctic ice sheet

There has been much speculation that climate change could lead to collapse of ice sheets, particularly the one in West Antarctica which rests on a bed so far below sea level. Predictions about its future must be based on reliable predictions of climate and an understanding of the controls on the ice sheet. The Intergovernmental Panel on Climate Change (IPCC) has predicted that global mean temperatures will rise by between 1°C and 3.5°C by the year 2100; their 'best' estimate is 2.0°C. However, local changes may be quite different to the average. In particular, there will be increased precipitation in polar regions and Antarctica will probably experience less warming than the Arctic.

So far a few meteorological records from Antarctica have shown more warming than predicted whilst others have shown no change at all. Climate change is the subject of considerable debate. The issues are summarised in Resources ICE4 and ICE5.

Task 5 Read Resources ICE4 and ICE5 and discuss the probability of the melting of the West Antarctic Ice Sheet (WAIS) and the likely future of global sea level over the next 500 years.

Oceanic circulation and the ice sheets

Comparing the overview in Resources ICE4 and ICE5 with recent press and media coverage may lead you to believe that the threat of catastrophic sea level rise has been overplayed. However, ice sheets influence the Earth in many other ways. Ice sheets and sea ice help to drive the thermohaline circulation (THC) of oceans. The THC spreads heat around the planet. For example, it brings warm waters to the shores of Britain and keeps us warmer than we would otherwise be. Changes in ice brought about by climate change could have considerable consequences for the THC. These are discussed in Resource ICE4.

Task 6 With reference to the account of the THC explain with the aid of sketch maps how the climate of Britain could be affected by changes in Antarctic ice.