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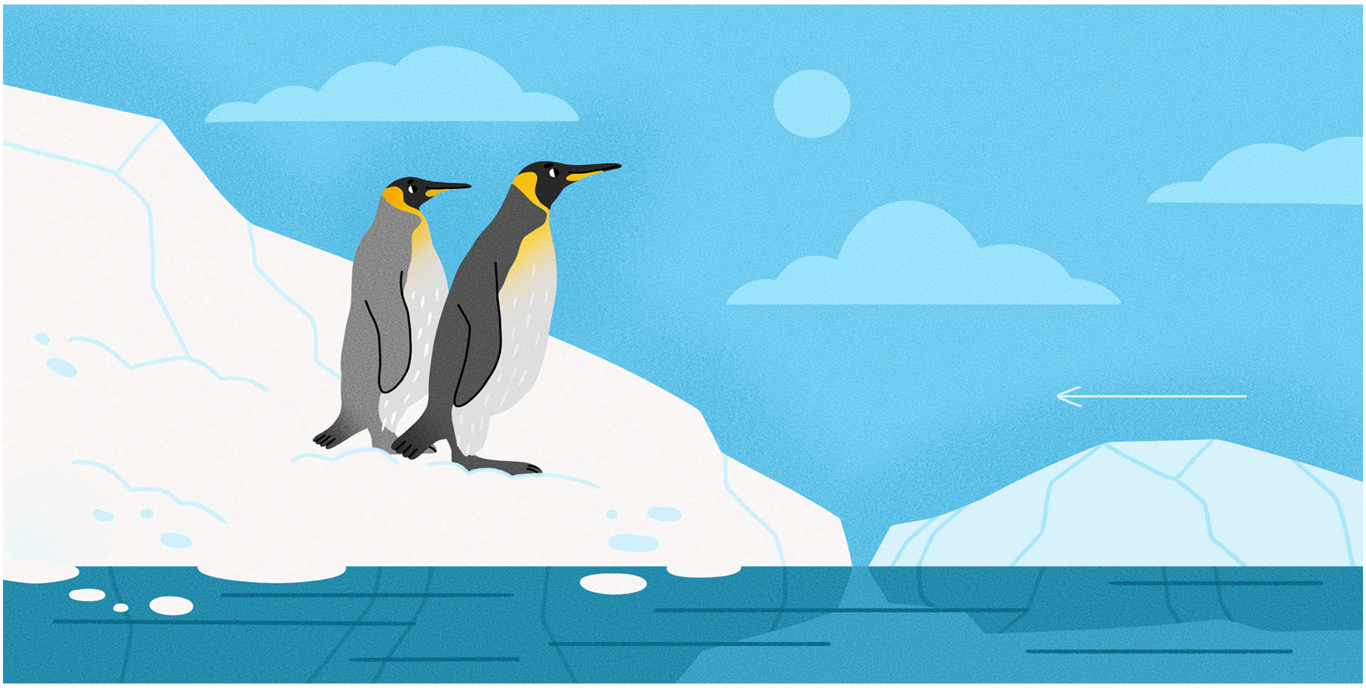

THE IMPORTANCE OF SEA ICE TO ANTARCTIC ICE SHELVES

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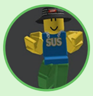
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Ice shelves are important because they act as a dam that regulates the amount of land ice that flows into the ocean. This means if Antarctica's ice shelves were to break up, more ice would be melted into the ocean and global sea level would rise at a much faster rate. Because Antarctic ice shelves float in the ocean, they are not only sensitive to warming air temperatures but also to changes in the Southern Ocean. One such important factor is how ice shelves interact with sea ice. When sea ice attaches to the front of ice shelves, it can act as a glue, preventing ice-shelf break-up and promoting ice-shelf growth. In the open ocean, sea ice can also help protect ice shelves from damaging ocean waves formed during large storms. Sea ice will play an important role in determining the fate of Antarctic ice shelves in the coming decades.

WHAT ARE ICE SHELVES AND WHY ARE THEY IMPORTANT?

ICE SHEET

A huge body of ice that covers vast expanses of the polar regions. Currently, Greenland and Antarctica are covered by ice sheets.

The Antarctic **ice sheet** is vast! Larger than the USA and United Kingdom combined, it is covered in a layer of ice that is over 4 km thick in places (Figure 1). If all the ice in Antarctica were to melt into the ocean, global sea levels would rise by 58 m. There is no chance of this happening anytime soon, but even relatively small contributions of 1 m to global sea-level rise in the next 100 years would cause significant coastal flooding and have important consequences for those who live near the coasts around the world.

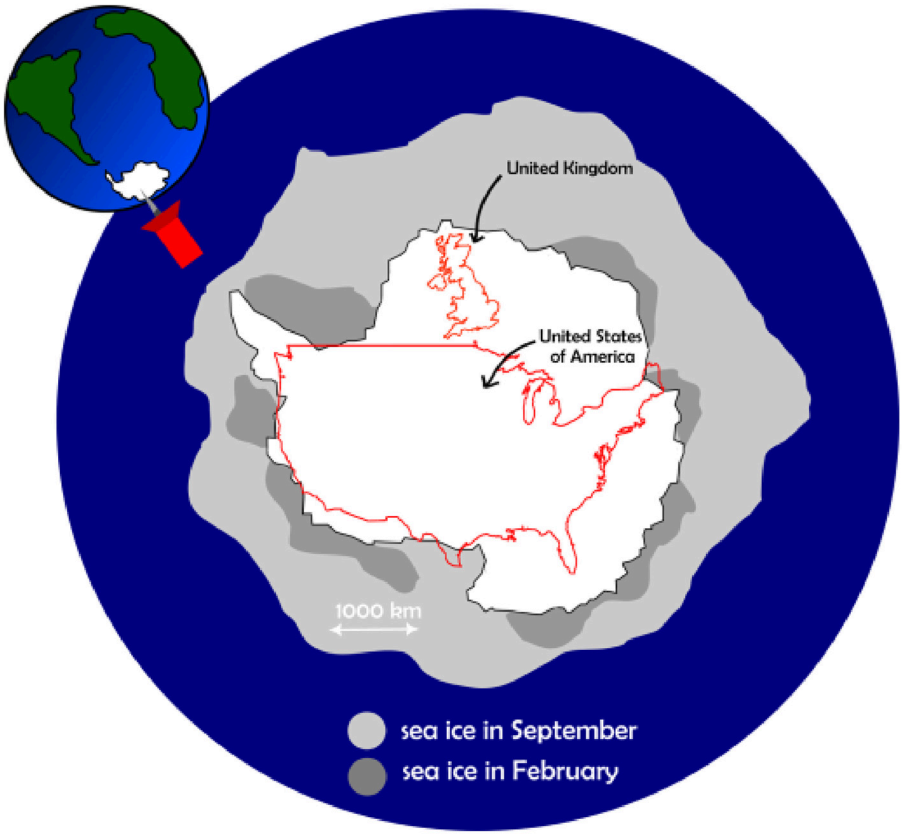

Figure 1

Figure 1

The Antarctic continent is located at the South Pole and is covered by a giant ice sheet. Antarctica is bigger than the USA and many times the size of the United Kingdom. At its annual maximum in winter (September), the sea ice surrounding Antarctica effectively doubles the size of the continent!

GLACIER

A slow-moving river of ice. The fastest flowing glacier in Antarctica is Pine Island Glacier, which flows at over 4 km year.

ICE SHELVES

A large platforms of ice that forms where an ice sheet flows into the ocean and starts floating.

Within the Antarctic ice sheet, large rivers of slow-moving ice form, known as **glaciers**. These glaciers flow from the middle of the ice sheet into the Southern Ocean, where they form floating platforms of ice called **ice shelves**. Ice shelves fringe most of Antarctica and are very important because they act as a dam and help slow down the rate of ice flow into the ocean. This means that if ice shelves are removed or get smaller, more ice can flow into the ocean and contribute to global sea-level rise. An example of this process happened in 2002, when an ice shelf called Larsen B completely broke up. This triggered the glaciers that formerly fed the ice shelf to speed up six-fold in just a few months, resulting in more ice melting into the ocean [1]. In fact, many of Antarctica's ice shelves have been getting smaller over recent decades, causing an increase in Antarctica's contribution to global sea-level rise [2]. This means the fate of Antarctica's ice shelves has global importance.

ICEBERGS

Large floating blocks of ice that have broken away from a glacier, ice shelf, or ice sheet.

CALVING

The break-off of icebergs from the fronts of ice shelves and glaciers.

WHAT CAUSES ICE SHELVES TO CHANGE?

A healthy ice shelf grows constantly because the glaciers that flow into the ice shelf are constantly moving forward. At some point in time, sometimes after several decades, large **icebergs** break away from the ice shelf through a process known as **calving**. This is a perfectly normal, natural cycle of ice-shelf advance and retreat. However, when warm ocean currents cause the ice shelf to melt more quickly and get thinner, the rate of calving increases and the ice shelves can retreat and get smaller. Generally, Antarctica is very cold and the air temperature rarely gets above freezing. This means there is very little melt on the surface of most ice shelves. But on some of the ice shelves furthest away from the South Pole, warmer air temperatures cause enough melt to form bright blue melt ponds on their surfaces. The weight of these melt ponds can help grow existing cracks in the ice shelf, leading to more rapid calving. But ice shelves can change for another reason: their complex interaction with sea ice [3–5].

WHAT IS SEA ICE?

At its maximum extent at the end of the Southern Hemisphere winter in September, sea ice around Antarctica covers up to 20 million km^2, almost 4% of the Earth's surface or an area greater than China and the US territories combined! In contrast, during the Southern Hemisphere summer, Antarctic sea ice reduces its size to roughly 4 million km^2 (Figure 1). Unlike the Arctic sea ice in the Northern Hemisphere that has been shrinking for decades, Antarctic sea-ice extent has only recently started to decline in response to climate change. In fact, in September 2023, the maximum Antarctic sea-ice extent was over 1 million km^2 lower than the previous low for this time of the year, and the magnitude of this decline in sea-ice extent has surprised scientists.

LANDFAST SEA ICE

Sea ice that has fastened to an ice-shelf front, coastline, islands, or icebergs that have become stuck to the seafloor.

ICE TONGUE

Similar to an ice shelf, a long narrow platform of ice that extends from a glacier flowing into the ocean.

Did you know there are many types of sea ice? Newly formed sea ice is called new ice, and we call it multi-year ice once it has survived multiple summer melt seasons. Some of the sea ice surrounding Antarctica is fastened to the coastline: we call it **landfast sea ice**, or simply fast ice [6]. It acts as a glue between ice shelves, **ice tongues**, icebergs that have become stuck to the seafloor, and small islands (Figure 2). When sea ice is freely moving around Antarctica, we call it pack ice. Unlike pack ice in deep water, which forms and breaks up seasonally, landfast sea ice is mostly present year-round as a narrow band around the coast. It can form decades-old slabs of ice tens of meters thick!

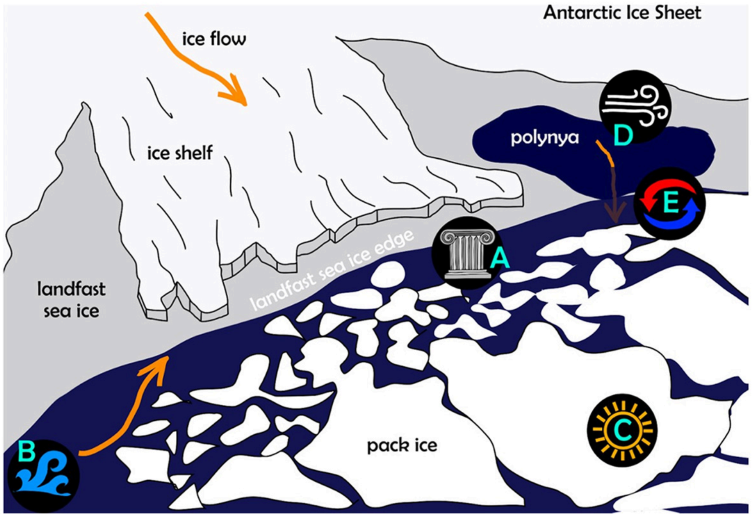

Figure 2

Figure 2

(A) As ice flows from the interior of the ice sheet into the ocean, it can form ice shelves—floating extensions of the ice sheet. Landfast sea ice attaches to the coastline and to the ice shelf, stabilizing the ice shelf. **(B)** It can also help protect ice shelves from damaging ocean waves during large storms. **(C)** The bright White Sea ice strongly reflects the sun's rays, which helps to cool the atmosphere. **(D, E)** Areas of open water called polynyas are regions of high sea-ice production that create a cold, dense, salty water mass that helps drive global ocean circulation.

GLOBAL IMPORTANCE OF SEA ICE

To understand why sea ice is so important for Antarctic ice shelves, we must first look at its role in the global climate system. Sea ice is extremely important because it has a direct influence on Earth's atmosphere and the global ocean circulation. First, sea ice acts as an insulating blanket by preventing heat transfer between the atmosphere and the ocean surface. The bright white surface of sea ice strongly reflects the sun's rays, which helps to cool the atmosphere. Each winter when cold ocean water freezes and forms sea ice, a very cold, dense, salty seawater is formed. This water is much denser than the water at the surface, so it sinks deep into the ocean. When this water sinks, it drives the global ocean circulation (Figure 2). Even during the coldest parts of winter, there can be sea-ice-free regions near the coast, known as **polynyas**. Polynyas form when strong winds blow sea ice away from the coastline, into the open ocean. More sea ice quickly forms in its place because the open ocean is exposed to the cold air temperatures. For this reason, we sometimes call polynyas "sea-ice factories".

POLYNYA

A stretch of open ocean water surrounded by sea ice.

PILLAR OF STRENGTH

The Southern Ocean is very stormy and these storms often create large ocean swells far out at sea that travel toward the Antarctic coastline. Large ocean swells can cause ice shelves to bounce up and down, much like a ship during stormy seas. Bouncing up and down can cause cracks to form in the ice, making an ice shelf more vulnerable to breaking apart. Fortunately, sea ice in the open ocean often helps reduce the strength of ocean swells by acting as a crash barrier, absorbing much of the energy of the swell before it reaches the coastline. However, when large storms and sea-ice-free conditions coincide, it can be bad news for ice shelves. There is growing evidence that ice-shelf break-up events tend to occur during these conditions, especially if those ice shelves have already been weakened by melt and thinning [3].

At the coastline, landfast sea ice can directly prevent icebergs from breaking away and promote ice-shelf growth. This is because landfast sea ice acts as glue holding weak ice shelves together, along with protecting ice shelves from waves directly crashing into them. Unlike sea ice in the open ocean, which melts every summer, landfast sea ice can persist for multiple years and sometimes decades. Indeed, some ice shelves continuously advance for decades when landfast sea ice remains fastened to the ice-shelf front! However, sometimes, landfast sea ice can "break out" by rapidly breaking up and being carried away by ocean currents. This can happen for different reasons, like when strong winds from the Antarctic interior weaken the landfast sea ice and help blow it offshore. Once the landfast sea ice is gone, this can trigger ice tongues and ice shelves to break apart [4, 5]. An example of this was seen in 2020 when the Parker ice tongue [4], which had previously been growing for many years, broke apart over the course of a few days after the loss of its protective landfast sea ice barrier (Figure 3).

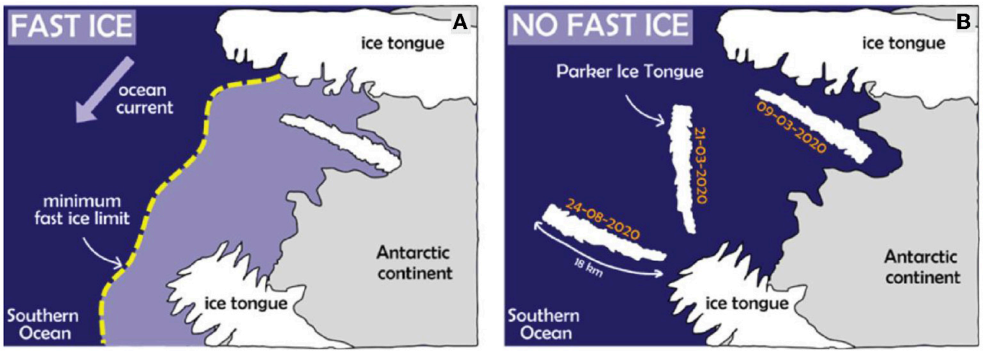

Figure 3

Figure 3

(A) Landfast ice, also called fast ice, provides stability to long, thin fingers of floating ice called ice tongues. **(B)** The large Parker ice tongue broke off in 2020, following the break out of the landfast sea ice. You can see how it drifted over the course of a few months.

OUTLOOK FOR THE FUTURE?

The continued decline in sea ice in the Southern Ocean over the next 50–100 years in response to human-caused climate change seems inevitable, but by how much? Well, in many ways the future of sea ice in the Southern Ocean depends on us! If we limit global warming to 1.5°C, we will limit sea-ice loss to as little as 30%. However, if we continue to burn fossil fuels at current rates, we cannot rule out losses of up 90% of sea-ice extent by 2100 [7]. Less sea ice will be bad news for Antarctica's floating ice shelves, and as a result we could expect a greater rate of iceberg calving and ice-shelf retreat as the protective barrier of sea ice diminishes. Future reduction in ice shelf extent will reduce the damming effect of ice shelves and lead to increased flow of inland ice into the Southern Ocean, raising global sea levels. Under current projections, melt from the the Antarctic Ice Sheet is projected to increase global sea level by up to 33 cm by 2100, but this is highly dependent on future emission scenarios.

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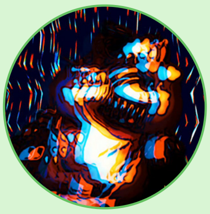

CEDRICK, AGE: 13
I like playing videogames and drawing.

JUDE, AGE: 15
I am a big fan of both dogs and cats. I have trained my cat to walk on a lead so we can go for walks together in my spare time. I also love music and spend a lot of time playing my guitar. I enjoy reading about biochemistry (especially plant related) and one day would like to study the subject at university.

MAYA, AGE: 13
I love science and reading. I love to sing and dance. My favorite TV show is the Umbrella Academy and any science/thriller related things.

NOAH, AGE: 12
I like gaming, watching YouTube and building Lego.

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