ALFRED-WEGENER-INSTITUT
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FACT SHEET

THE CONSEQUENCES OF CLIMATE CHANGE FOR LIFE IN THE Southern Ocean

A habitat for tough species

The Southern Ocean is the body of water around Antarctica. It completely surrounds the iced continent and stretches over an area of 20.3 million square kilometres, corresponding approximately to 57 times the size of Germany. Geographers draw its official northern boundary at 60 degrees latitude South. In the south, by contrast, the coastline of the Antarctic continent forms a natural boundary to the sea.

This southernmost marine region of the Earth is known among seafarers, adventurers and scientists as being extremely stormy and ice-cold. The Southern Ocean owes this and other features to its immediate proximity to the Antarctic. Here are three examples for the close interplay. The great temperature and pressure difference between the cold air masses over the Antarctic continent and the warmer air over the subtropics fuel west winds that are so strong that they drive the most powerful ocean current of the Earth, the Antarctic Circumpolar Current. Where the ice masses of the Antarctic ice sheet float on the Southern Ocean as an ice shelf, the temperature of the seawater drops to as low as minus two degrees Celsius. Its high salt concentration alone then prevents it from freezing on the spot. And during the nine-month-long Antarctic winter an up to 1.5 metre thick sea ice cover forms on

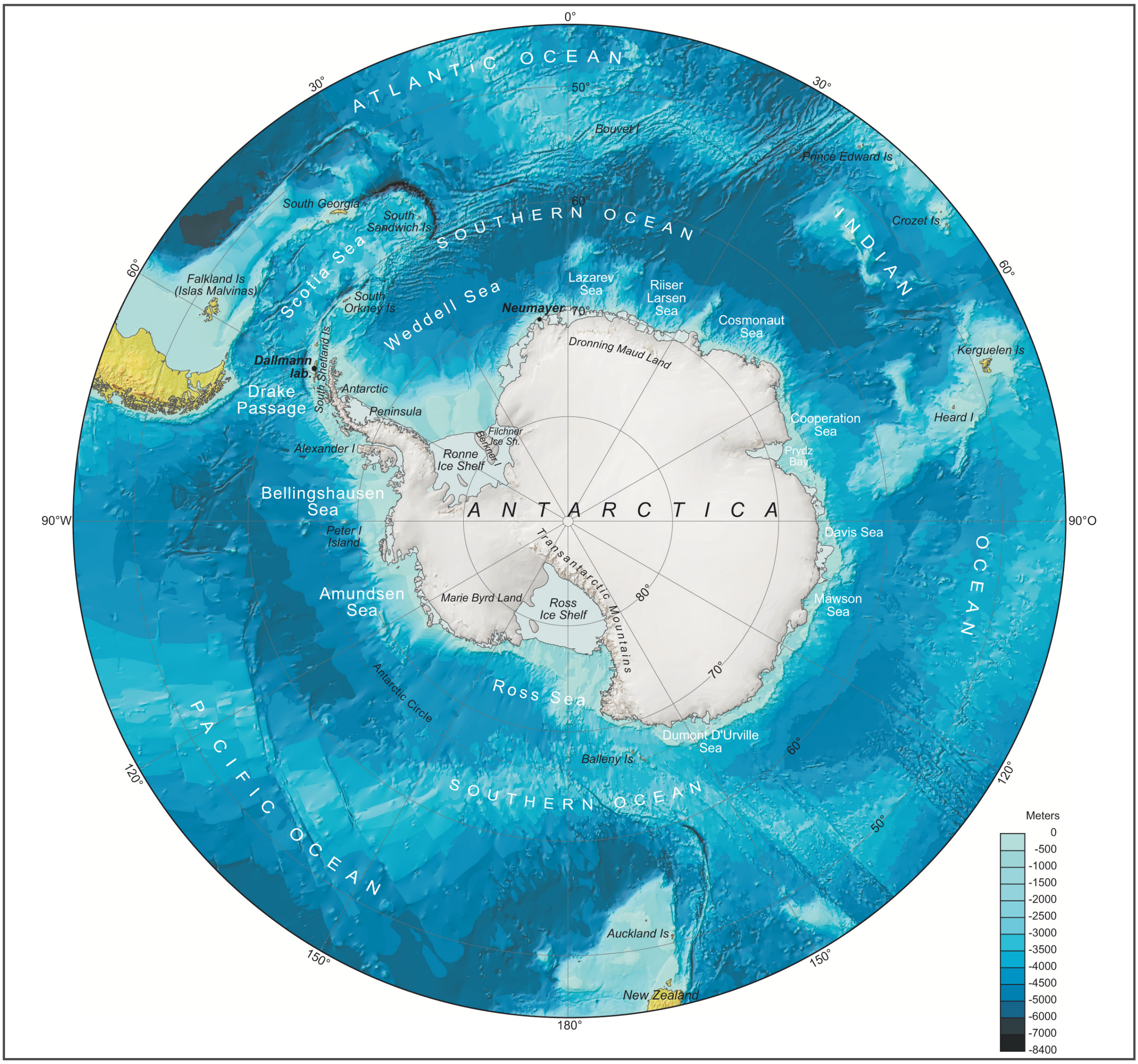
In contrast to Arctic sea ice, most pack ice in the Antarctic does not get older than one year. The ice cover, 60 centimetres thick on average, forms in the first winter weeks, reaches its largest extent of about 19 million square kilometres in September and then melts to an area of three million square kilometres during the short Antarctic summer. (Photo: Mario Hoppmann, AWI)

the Southern Ocean. The air temperature above the sea then falls to minus 30 degrees Celsius and colder – conditions which only species that have developed extraordinary survival strategies survive.

In the past polar researchers spent a great deal of time and effort on investigating the species diversity of Antarctic dwellers and understanding their tricks of survival. For instance, they discovered the antifreezing proteins in the blood of icefish and determined how emperor penguins keep each other warm by forming a huddle. Today, however, new questions arise in view of global climate change:

How does warming and the increasing acidification of the oceans change the biocoenoses in the Antarctic and the adjoining Southern Ocean? Will the cryophilic species be able to adapt to the new living conditions? How well does the ecosystem cope with human intervention, such as icefish and krill fishery? And finally: What impacts do changes in the Southern Ocean have on the ecosystems of other marine regions? The Antarctic waters are, after all, one of the most important feeding grounds on our planet, not only for baleen whales.

Climate research results to date draw a picture of a two-section polar region. While the average temperature over the eastern part of Antarctica as well as in the eastern Weddell Sea and in the Ross Sea remains stable or even drops, scientists find evidence of a rapid warming in West Antarctica and on the An-



The Antarctic is the coldest, windiest and driest continent on Earth. The climate over the land mass covered by ice around the South Pole has a major influence on the living conditions in the Southern Ocean, which encompasses such marginal seas as the Ross Sea. (Map: AWI) tarctic Peninsula. In these regions the air and water temperature is rising, the winter sea cover is declining, ice shelves are disintegrating, glaciers are retreating and winds are increasing. This development has severe consequences for the ecosystem of the Southern Ocean and its dwellers. Scientists put it this way: In some areas of the Antarctic everything is suddenly different. Climate change is putting the squeeze on the biocoenoses of the Southern Ocean in a variety of ways. How this is taking place will be shown by the following examples of research conducted by the Alfred Wegener Institute.

Fact box: Figures on the climate in Antarctica

- Warming: In the past 50 years the summer air temperature on the Western Antarctic Peninsula rose by two degrees Celsius and the winters were 2.5 degrees Celsius warmer. The shift in wind systems over Antarctica is assumed to be a reason for this rise. In this way more warm air reaches the peninsula today than previously.

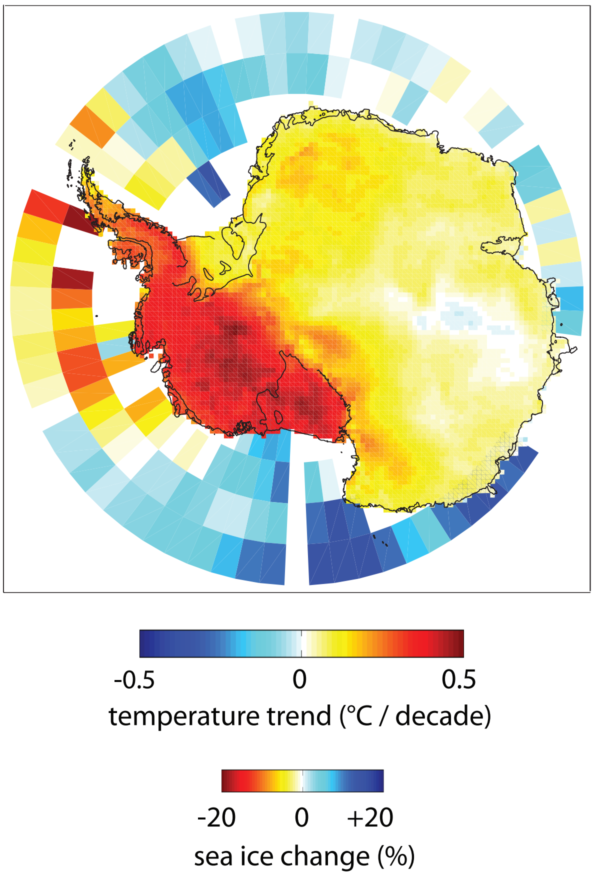
- Glacier retreat: The Antarctic ice sheet lost around 147 gigatons of ice per year in the period from 2002 to 2011. In the 1990s the figure was 30 gigatons on average. The glaciers in the West Antarctic recorded the biggest losses.

- Sea ice record: In September 2013 researchers noted the largest area of sea ice in Antarctica in the past 30 years. The ice had formed on an area of 19.48 million square kilometres. However, there was growth only in the Ross Sea and Weddell Sea. The ice cover is constantly dwindling in the Amundsen Sea and Bellingshausen Sea as well as at the tip of the Antarctic Peninsula and is thus less and less available as a habitat for krill, seals, penguins and other ice dwellers.

- Sea level rise: The Antarctic ice sheet is up to 4,770 metres thick. Altogether its ice masses store around 63 percent of the Earth's freshwater reserves. If these glaciers melted, the global sea level would rise by 58 metres. Currently the losses in mass of the Antarctic ice sheet cause the global sea level to rise 0.4 millimetres a year.

- Winds: The west winds over the Southern Ocean have increased since the 1980s. The reasons for this are the thinning of the ozone layer over Antarctica (ozone hole) and the rise in greenhouse gases in the atmosphere (warming).

- Ozone layer: The so-called ozone hole over Antarctica has had a major influence on the Antarctic climate since 1980. It reinforces the southern polar vortex, a wind belt around the South Pole, alters weather conditions around the continent and boosts the west winds by up to 15 percent.



The two faces: This map shows the extent to which the surface temperature on the Antarctic continent and the sea ice cover of the Southern Ocean have changed in the period from 1979 to 2003. The division of the continent is easily identifiable. While the warming in the west progressed rapidly and the sea ice cover declined, the temperatures in the east remained nearly stable. At the same time the sea ice cover in the Ross and Weddell Seas grew. (Illustration: Eric J. Steig et al. Nature 457, 459-462 (2009), doi: 10.1038/nature07669)

Ice floes like this specimen from the Weddell Sea are vital grazing grounds for the Antarctic krill. As juveniles, the crustaceans predominantly feed on algae that grow in the ice, especially on the bottom of ice floes. In this picture the carpets of algae are discernible by virtue of the green to brown colouring of the top blocks of ice. (Photo: Mario Hoppmann, AWI)

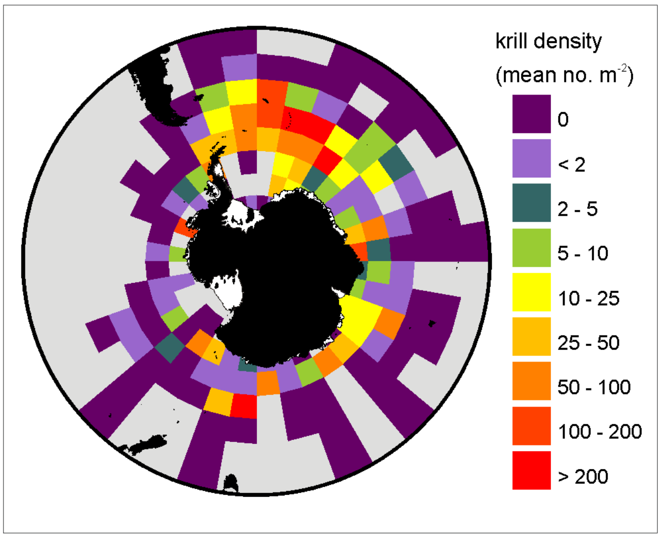
Sea ice: Lack of pack ice in krill nursery grounds

Blue whales, penguins, seals and icefish – all of them would starve in Antarctic waters if there were no Antarctic krill. These shrimp-like crustaceans measuring up to six centimetres in length represent the main food for all larger dwellers of this unique habitat. Krill move through the Southern Ocean in such big swarms that even today we can only estimate their numbers, i.e. a total mass of 100 to 400 million tons. It is well established, however, that krill need an adequately large and thick pack ice cover, particularly during their first year of life, in order to survive the more than nine-month-long Antarctic winter. The hungry larvae graze on the underside of the ice covered with algae. In the many cavities and spaces in pack ice they find refuge from enemies and drift with the ice floes to faraway regions of the Southern Ocean.

However, the nursery grounds and main range of the Antarctic krill (Bellingshausen Sea, Amundsen Sea, southern Scotia Sea) are located for the most part in precisely that part of the Southern Ocean in which the consequences of climate change are clearly felt already today. The surface water west of the Antarctic Peninsula, for example, has become one degree Celsius warmer in the past 50 years. At the same time scientists observe the most rapid decline in sea ice in this and other regions relevant for krill. In the past three decades, for instance, the ice season shortened by 85 days in the southern Bellingshausen Sea and in the area west of the Antarctic Peninsula. Simultaneously, however, the extent of the pack ice in the Ross Sea increased to such a degree that AWI experts reported a new sea ice area record for the Southern Ocean on 18 September 2013.

Under these circumstances isn't it possible for krill to move their nursery grounds to regions with a growing ice cover? They are trying. On the Antarctic Peninsula, for example, researchers observe that krill are increasingly moving toward Amundsen Sea – where the consequences of ocean warming have not yet reached

The Antarctic krill feels most comfortable at temperatures from -1 to +1 degree Celsius. Should the Southern Ocean undergo a temperature rise, the fully grown animals would be able to withdraw to greater water depths for a certain time. Without adequate sea ice, however, survival for this keystone species would be jeopardised. (Photo: Carsten Pape, AWI)



This graphic map shows the main ranges of Antarctic krill. The population density is currently declining - particularly in the Atlantic part of the Southern Ocean. The main reasons for this are the regional warming of the sea as well as the decline in sea ice. (Graphics according to: Atkinson A, Siegel V, Pakhomov EA, Rothery P and others (2008) Oceanic circumpolar habitats of Antarctic krill. Mar Ecol Prog Ser 362:1−23.)

the proportions as at the tip of the peninsula. At the moment we do not yet know how krill will continue to react to the increasing environmental changes. This also applies to the question of what will happen to these cryophilic crustaceans if the Southern Ocean gets even warmer. Researchers know from experiments that the animals can withstand a temperature jump to 3.5 degrees Celsius and more for a short time. If the water remains warmer for a longer period, however, the higher temperature disrupts the growth of this keystone species, among other things.

For baleen whales like this humpback whale Antarctic krill is the most important source of food. In the Southern Ocean especially female whales build up the fat reserves they need to manage the long journey towards the equator. They give birth to their calves in the warmer tropics and subtropics. (Photo: ITAW/Carsten Rocholl)

Special features of the Antarctic animal world

- Many species are endemic. That means they only occur in Antarctica.

- As a rule, most creatures living at the bottom of the Southern Ocean grow 4 to 18 times slower than the same species in warmer regions. They have a slower metabolism and therefore need more time to become sexually mature; in most cases they reach an older age than their relatives in warmer regions. However, there are also exceptions, such as extraordinarily fast-growing ascidians (tunicates) and sponges.

- Some Antarctic species become significantly bigger than related species in the tropics or temperate latitudes.

- Many cryophilic marine dwellers tolerate only slight fluctuations in water temperature.

- The Antarctic sea ice maintains its very own varied biocoenosis. It primarily includes microalgae and small animals that live in the tiny brine channels of the ice. Some copepods spend part of their lifecycle in sea ice, such as amphipods and krill, which graze on algae on the bottom of the ice and may become several centimetres long. Sea ice serves some fish species as a habitat and spawning grounds. Various penguin and seal species are also dependent on sea ice as hunting and resting grounds.

- The biological rhythms of Antarctic dwellers are closely tied to seasonal rhythms like the increase or melting of sea ice. If these rhythms change, the chances of survival of the native animals may drop.

- Scientists today are sufficiently familiar with less than two percent of all Antarctic dwellers to be able to identify climate-related changes.

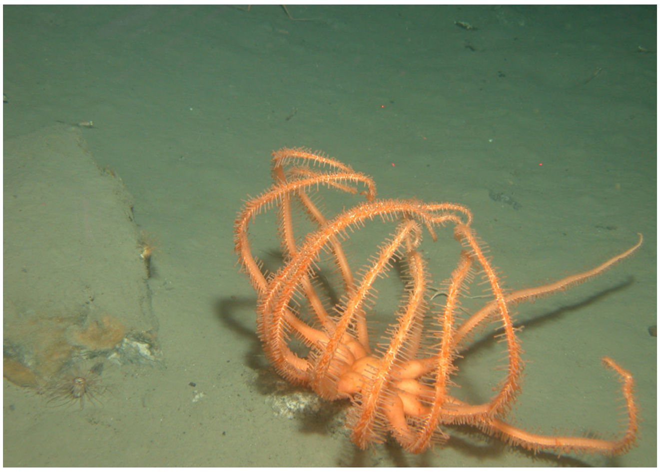
Southern Weddell Sea: this photo shows the calving edge of the Filchner-Ronne Ice Shelf, the biggest ice shelf in Antarctica. Its area is large enough to cover Spain almost completely with ice. (Photo: Ralph Timmermann, AWI)

Ice shelves: Glass sponges and entourage conquer the terrain where mega ice sheets break up

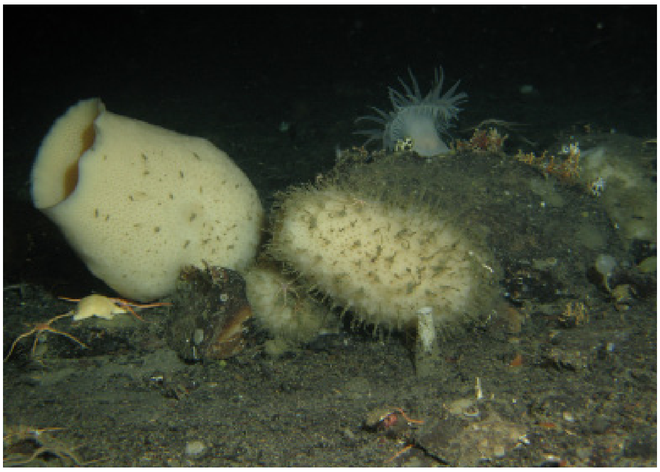
The Antarctic Peninsula was once a mecca of ice shelves. Imposing floating extensions of grounded ice sheets projected into the sea both on the eastern and western coast of the peninsula.

Today, however, there remains only a small part of the ice shelf splendour around the Antarctic Peninsula. As a result of a rise in the air temperature of two to three degrees Celsius on average, seven of the twelve floating ice shelves have broken up in part or completely in the past 50 years and cracked into hundreds of icebergs, which have finally broken up in the meantime.

Such a breakup of an ice shelf is both a curse and a blessing for marine dwellers on the seafloor. A curse because an iceberg passes over the seafloor like a knife during its drift through shallow coastal waters and shaves off everything that cannot get out of the way fast enough. A blessing because as the ice shelf disappears, light can finally reach places where previously darkness, food shortage and thus



When AWI biologists examined the seafloor in the former Larsen A Ice Shelf area in 2007, they found a thinly populated habitat – with sub-ice shelf species like the multi-arm starfish Feyella fragillisima. (Photo: Julian Gutt, AWI)



Many years later an entirely different picture presented itself to the scientists: glass sponges, comatulids and other species had moved in and already populated the seafloor more densely. The species diversity overall had increased. (Photo: Thomas Lundälv, AWI) conditions similar to those in the deep sea prevailed, at least during the ice-free summer. It thus also holds for the Southern Ocean that wherever sunlight floods the upper water layer, flora and fauna start to come alive, giving rise to a race for the best places on the bottom below.

The species taking part in this race include the Antarctic glass sponges, which scientists previously thought would need decades to grow a few centimetres in the minus two degrees cold water. In summer 2011, however, AWI biologists were able to verify in the region of the former Larsen A Ice Shelf that glass sponges are anything but lethargic. In this part of the western Weddell Sea the glass sponges had populated large areas of the seafloor within four years. They displaced deep-sea and pioneer species, such as ascidians, and permanently altered the ecosystem.

Today, around 20 years after the breakup of the Larsen A Ice Shelf, significantly more species live in this region than before. Along with the sponges, starfish, krill, icefish, corals, seals and Antarctic minke whale moved in as well. And in a few decades the biocoenoses in this formerly deep-sea-like, low-nutrient and species-poor ice shelf area will in all likelihood hardly differ from the "normal" Antarctic biocoenoses in the ice-shelf-free eastern Weddell Sea.

It is questionable, however, how the Antarctic ocean dwellers will react if the temperatures on the seafloor rise and acidification of the Southern Ocean progresses. Up to now scientists have assumed that the animals living in Antarctica only really feel comfortable in a relatively small and extremely cold temperature range. If the water undergoes a temperature rise above a certain threshold value or exceeds a certain acid concentration, the chances of survival for these animals drop. At present, however, researchers are aware of such threshold values only for very few dwellers of the Southern Ocean.

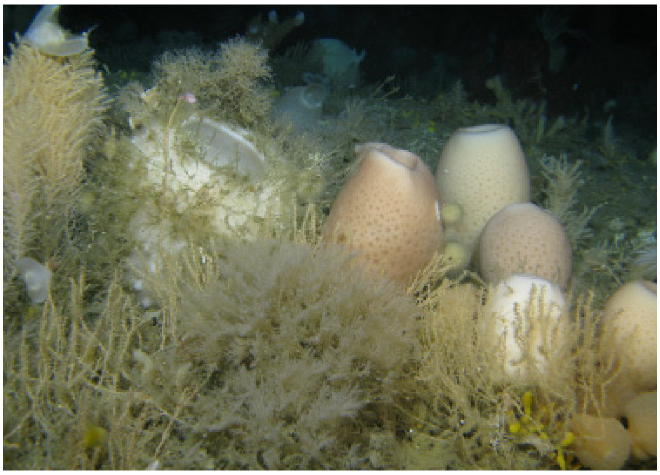
Fact box: ice shelves

- In the past 50 years seven of the twelve ice shelves on the Antarctic Peninsula have broken up or lost large sections of their ice. The triggering factor on the western side of the peninsula was ocean warming and on the eastern side the rise in air temperature.

- The number of ice shelf breakups increased after a series of several warm summers had occurred in the 1990s.

- Altogether an ice area of 28,100 square kilometres was lost on the Antarctic Peninsula; that roughly corresponds to the area of the German federal state of Brandenburg.

- The breakup of the Larsen A Ice Shelf made big headlines in 1995. It lost 90 percent of its area within a few days.



Sponges, icefish, comatulids: on the bottom of the eastern Weddell Sea the many different seafloor dwellers are crowded closely together. AWI biologists presume that in a few decades such pictures will also be possible in the former ice shelf areas of the western ...

... Weddell Sea. After all, the living conditions there have been becoming similar since the breakup of the ice shelves. Species from the eastern part of the Weddell Sea may therefore migrate into the former ice shelf areas. (Photos: Thomas Lundälv, AWI)

Research focal point Potter Cove: the Alfred Wegener Institute operates the Dallmann Laboratory jointly with its Argentinean partners at the Carlini Antarctic research station at the foot of an extinct volcano. From there AWI biologists investigate changes in the cove's ecosystem. (Photo: Katharina Zacher, AWI)

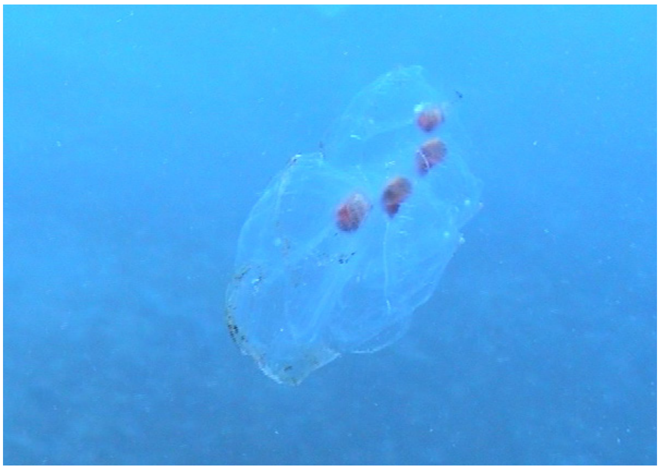
King George Island: Retreating glaciers alter an ecosystem

A 400 metre thick ice sheet covers King George Island, the largest of the South Shetland Islands at the tip of the Antarctic Peninsula. Due to Earth warming, which has an extremely strong impact on this region of Antarctica, the ice sheet is retreating by several metres in height a year. The ice loss appears even more clearly at the ice shelves. The floating extension of the Fourcade Glacier in Potter Cove located to the south, for instance, has lost more than 1,000 metres in length in the past 50 years. A development with far-reaching consequences!

When the Fourcade Glacier retreats, it exposes the seafloor and parts of the island rock base. Marine algae and seaweed migrating from the marginal areas of the cove conquer this new habitat and represent a new source of food for algae-eating bottom dwellers. However, not all algae species manage to survive at the foot of the glacier because they can grow there undisturbed only in spring. As soon as the air temperature rises in summer, melt water flows down the glacier. It washes

Today large algae grow in places where the Fourcade Glacier used to cover the seafloor with its ice masses in Potter Cove on King George Island (right). The new habitat has its vagaries, however. On summer days the melt water flows in torrents down the glacier ...

... In doing so, it washes over the thawed permafrost soil and carries fine-grain sediments such as sand to the cove. The latter make the seawater cloudy and take away vital sunlight from the algae. (Photos: Lic Dolores Deregibus/www.glakma.es)



Salps have taken the place of krill in Potter Cove. The invasive species come to terms with the new living conditions better than the crustaceans. (Photo: Hartwig Krumbeck, AWI)

over the thawed permafrost soil on its way to the sea and in this way carries away large amounts of fine-grain sediments. As a result, the sea turns brown and up to five-metre-thick sediment clouds form in the upper water layer, hardly permitting any light to shine through.

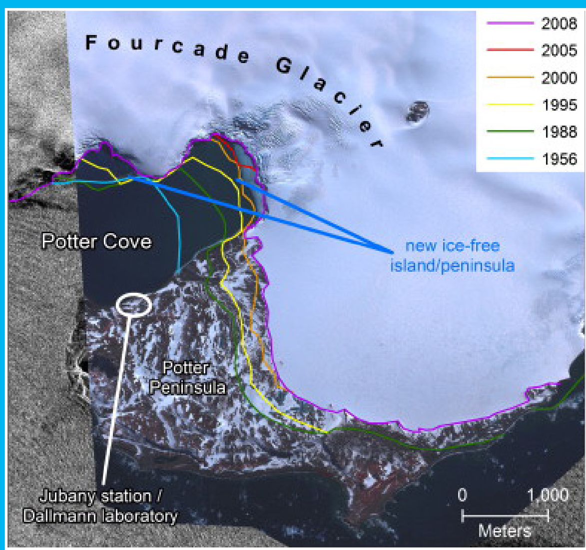
However, cloudy water means less light for the various algae species that live in the water column or on the seafloor. They can no longer carry out photosynthesis adequately and consequently grow much less or die after a short time. Their remains drop to the bottom and are decomposed by microorganisms. Their decomposition processes lead to a decline in the oxygen concentration on the seafloor. The latter silts up, leading in turn to a change in the communities of organisms living there. This is because wherever dying algae gather, the typical Antarctic filter feeders, such as mussels, ascidians and sponges, have no chance of survival any more. They are replaced by predatory marine dwellers that feed on smaller animals and algae remains and cope well with the low oxygen concentration on the seafloor as well as with the sediment rain.

The sediment clouds were the undoing of the Antarctic krill in Potter Cover. The crustaceans need a lot of food. If the animals filter more grains of sand out of the water than plankton, however, they starve. Krill have now disappeared from the cove. Salps have taken their place in the food web. The victims of this change are Adélie penguins and Gentoo penguins. They have to swim farther out to find sufficient nourishing prey.

At the moment the climate-related change in the ecosystem in Potter Cove is in full swing. When this change will end and what the biocoenoses will then be like are questions for which an international team of scientists wants to find answers in the IMCONet project, in which AWI biologists play a major role.

This is how glaciers are retreating

Floating extensions of grounded ice sheets that project into the sea are retreating along the Antarctic Peninsula. This development is triggered by the rise in air temperature, in this case particularly in winter, as well as the increase in water temperature on an annual average of nearly 2 degrees Celsius.
But what exactly happens? The warmer water pushes under the ice masses and detaches their anchoring to the seafloor. At the same time the warmer air in winter reduces the stability of the ice. On the glacier surface melt water flows form repeatedly and seep into the ice mass. There the water freezes again, expands and bursts the ice. As a consequence, the glacier “calves” an iceberg. In this way and by virtue of melt water runoff a large portion of the ice mass is gradually lost. Measurements on the Fourcade Glacier in Potter Cove showed that it is losing up to 20,000 tons of ice per day. Altogether the ice cap on King George Island lost around 20 square kilometres of its area in the period from 2000 to 2008.



This satellite image shows the rate at which the Fourcade Glacier in Potter Cove, King George Island, retreated in the period from 1956 to 2008. (Image: Rückamp, Braun et al. (2011) Global and Planetary Change 79, 99-109)

Waves surge when the west winds in the southern hemisphere propel the water masses of the Southern Ocean and set in motion the most powerful ocean current in the world, the Antarctic Circumpolar Current. If a ship intersects this current, it crosses various fronts. This is what currents are called where the water temperature and salt concentration change quickly over a short distance. (Photo: F. Rödel, AWI)

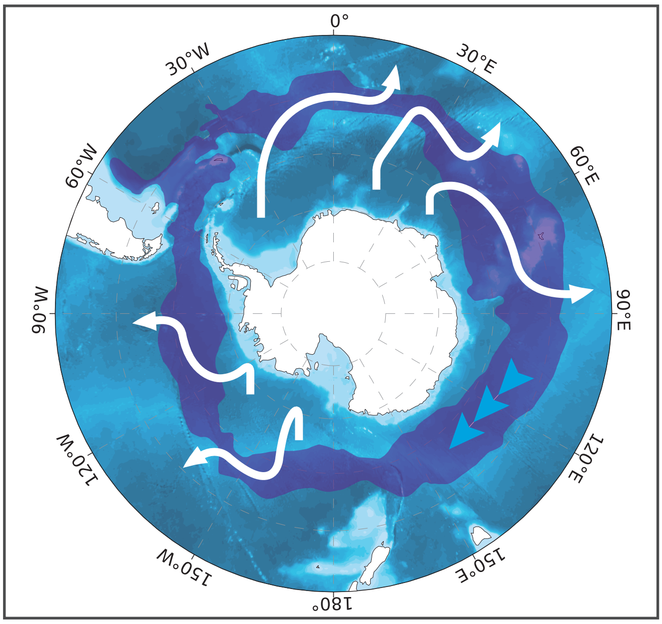
West winds: The engines of the ocean currents crank up

Antarctic owes the most powerful ocean current in the world, the eastward flowing Antarctic Circumpolar Current, to the west winds in the southern hemisphere (see graphic illustration). It circles the entire Antarctic continent without meeting land masses even once and being slowed by them – a unique ocean current phenomenon with positive side effects for the phytoplankton of the Southern Ocean. The reason: water on the surface of the circumpolar current is conveyed away to the north and the resulting "gap" is replaced with rising deep water rich in nutrients. Among other things, it contains iron – a fertiliser that is considered to be a scarce commodity in the Southern Ocean.

However, diatoms in particular can grow in places where the water contains sufficient iron – and where diatoms and other plankton grow, prey is available to all those that feed on these algae or their predators – starting with krill, fish and penguins and extending all the way to the 33-metre-long blue whale.

In the course of climate change the west winds south of 45 degrees latitude now change as well. They become stronger because the temperature and air pressure differences between the air masses near the Antarctic continent (subpolar low pressure area) and those in the temperate latitudes (high pressure area) increase due to global warming. The engines of the ocean currents thus crank up and now propel the water masses of the Southern Ocean with even greater force. A change with global consequences:

First of all, the Antarctic Circumpolar Current shifts around 50 to 80 kilometres to the south, i.e. poleward. Secondly, the upwelling of the deep water rich

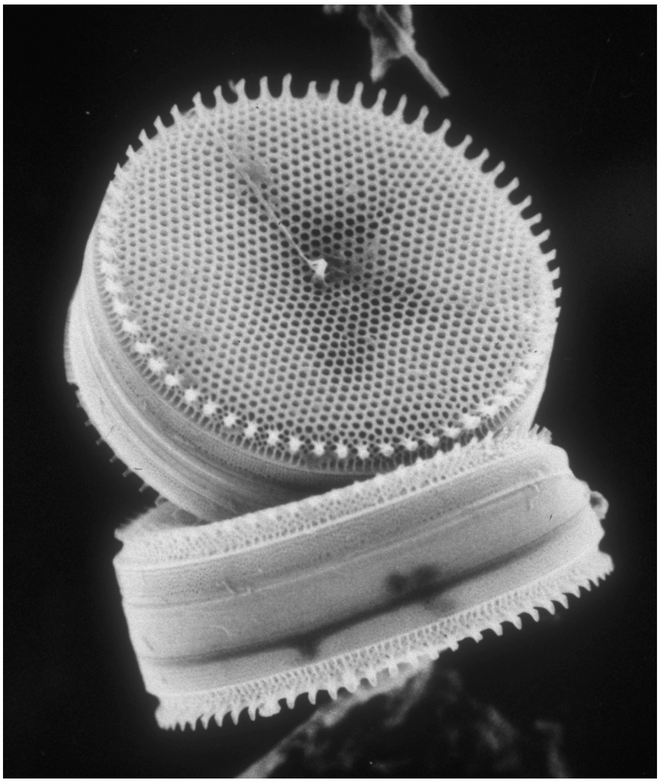


The Antarctic Circumpolar Current (violet) transports on average about 140 million cubic metres of water per second. Nevertheless, it does not form an insurmountable barrier. Water on its surface is carried away to the north and the resulting gap is filled with rising deep water (white arrows). (Map: AWI) in nutrients in the Southern Ocean increases along with the west winds.

For the world of algae in Antarctic waters this is presumably good news since it promises a greater supply of nutrients at least for the summer and thus improved growing conditions for algae. Recent AWI research results have additionally shown that especially diatoms will profit from these changes. In all likelihood they will play a greater role in the future, probably at the expense of the smaller plankton species.

However, what do the changes in the west winds and a possible change in the world of algae mean for the remaining ecosystem of the Southern Ocean? This question currently preoccupies not only scientists at the Alfred Wegener Institute. In a joint research project experts from all over the world are attempting to gain an understanding of future developments for life in the Southern Ocean by means of ecosystem computer models.

At the same time they are trying to find out how the increasing upwelling of deep water containing carbon and nutrients will influence one of the most relevant characteristics of the Southern Ocean for the climate: its ability to absorb carbon dioxide from the atmosphere. Up to now the Southern Ocean has been regarded as a carbon sink, i.e. as a region in which the ocean removes the greenhouse gas carbon dioxide from the atmosphere and stores the carbon contained therein either as a dissolved gas ("carbonic acid") or in the form of dead algae particles in the deep sea.



Antarctic diatoms like this Fragilaropsis species, photographed using a scanning electron microscope, grow in places where the topmost water layer of the Southern Ocean contains sufficient iron. (Photo: Richard Crawford, AWI)

Increased algae growth could reinforce this effect of the so-called "biological carbon pump". However, this process is one of many parts of the puzzle in the future carbon cycle of the Southern Ocean that remains to be unravelled.

Other examples of reactions to climate change in the Antarctic animal world

- Penguins: The population of Adélie penguins at the northern tip of the Antarctic Peninsula is declining. In East Antarctica the emperor penguins indigenous there rear fewer offspring. The reasons for the two phenomena are presumably changes in the food web and sea ice cover of the Southern Ocean.

- Seals: The Antarctic elephant seals are shifting their territories to colder areas further to the south. The animals have abandoned their more northern territories.

- Invasive species: Deep water that is getting warmer may pave the way for the red king crab from the deep sea to the Antarctic continental plate. However, the animals there are not adapted to predators with claws like the crabs.

- Plants: Due to rising summer temperatures on the Antarctic Peninsula, various grass and lichen species now grow in the region.

- Algae: Changes are taking place in the world of algae in this region because of the decline in sea ice in the waters west of the peninsula. Instead of larger species, primarily smaller ones thrive.

The German research vessel Polarstern has tied up to an ice floe in the Antarctic Weddell Sea so the expedition participants can step onto the ice to carry out detailed investigations of the air, sea ice and the water beneath the ice. (Photo: Mario Hoppmann, AWI)

From the atmosphere to the deep sea – how does the ecosystem of the Antarctic function?

The times when Antarctica could be called uncharted territory are long passé. Today there are more than 80 research stations on the continent. Satellites and aircraft observe its glaciers, research vessels survey the Southern Ocean from its bays to the oceanic trenches. Nevertheless, we humans have yet to gain an extensive understanding of the mechanisms of life in the Southern Ocean. Scientists at the Alfred Wegener Institute are making efforts to grasp these processes. They combine marine, ice and atmospheric data with biological observations and develop computer models with which changes in the ecosystem can be simulated and forecast. Their focus is on the waters around the Antarctic Peninsula and the Weddell Sea, which is also known in researcher circles as AWI's home sea.

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