SouthWind

ANTARCTICA *and the* SOUTHERN OCEAN

TEXT PREPARED FOR ANTARCTIC AND SOUTHERN OCEAN EXHIBITION

TASMANIAN MUSEUM AND ART GALLERY, 2005–2006

AN OCEAN OF MYSTERIES

'How inappropriate to call this planet Earth when clearly it is Ocean.' – Arthur C. Clarke, quoted in *Nature*, volume 344, page 102, 1990

'The seas around Antarctica are the moat that surrounds a fortress and contributes to that vast continent's isolation.' – Richard Corfield, *The Silent Landscape*

Of all the parts of our planet's surface, we know least about the oceans. And of all the oceans, we know least about the Southern Ocean.

Until fairly recently, most of the world didn't know there *was* a Southern Ocean. It is now generally accepted that the ocean waters around Antarctica have their own identity, distinct from the great oceans to the north.

What sets the Southern Ocean apart?

An obvious difference is that it is colder. Antarctic waters are cut off from warmer ocean waters by the largest water movement in the world. The Antarctic Circumpolar Current – the only current that circles the globe – is the driving force behind the global ocean circulation that helps to keep our oceans healthy.

Then there are the animals and plants. The Subtropical Convergence, the northern limit of cool, fresh subantarctic waters, also defines a biological region that contains an array of species and ecosystems found nowhere else on the planet.

We know enough to define the Southern Ocean, and we know it holds many keys to the health of all our ocean waters. But our long journey to understand how it works is just beginning.

RESTLESS WATERS

Storm warning: *Generally heavy overcast; south-westerly winds gusting to over 60 knots; seas rising above ten metres with dense spray and foam; frequent snow showers to sea level causing heavy build-up of ice on decks and rigging. Conditions likely to persist for up to 48 hours.*

The Southern Ocean has the world's most unsettled ocean waters. With virtually no land to break their force, globe-encircling winds can turn into gales that last for days, stirring the sea into colossal waves and streaking it white with foam.

In the 'roaring forties' and the 'furious fifties' – latitudes named after their westerly winds – clipper ships and windjammers of the nineteenth and early twentieth centuries made good use of the winds to reach unprecedented speeds. But the sea took its inevitable toll on ship and sailor, as it has with the racing yachts of more modern times.

Closer to Antarctica the sea freezes – at first a thin, greasy, almost invisible film, then whitening and thickening over time. Even in high winds, the ice serves to dampen the ocean swell. A gap in the pack-ice appears as a lake, though the water may be thousands of metres deep.

Breaking the horizontal patterns of sea-ice and water are floating ice-mountains, broken from Antarctica's continental ice sheet.

Antarctic icebergs are the world's biggest, sometimes reaching the size of large islands. Because most of their bulk is below the surface, they are driven more by currents than wind. Sometimes they are pushed far to the north, into the open ocean, before they finally melt and break up.

THE ROCKS THAT SHAPE THE SEA

If the world's oceans were to disappear, a landscape unlike any seen above sea level would reveal itself. We would see massive arrays of ridges and ravines, volcanic cones rising from vast plains, and chasms deep enough to accommodate our highest mountains.

The Southern Ocean has its own shapes – unique landforms, or bathymetry – which strongly influence the behaviour of the waters above them.

Along much of the length of the Antarctic continental shelf, the seabed descends to 4500 metres or more, serving as a channel for the deep Antarctic Circumpolar Current.

But south of South America, Heard Island and New Zealand, submarine plateaus and ridges cross these deeper parts, forcing the current to seek ways around the obstacles, changing course and in places branching off into ocean waters to the north. Thus the Southern Ocean's bathymetry helps to direct ocean circulation.

The ridges and chasms beneath the Southern Ocean are themselves indicators of powerful forces at work. The outer part of Earth's crust, the lithosphere, is made up of ten or more 'plates', which move in relation to each other.

Where plates move apart, the gap is filled by hot material from Earth's interior, forming mid-ocean ridges. We can see one such spreading ridge in a large arc around southern Africa – an extension of the Mid-Atlantic Ridge – and another in an immense ridge system that extends from the Red Sea, around southern Australia and into the Pacific Ocean.

Where plates come together, one of the plates will tend to slide under the other – a subduction zone – usually forming a deep trench such as the one east of South Sandwich Islands – the deepest part of the Southern Ocean. Subduction zones are the sites of the world's largest and most destructive earthquakes.

A major feature is Kerguelen Plateau – one of the world's largest submarine plateaus. Part of this is a continental remnant that millions of years ago was joined to the lands we now know as India, Australia and Antarctica in the southern supercontinent of Gondwana.

ANTARCTIC CIRCUMPOLAR CURRENT: THE OCEANS' LIFE-SUPPORT

If you could bring together the flow of all the world's rivers, you would still have less than one percent of the flow of Earth's largest ocean current – the Antarctic Circumpolar Current.

This is the only ocean current that can flow unimpeded around the globe, made possible by the separation of Antarctica from other land masses millions of years ago. Driven by westerly winds and the exchange of moisture and heat energy with the atmosphere, this vast stream – four kilometres deep and as much as 200 kilometres across – transports around 140 million cubic meters of water each second around Antarctica.

But the size of the Antarctic Circumpolar Current is not so important as its role as one of our planet's great revivors, driving and resuscitating the waters of its oceans and sustaining life in their deepest parts.

The Southern Ocean's influence can be felt through all levels of the world's oceans. Connecting the Atlantic, Indian and Pacific Ocean basins, the Antarctic Circumpolar Current drives a global circulation of heat energy and saltiness. This phenomenon, called the 'thermohaline circulation', in turn exerts a profound influence on patterns of temperature and rainfall around the world.

One of the keys to this vital function is what has become known as 'Antarctic bottom water'.

At some places near Antarctica's coast, while the sea's surface is turning to ice in the winter air, powerful winds are driving the ice away. Because the water is kept exposed to the cold air, the ice forms at a very rapid rate. Ice cannot accommodate salt in its crystal structure, so the freezing sea-ice expels salt into the water below. This dense, very cold water, carrying oxygen and other gases from the surface, sinks down the continental slope to the bottom of the ocean.

Here, it is picked up by the deep circumpolar current. At stages during its travels around Antarctica, parts of the current branch off to the north, through channels in the bedrock. Over centuries, this water from the Antarctic coast finds its way through the world's ocean deeps, carrying gases that enable life to exist in these otherwise barren places.

FRIENDLY BARRIERS

It isn't hard to fathom that as you sail the ocean south from the equator, you'll find surface waters getting colder. This doesn't happen gradually, but in a series of steps, or 'fronts'. It's as if Antarctica were a fort, surrounded by invisible, increasingly hostile barriers.

But far from being hostile, these fronts provide some of the best environments for life anywhere in the world's deep oceans. The mixing of colder, fresher water from the south with warmer, saltier water from the north enriches the ocean's surface with nutrients brought up from below while helping to transport oxygen and other atmospheric gases to deeper waters.

About halfway from the equator to Antarctica, around latitude 40 degrees South, the water suddenly gets colder – by about four degrees over 100 nautical miles – and less salty. This is the Subtropical Front, considered by biologists and oceanographers to be where subantarctic waters begin: the northern boundary of the Southern Ocean.

Some 1000 or 1500 kilometres further south, usually between 50°S and 60°S, you come to another divide, commonly known as the 'Antarctic Convergence', where relatively temperate subantarctic waters meet Antarctic waters. Here, in the full flow of the Antarctic Circumpolar Current, tiny plants and animals provide food in abundance for subantarctic birds and mammals.

The edge of the pack ice around Antarctica is a very happy hunting ground, particularly late in the spring when it is retreating and sunlight is returning, and especially in the vicinity of the Antarctic Divergence. Here the deep Circumpolar Current gives way to Antarctic continental waters that generally move in the opposite direction, from east to west, and the diverging waters bring nutrients from the deep ocean to the surface.

The high productivity of such waters may give the impression that nutrients are abundant throughout the Southern Ocean, but in the deep ocean between the fronts, food is scarce and life is noticeably absent. Scientists have found clues to changing productivity in the colour of the water. Where the ocean's predominant dark colouration gives way to a greenish 'pea-soup' appearance, nutrients are plentiful and larger fish, birds and mammals won't be far away.

AN INVISIBLE LIFE-SUPPORT SYSTEM

When we think of life, we think of the animals and plants we can see, tree-size down to ant-size. But put all of these creatures together into one mass of living matter ('biomass') and you'll still have only a tiny part of Earth's total biomass – because the single-celled organisms that we can't see make up the vast bulk of life on Earth.

This is nowhere more glaringly true than in the Southern Ocean. The ocean's biomass of whales, seals and penguins adds up to about 16 million tonnes. There are from four to ten times that amount of krill, the shrimp-like animal that forms a big part of their diet.

But all this pales into insignificance against the Southern Ocean's biomass of phytoplankton or single-celled plants (about 5000 million tonnes) , protozoa or single-celled animals (about 1200 million tonnes) and bacteria (about 600 million tonnes).

Phytoplankton, free-floating in the surface waters or attached to sea ice, survive and grow by converting the sun's energy into carbohydrates. Some protozoa graze on them, just as land-based herbivores eat grass, while the grazers in turn are potential prey for other protozoa.

These tiny organisms – some of them are only a thousandth of a millimetre across – form the essential base of the oceanic food chain. Phytoplankton (like all plants) also produce oxygen, enabling animals to survive in the ocean. All the ocean's larger animals depend upon them.

But so do we all. The stormy Southern Ocean absorbs more carbon dioxide – one of the 'greenhouse gases' that cause global warming – than ocean waters elsewhere. The ocean's microscopic plants take in this dissolved carbon dioxide and turn it into organic carbon, some of which is transported to deep waters where it remains for hundreds or thousands of years – the so-called 'carbon trap'.

FABULOUS CREATURES

Our classic 'monsters of the deep' are inspired by the animals of northern seas, familiar territory for early mariners. But far more fantastic are the creatures of the South.

For sheer size, these animals take all the prizes. Most blue whales, which may be the largest animals ever to have lived on Earth, live in southern waters. Bigger than the fabled walrus is the male southern elephant seal. Subantarctic seas are home to the largest flying seabird, the wandering albatross, while the bigger species of their flightless cousins the penguins are the world's largest seabirds, fullstop.

There is the mystery of their lives. James Cook's encounters with albatrosses that appeared from nowhere on the high seas inspired Samuel Taylor Coleridge to attribute supernatural qualities to this great bird, killed by the Ancient Mariner. Real-life hunters were astonished at the profusion of seals and penguins ('ducks without wings') on remote islands, knowing nothing of their lives at sea. They too could not resist killing, driving many species to the verge of extinction.

The truth is more astonishing than the legends. We have found that these animals travel hundreds, thousands of kilometres across this wildest of oceans in search of food. The wandering albatross circles the globe. We have discovered that penguins can dive hundreds of metres below the surface and remain under water for 20 minutes, and that elephant seals can descend over a kilometre down and remain under water over an hour.

EXTREME EVOLUTION

'How have all those exquisite adaptations of one part of the organisation to another part, and to the conditions of life, and of one distinct organic being to another being, been perfected? We see these beautiful co-adaptations most plainly in the woodpecker and missletoe; and only a little less plainly in the humblest parasite which clings to the hairs of a quadruped or feathers of a bird; in the structure of the beetle which dives through the water; in the plumed seed which is wafted by the gentlest breeze; in short, we see beautiful adaptations everywhere and in every part of the organic world.' – Charles Darwin, *The Origin of Species* (1859*)*

Adjusting to an ever-changing world, as Darwin taught us, is what life is all about. The species that survive are the ones that can change with their environment. When the Antarctic became an icebox millions of years ago, the animals, plants and microbes that lived there had to adapt – or perish.

Conditions in the Antarctic are more hostile to life than anywhere else on our planet's surface. Its interior is so cold – winter-time temperatures drop below minus 60°C – that life occurs only in microscopic form. Even on the coast it gets down to minus 35°C. The sea temperature is constantly around minus 1.8°C.

Cold is only one of life's hazards in the Antarctic. There is the wide winter-summer temperature range around the coast, sometimes as much as 70°C. There is the short growing season, often only a matter of weeks. And intense ultraviolet light, made worse by the gap over the Antarctic in Earth's protective ozone layer.

Add to this a dry atmosphere, frequent very strong winds and the unpredictable behaviour of sea and ice, and you have an environment in which only the strongest – that is, the most adaptable – will survive.

WEDDELL SEALS: EXPLOITING A NICHE

In winter the sea around Antarctica is frozen solid, a metre or two thick. For a marine mammal depending on the sea for food, this isn't the place to be – unless you're a Weddell seal. In remaining close to the coast year-round, it can operate free of competition (and danger) from other large animals such as killer whales, which need open water to breathe.

To achieve this unique position, the Weddell has developed some special adaptations that enable it to work in these conditions. To start with, it has developed strong, forward-directed canine teeth that enable it to maintain breathing holes through winter sea ice.

The Weddell seal is an excellent diver, able to stay underwater for over an hour while swimming for kilometres in search of food. To do this, it deliberately slows its heart rate and stores exceptionally large amounts of oxygen in its blood and muscles. For deep dives (down to 600 metres) it can collapse its lungs to equalise air pressures and help prevent absorption of nitrogen – potentially fatal in humans.

Then there's its large size, increasing its resistance to cold with plentiful reserves of heat and fat, and its fat-rich supply of milk to pups. In the first 12 days of life the pups double their body weight and develop a 20 mm blubber layer, enabling them to enter the water.

The Weddell has especially acute sight to help it locate prey and navigate under sea ice in winter darkness. Its large, reflective eyes are able to detect the faintest light, and are directed upward so that it can easily see the underside of the ice above it. It may also use its powerful, varied vocalisations to find its way; certainly they are essential to its social life.

EMPEROR PENGUINS: LIFE ON THE EDGE

It is pitch-black, the air temperature is minus 40°C, a 70-knot wind comes howling off the Antarctic plateau. And a thousand huddled penguins – each balancing a precious egg on its feet – sit on the sea ice enduring the most extreme conditions imaginable.

Only two penguin species, Adélies and emperors, are exclusively Antarctic, and of these only emperors spend winter ashore. They do it because they have to. They are big animals – over a metre tall – and need more than an Antarctic summer to incubate their eggs. To survive, the emperor has developed behaviours and physical adaptations, some common to other species, some unique, that protect it from a hostile world.

An emperor's insulation consists of a layer of fat under its skin – as much as 3 cm thick – and extremely dense, stiff, short, double-layered feathers. In cold conditions ashore it can hold its feathers erect to increase the amount of air held next to the skin, while flattening them underwater to improve water-resistance and streamlining. It also improves waterproofing by oiling its feathers through preening, and resists the effects of cold water by increasing its metabolic rate while diving.

Standing on ice for months at a time is a sure way to get cold. Veins and arteries in an emperor's feet, flippers and head are close together, enabling a heat exchange process that minimises loss of heat energy. A similar exchange system operates in the bird's nasal passages, transferring heat from exhaled air to incoming air.

More astonishing, the emperor's feat of protecting its egg through winter is achieved without food. It manages to keep its body temperature stable only because it has friends to help. At the coldest times, the birds huddle together in large, dense groups, moving all the time so that those on the colder, windward side of the huddle gradually shift to the leeward side and thence to the centre of the huddle, where the temperature is some 10°C warmer than outside.

The egg, meanwhile, remains on the parent's feet under a protective flap of skin until mid-July when it hatches, when the other parent returns from the sea to take over the shift and feed the young.

ANTARCTIC FISH: A CLASS APART

Fish with built-in antifreeze… ghost-fish with white blood… herrings that aren't herrings… fish that float without swim-bladders….

More than any other class of larger animals, the 200-odd fish species of the far south mark the Antarctic as a place apart. Most of them are found nowhere else in the world, indicating millions of years of separate development, a bit like marsupials' evolution in isolated Australia.

Most free-swimming fish have a gas-filled swim-bladder that gives them buoyancy, but no Antarctic species have one, suggesting they were once all bottom-dwellers. But some of them, such as the giant Antarctic cod, have found other means of rising above the sea floor. They have lightened their weight by reducing the mineral content of their bones, and incorporating oily compounds that are lighter than water into their tissues.

Another free-swimming Antarctic fish using similar techniques is the Antarctic silverfish, otherwise known as the Antarctic herring. It looks a lot like a true herring but is completely unrelated, coming from Antarctic icefish stock. This is a fine example of convergent evolution, where animals with different origins develop similar characteristics through adapting to similar environments.

All species in the family of Antarctic icefish have a whitish blood – the only vertebrates with this characteristic – caused by a lack of red, oxygen-carrying haemoglobin in the blood. Their blood plasma is thinner and in greater volume than normal, pumped through large-diameter capillaries by an enlarged heart, supplying sufficient dissolved oxygen for their needs.

The salt in sea water lowers its freezing point to nearly 2°C below that of fresh water – potentially lethal to Antarctic fish. Their body fluids would freeze around minus 1°C except for a remarkable adaptation – an antifreeze protein-sugar compound called glycoprotein. This compound, carried in body fluids, has the ability to attach to microscopic ice crystals and inhibit their growth.

ANTARCTIC KRILL: SIZE ISN'T WHAT IT SEEMS

It's hard to get close to these small, enigmatic Southern Ocean crustaceans. They roam the wide Southern Ocean, especially around the edge of the pack ice. They are occasionally seen in vast schools, up to 50,000 animals in a cubic metre covering many square kilometres, so dense that when they surface in daylight the ocean turns red. They are the most important food for the larger animals of the Southern Ocean.

But it's hard to get a handle on them. While they are seen most often on the surface, they can also be found on the bottom of the ocean – even larval krill are found 2000 metres down. And we don't know where they go in the dark winter, when food is scarce. They may spend part of it grazing algae growing on the under-surface of the pack ice. Or they may go deep to feed off animal and plant remains that have sunk to the ocean floor.

It took us a long time to discover that for a creature only 6 cm or so long they can be quite long-lived – they can live a decade or more in captivity, though less in the wild. We were confused about their life-span because of a special trick they use to cope with the inevitable shortages of food – getting smaller.

At least once a month Antarctic krill cast off their outer skeletons – about six percent of their dry weight – which is a significant drain on the animal's resources. They continue to do this even in times of scarcity, as they do in laboratories when deprived of food (where they have survived more than 200 days without food).

In other marine animals fat reserves is both a food resource and an aid to buoyancy, but krill don't carry fat reserves. Their winter fuel seems to be their own body protein, which causes their bodies to shrink. This enables them to conserve the energy they need to remain buoyant.

LIFE ASHORE: SURVIVING THIRTY BELOW

The water temperature off Antarctica never gets much below zero, but ashore it's much colder, getting well below minus 30°C in winter. No large animal can remain there and survive – all must return to the sea for food, carrying with them tiny parasites that use their host's warmth to survive. But other small creatures have found ways of eking out an existence on their own in the world's harshest environment.

The biggest Antarctic animal that is exclusively terrestrial (land-living), a 12 mm wingless midge, lives in the warmest part of the continent on the Antarctic Peninsula. In some rocky places elsewhere in Antarctica you can find springtails – barely-visible insects 1.5 mm long – and some mite species that are much smaller than that.

Dealing with the potentially lethal effects of freezing is a major obstacle to survival for these tiny animals. Springtails and mites can resist freezing at temperatures of minus 30°C by using antifreeze agents including alcohols and sugars, much as the icefish survives in cold water. They also appear to use cryptobiosis – reducing their body's chemical processes to an undetectable level through winter.

Another challenge is finding suitable refuges. Springtails and mites need warmth and water, such as in soil (with water-retaining layers underneath) near heat-retaining stones on north-facing slopes providing meltwater from snow or ice – also the likeliest habitat of plants such as moss.

Antarctica's two flowering plant species use different strategies against cold. One accumulates fatty substances and carbohydrates to resist the effects of freezing, while the other avoids freezing altogether by preventing ice crystals from forming in its fluids when the temperature drops below freezing point, remaining ice-free even at minus 10°C.

Lichens, which have been found only 400 km from the South Pole, can tolerate lower levels of light, water and temperature than other larger plants. They do this by reducing their metabolic rate virtually to zero in winter, recovering very slowly through spring so that growth coincides with maximum light levels, temperatures and water availability.

Simpler plants such as algae, which can grow on ice and snow and even inside rocks, have a cellular structure so small that they can withstand extended periods of freezing without harm.

ANTARCTIC MICROBES: LIFE IN THE UNLIKELIEST PLACES

Getting to know the extreme limits of life on Earth is essential to understanding our place in the universe – where we might look on other planets for signs of life. It's not surprising that we're finding important clues about extra-terrestrial life on the Antarctic continent – about as extreme an environment as you can get on Earth. This is the home of true 'extremophiles' – organisms that live where nothing else can.

Antarctica's lakes occur mostly in the continent's few rocky areas, mainly close to the coast, but there are some that lie under the vast Antarctic ice sheet, below several kilometres of ice. Microscopic forms of life have been discovered in Antarctic lakes that have been cut off from other aquatic environments for thousands of years.

Microbes have evolved from shallow-water organisms to live in permanently-dark, salty sludge containing no oxygen or carbon, obtaining energy from chemicals around them. At Ace Lake in the Vestfold Hills, near Australia's Davis station, for example, scientists have identified two organisms that have evolved cold-tolerant 'flexible' proteins that allow the organisms' cells to continue to function under extreme conditions.

Not even Antarctica's ice plateau is without life. Microorganisms have recently been discovered in ice-cores from deep in the ice sheet. It has been calculated that Antarctic ice and the water beneath contain as much bacteria as all the world's lakes and streams. They have evolved to survive deep inside the world's biggest iceblock – raising some important questions about the evolution of life on Earth and how life forms might survive in similar environments elsewhere in the universe.

ANTARCTIC ORACLE

Climate change is the most severe problem that we are facing today, more serious even than the threat of terrorism. – David King, chief scientific adviser to the UK government, January 2004

One way or another, water dominates the world. Its presence or absence will have a telling effect on our future. And the most watery part of the planet – Antarctica and the Southern Ocean – can provide advance warning of what may be in store for us.

Evidence from rocks and ancient glacial ice tells us that our world has gone through regular warming-cooling cycles, with major 'spikes' between cooler times every 100,000 years or so. Right now we're going through one of these 100,000-year interglacial spikes, where temperatures are warmer than average.

Glacial ice and tree rings also tell us that for the past two centuries our own activities have affected this warming. There has been a measurable build-up of heat-containing or 'greenhouse' gases in our atmosphere – such as carbon dioxide and methane.

A big slice of evidence for this has come from Antarctic ice. Tiny air samples trapped in snow when it originally fell, going back hundreds of thousands of years, tell us there has been a 37 percent increase in atmospheric carbon dioxide concentrations since the 1700s, rising to unprecedented levels today.

The ice that covers Antarctica, and in winter much of the Southern Ocean as well, is one of our planet's best indicators of global climate change. It affects our planet in three major ways:

- Changes in the vast Antarctic ice sheet, which holds two-thirds of our planet's fresh water, have a profound effect on world sea levels.
- Sea ice – for much of the year covering millions of square kilometres of ocean – significantly affects air and ocean temperatures.
- The melting of Antarctic ice into the Southern Ocean controls the mixing of surface and deeper waters that ultimately affects the health of all the world's oceans.

There's another factor. Carbon in our atmosphere is the main culprit in the 'greenhouse effect', preventing solar heat from escaping back to space. The stormy surface waters of the Southern Ocean, unlike other ocean waters, absorb more carbon than they release back to the atmosphere. We'd like to be sure things stay that way.

THE GIANT IS WAKING

'The last IPCC [Intergovernmental Panel on Climate Change - 2001] *report warned that Antarctica was a "slumbering giant". Recent scientific evidence leads us to believe that the giant is waking up.'* – Professor Chris Rapley, Director, British Antarctic Survey, May 2005

The size of Antarctica's ice sheet defies imagination. It's bigger – much bigger – than Australia. It's over two kilometres deep on average but in places approaches five kilometres. It's ten times the size of the next biggest ice sheet (on Greenland) and its weight depresses Earth's crust by hundreds of metres.

A big ice sheet has big implications for the world's sea level. If Antarctica's ice cover were to melt away completely, the sea level around the world would rise by about 55 metres, submerging most populated parts of the world.

That's not going to happen any time soon. After a period of growth, the present-day Antarctic ice sheet seems to be 'in balance' – neither shrinking nor growing. But some big changes may be afoot.

Antarctica is surrounded by ice shelves hundreds of metres thick – extensions of its ice sheet which have been pushed out over sea water by ice flowing from the interior. In the normal course of events bits of ice shelf break off to form icebergs, but occasionally something big happens.

Something big happened in 2002, on the east coast of the Antarctic Peninsula. A 10,000-year-old ice shelf named Larsen-B took 35 days to disintegrate into thousands of icebergs, most of which are slowly drifting away into the ocean. That underlined a significant warming around the Antarctic Peninsula over the past 50 years, emphasised by a 2005 finding that nearly all the region's glaciers are retreating.

These are signs of things to come. Computer modelling predicts that Antarctica's ice shelves will disappear within 200 years – possibly much sooner than that – allowing ice from the interior to flow more quickly into the sea. While increased snow accumulation in Antarctica's interior should lessen the impact, sea levels will almost certainly rise.

Looking further ahead, computer models are saying that most of the West Antarctic ice sheet, south of South America, will disappear within 1500 years – again, it's possible it will be much sooner. Combined with the loss of most of the Greenland ice sheet, this would contribute about six metres to the global sea level.

OUR CHANGING OCEANS

"The ocean may turn out to be the most reliable forward indicator of global climate change. Changes in the ocean climate are already observable and there is evidence that the human influence is separable from natural long-term variability. In wide regions, the deep ocean is perceptibly warmer and fresher. This warming can also be detected through its contribution to sea-level rise." International Council of Academies of Engineering and Technological Sciences (July 2005), *Oceans and the World's Future*

Our existence on this planet is very much tied up with the oceans around us. They have a dominant impact on our climate – an impact we'll feel directly if global warming continues at its present rate. As their waters get warmer they will expand, adding three metres to the sea level by the end of this century. That's on top of changes caused by other factors like melting icecaps.

The Southern Ocean – linking the world's oceans with the world's largest ocean current – is crucial to the health of all our ocean waters. The Antarctic Circumpolar Current is the principal driver of the global 'conveyer belt' that refreshes ocean waters from Alaska to India to North America and Europe. Among its offerings to the world is 'Antarctic bottom water', carrying atmospheric gases and nutrients that enable life to exist in the deepest parts of our oceans.

Australian studies of bottom water formation south of Tasmania show that it is very sensitive to climatic changes, with even small temperature rises radically reducing the rate of production. If the rate of global warming continues to rise, today's evidence suggests that deep water formation around Antarctica will virtually cease by the end of this century. It will be substantially reduced even if greenhouse gases stay at their present level.

The Southern Ocean is vital to the health of the planet for a second reason, to do with carbon. The presence of carbon in the atmosphere, much of it coming from human burning of fossil fuels, contributes to warming by trapping solar heat, and its absence has a cooling effect.

Alone among the world's oceans, the Southern Ocean currently takes in more carbon than it releases – having a net cooling effect on the atmosphere. But global warming will diminish the capacity of the Southern Ocean to perform this vital task.

There's an additional factor here, called phytoplankton – abundant microscopic plants that live in the ocean – which in life absorb carbon dioxide in the ocean's surface waters and in death cause the carbon to be carried downward, where it is trapped for hundreds or thousands of years. The big question of how climate change will affect these transports is yet to be answered.

LABORATORY FOR THE WORLD

'Scientific study in Antarctica is critical to understanding the Earth system.'
– Dr Anna Jones, British atmospheric scientist, in address to Antarctic Treaty Consultative Meeting, Madrid 2003

Once humans went south to learn about the Antarctic. Now we go there to learn about our planet and our universe.

If we want to know how our oceans work, we are drawn inevitably to the Southern Ocean – the engine that drives the world's ocean circulation and influences much of its climate – and the unique marine processes around the icy continent that breathe life into the ocean depths. And crucial to understanding life on Earth is getting to know the intricacies of Antarctic ecosystems.

Antarctica's icecap provides the best places on Earth to study the upper atmosphere, to find meteorites, and to decipher the mysteries of cosmic neutrinos. Its crystal-clear atmosphere makes it the planet's best platform for studying the heavens.

Most importantly, Antarctica's ice stores information about our distant past that help us determine where we're headed today. And studying how its gigantic ice sheet is changing in the face of a warming world provides crucial clues to our distant – and perhaps not so distant – future.