Australia's climate Cerberus

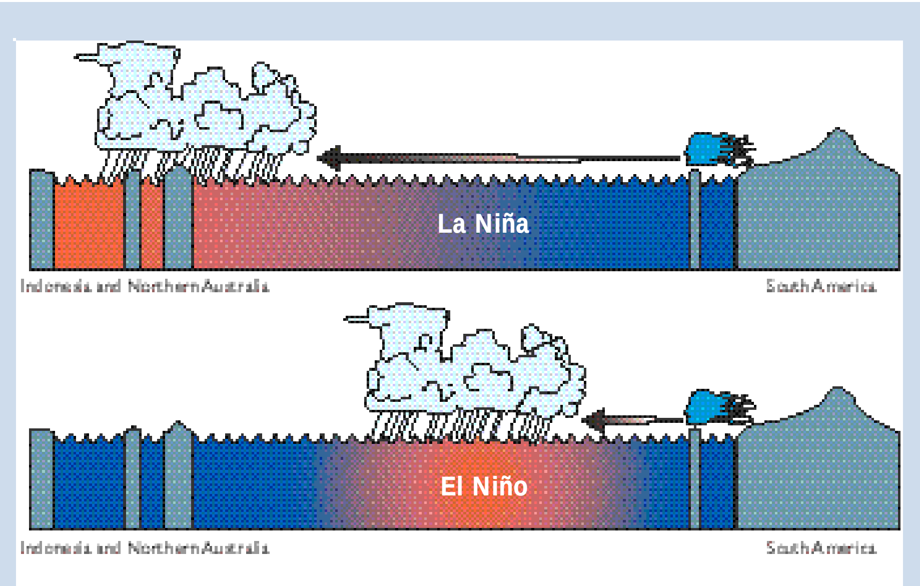
The puzzle of three oceans

Dr Peter Baines, leader of the ocean modelling group at CSIRO Atmospheric Research, likens the oceanic influences on Australia's climate to the antics of a three-headed dog. The challenge lies in predicting which head will bark the loudest.

We are all familiar with the day-by-day and week-by-week fluctuations in the weather, and how it varies with the seasons. Summer is warmer, winter is colder, and we can understand this in terms of the passage of the Earth around the Sun. But there are other powerful but less obvious factors at work, that tend to make one summer hotter and dryer than the next, and some winters colder or wetter. This article examines what we know about these underlying factors.

The name Cerberus was given to an Australian naval base, after an earlier Victorian warship (and now breakwater). It was originally the name of the three-headed dog of Greek mythology that guards the entrance to Hades. The variations in Australian climate also have three heads, each stemming from one of the three oceans (Pacific, Indian and Southern) surrounding the continent. The effects of each of these wax and wane, adding to and subtracting from each other, making each year different from the last. Sometimes, they all say 'woof' together!

These three effects are known as El Niño (or ENSO, short for El Niño Southern Oscillation) for the Pacific Ocean, the Indian Ocean dipole, and a recent discovery, the Antarctic Circumpolar Wave for the Southern Ocean. Each involves both the atmosphere and the ocean acting together and affecting each other. Together, these appear to be responsible for most of the droughts, floods, dry summers and cold winters, and most of the other complaints expressed about our variable climate. (It is possible that there are other influences with smaller impact on climate, yet to be identified.) Comparable variations have been identified in other parts of the globe, notably in the North Pacific and North Atlantic, but these seem to have little impact on Australia.



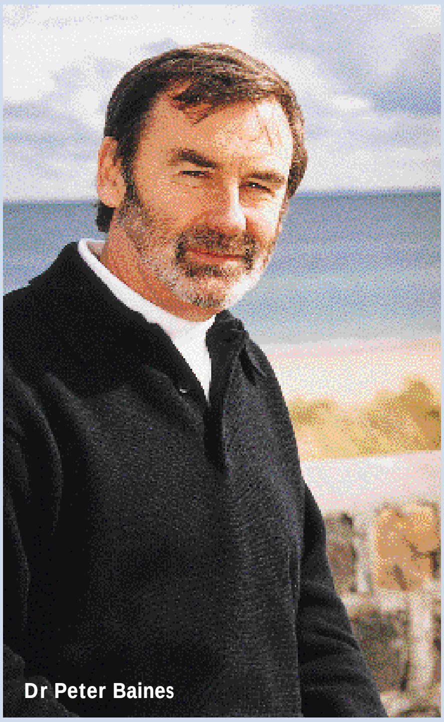
Vertical sections across the equatorial Pacific. During El Niño the easterly surface winds weaken and retreat to the eastern Pacific, allowing the central Pacific to warm, and the rain area to migrate eastward to the centre.

El Niño

Of these three factors influencing our climate, El Niño is perhaps the most important, the most studied and best known. El Niño affects many parts of the globe, including most of Australia and particularly Queensland. Its focus is the tropical Pacific Ocean – a very large area – where big changes can occur that involve both the atmosphere and ocean interacting and affecting each other. These changes occur between two main states: El Niño and La Niña.

The La Niña state generally lasts for more than one year. In this state, the atmospheric trade winds blow from east to west across the Pacific and the surface temperature of the ocean becomes progressively warmer along this east-to-west track. As a result of

Paul Holper, CSIRO Atmospheric Research



Dr Peter Baines

A new wave of understanding

DISCOVERY of the Antarctic Circumpolar Wave was announced two years ago in the journal Nature by researchers from California's Scripps Institute of Oceanography. Their analysis of satellite-derived ocean height and temperature measurements revealed undulations in the Antarctic Circumpolar Current, a body of water that circles eastward between Antarctica and the Indian, Pacific and Indian oceans.

News of the wave's discovery drew the attention of Dr Peter Baines and Dr Wenju Cai, from CSIRO Atmospheric Research, who have since been piecing together the mechanics that drive it. Their expectation is that the wave probably exerts a stronger influence on the climate of southern Australia than its notorious counterpart, El Niño.

The challenge for Baines and Cai has been to describe mathematically the major interactions occurring between the ocean and atmosphere that make the wave effect self-sustaining. Baines says large patches of warmer or colder water in the ocean, if left alone, would simply fade away. The warm and cold 'blobs' that form the Antarctic Circumpolar Wave, however, somehow force a pattern in the atmosphere that causes a positive feedback, thereby reinforcing their existence.

'We're looking for positive feedback mechanisms,' Baines says. 'Our equations describe interactions such as the motion and temperature of the atmosphere and their effects on heat exchange with the ocean. The atmosphere "tugs" the ocean with the effect of wind, and the ocean affects the atmosphere by giving it heat or absorbing heat. The atmosphere then responds by changing the direction of the "tug". These two processes feed on each other.'

Baines and Cai believe they have developed a candidate model to explain what is causing the positive feedback and have submitted two research papers on their findings. Their analysis of the wave's mechanics will help climate modellers to predict the effects of the wave on southern Australia's climate. 'The wave doesn't work like clockwork,' Baines says. 'We need the model to tell us how it will behave at a given point in time, its size and strength. It's the same as what we're trying to do with El Niño. Further research will investigate the degree to which the Antarctic Circumpolar Wave is linked to El Niño.'

Baines says ultimately a deeper knowledge of the wave should improve the accuracy of climate predictions one to two years ahead, and improve regional forecasting for southern Australia. 'Research by New Zealand and United States scientists has shown the wave to have a significant effect on rainfall and temperatures over the whole of New Zealand. We expect the same to be so for southern Australia,' Baines says.

Baines says there are several factors to explain why the mechanism had not been discovered earlier. First, sea-surface temperatures vary greatly across the width of the Antarctic Circumpolar Current, from 0°C near Antarctica, to 16-18°C near southern Australia. Exhaustive analysis is needed to tease out any underlying pattern of temperature anomalies, which may vary only 1°C from normal. Secondly, the wave takes eight to nine years to complete its circuit around the globe, yet only 12 years of relevant satellite data are available. Thirdly, the Southern Ocean is not a favourite field destination for climate researchers!

Since hearing of the wave's discovery, climate modellers at Atmospheric Research have searched the output of their Mark 2 Global Coupled General Circulation Model (CGCM) for further evidence of its existence. 'Now that we know what to look for, we can see a similar phenomenon occurring in the CGCM,' Baines says.

Bryony Bennett

the very large pool of warm water that accumulates in the west, there is generally heavy and persistent rain in Indonesia, New Guinea and Northern Australia, particularly in the summer monsoon season (see diagram opposite).

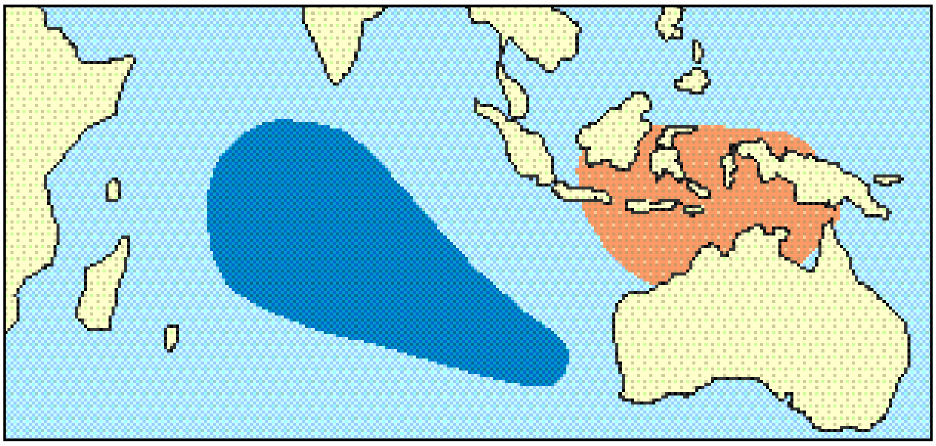
However, sometimes this large pool of warm water, with its associated rain, can move eastward out into the central Pacific. The trade winds in the western Pacific then reverse direction and blow westward (from west to east) toward this warm pool. Isolated Pacific islands in the warm pool become deluged with rain, and droughts occur in South-East Asia and northern Australia. This is the El Niño state.

The transition from La Niña to El Niño, and vice versa, appears to happen in the Southern Hemisphere autumn (March, April, May) locking these states into the seasonal cycle. El Niño normally lasts for only one year, but in the 1990s we have had several El Niños, some in succession. The reasons for these changes are still only partly understood.

The El Niño and La Niña phenomena affect many areas outside the tropical Pacific, particularly in Australia and North and South America. Of the two states, La Niña is generally friendlier toward the Earth's human population, whereas El Niño is generally less welcome and has some adverse consequences. Fishing on the coasts of North and South America is severely curtailed, some coral reefs are threatened by unusually warm water, droughts occur in parts of South America, Africa and India, and there are floods in Peru. In Australia, droughts and bushfires in the east and south-east are part of El Niño's signature.

The Indian Ocean dipole

A dipole pattern of sea-surface temperatures in the Indian Ocean (named the Nicholls dipole after Dr Neville Nicholls of the Bureau of Meteorology) has been shown to cause, or at least be related to, rain-producing disturbances across Australia from north-west to south-east. These disturbances, termed north-west cloud-bands, are the principal source of rain in the dry centre, although most of the associated rain actually occurs in the south-east (South Australia and Victoria).

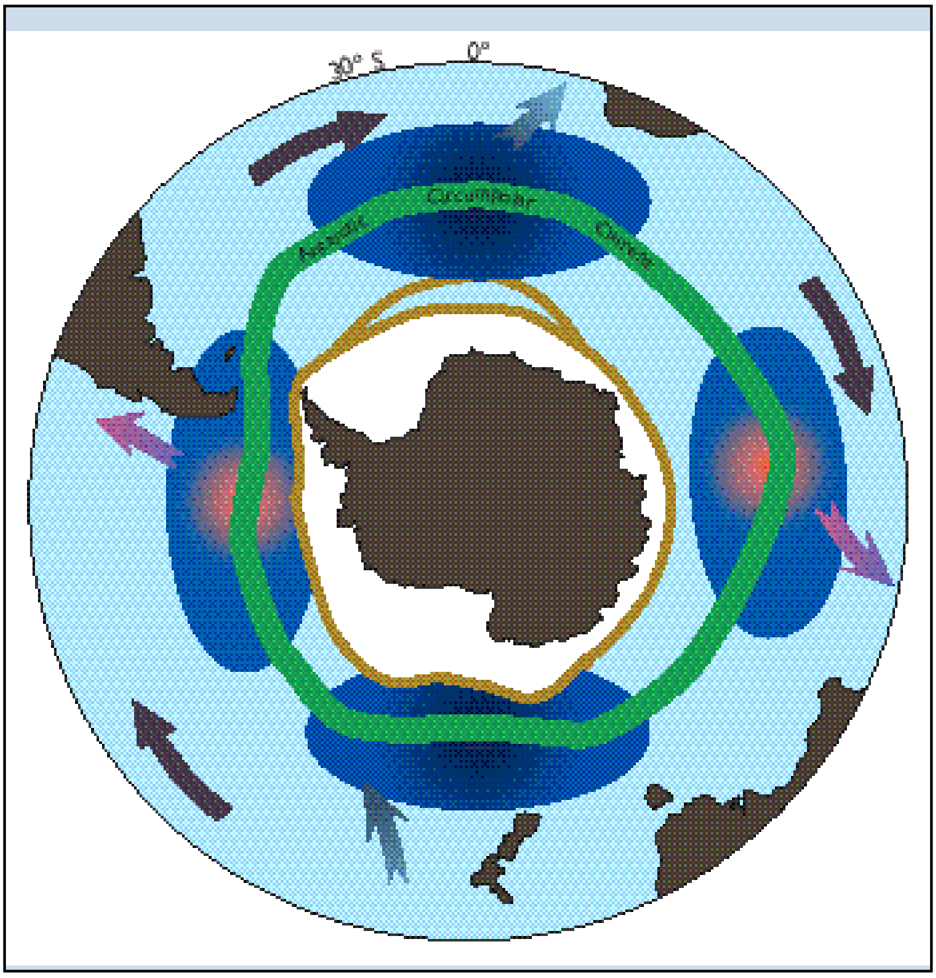


Above: The Indian Ocean dipole. When this pattern of sea-surface temperatures occurs as shown, with warm (red) water in the Indonesian region and cold (blue) water in the central Indian Ocean, it tends to produce rain across Australia in a band from north-west to south-east.

Below: The Antarctic Circumpolar Wave. Regions of relatively warm (red) and cold (blue) water (which vary by about +/- 1°C) are carried around the hemisphere by the Antarctic Circumpolar Current. Sea ice, atmospheric winds and pressure vary in accordance with this travelling temperature pattern.

The dipole, when it is present, consists of a warm water region around Indonesia and New Guinea, and a relatively colder region in the central Indian Ocean west of Australia (see map above). The warm region is fairly common, particularly in La Niña years, and the dipole effects are sensitive to the presence of the cold region.

This dipole produces north-west cloud-bands and associated rain because it works like a smaller scale version of the westerly-wind patterns in the mid-latitudes. The Southern Hemisphere's extremities, the Equator and the Antarctic, are separated by a mid-latitude region where westerly winds prevail. These winds are driven by the Coriolis force, the combination of the Earth's rotation and the north-south temperature gradient.



The Indian Ocean dipole works in much the same way, causing westerly (or north-westerly) winds to be directed over the continent. Since this air comes from the tropics, it is laden with water (initially in vapour form), which condenses and then precipitates as it moves south. During a typical winter with the dipole present, these north-west cloudband events occur two or three times each month, lasting from one to eight days.

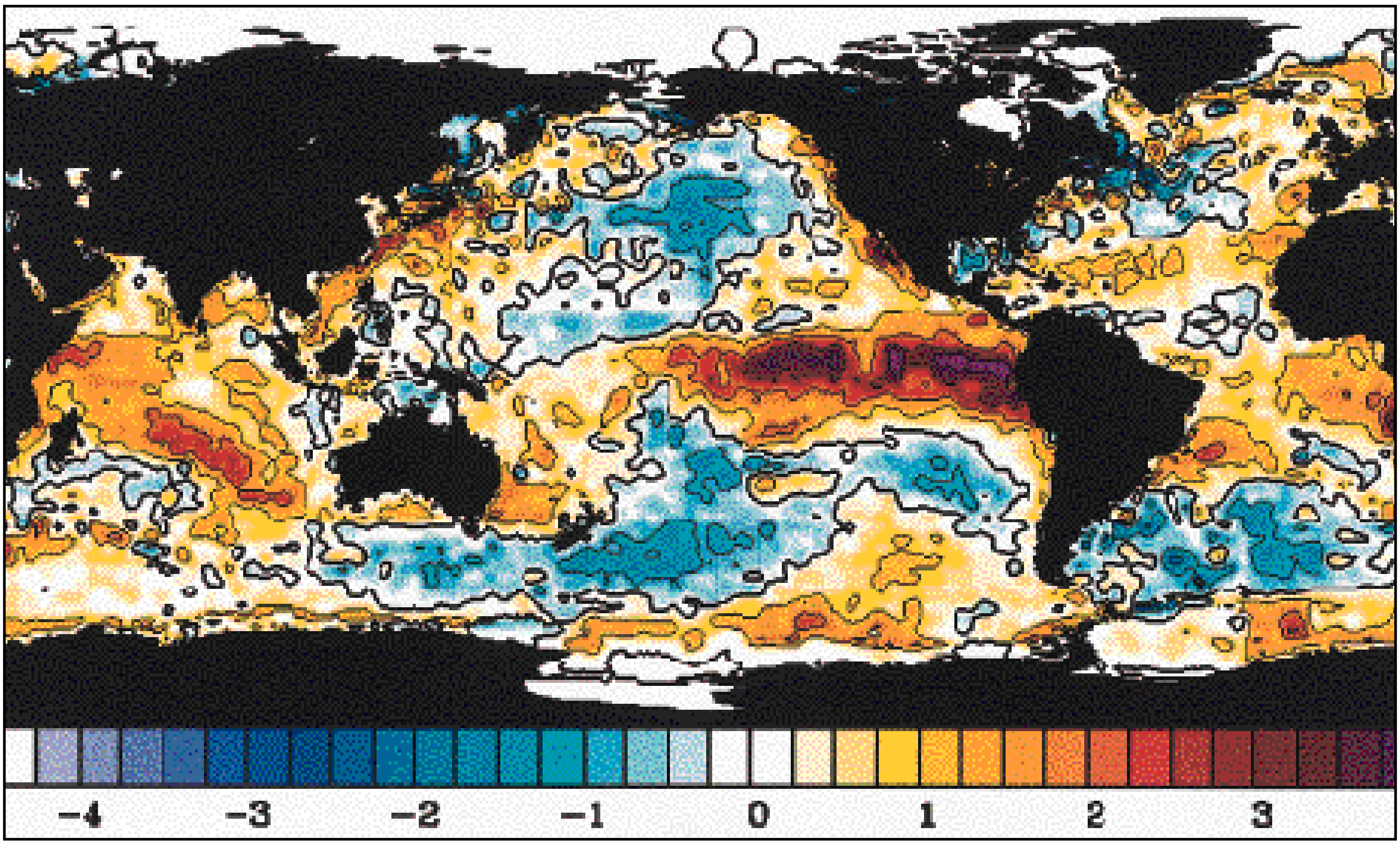
The Antarctic Circumpolar Wave

The third member of the trio of climatic factors is the most recently identified and least studied. Its impact is still being explored, but it appears to be strongest in the southern part of the continent.

The Southern Ocean lies between Australia and Antarctica and extends around the globe at these latitudes, making it different from all the other oceans. It contains a large current which flows continuously around the Southern Hemisphere at about 10 cm per second, carrying most of the water with it. It takes about eight or nine years for this current to transport water completely around the world.

Carried along with this current are two large regions of relatively warm water, thousands of kilometres across and 1 km deep, alternating with two equally large regions of relatively cold water (see diagram at left). These alternating warm and cold regions are termed the Antarctic Circumpolar Wave, and like El Niño, they appear to be due to interactions between the atmosphere and the ocean. Other factors such as the atmospheric pressure and wind patterns, and the extent of the sea ice northward from the Antarctic coastline, all tend to vary in accordance with this travelling temperature pattern.

The chart of recent sea-surface temperature anomalies in the Southern Ocean shows the presence of the Antarctic Circumpolar Wave (see chart above right). Here, the two warm regions (yellow/red) are seen in the south-west Pacific and in the Indian Ocean area, and the cold regions (blue) are in the South Atlantic and south-west Pacific regions. These blobs are irregular in shape and size, and numerical models are required to forecast their details as described below.



A chart of satellite observations of sea-surface temperature anomalies (with the average temperature for each location at this time of year subtracted out) in the Southern Ocean for the week ending January 4 1998, showing the alternating warm and cold regions of the Antarctic Circumpolar Wave. The two warm regions (yellow/red) are seen in the south-west Pacific and in the Indian Ocean area, and the cold regions (blue) are in the South Atlantic and south-west Pacific regions.

This 'noisy' picture illustrates that real data are much less tidy than the schematic diagram at left. Nonetheless the basic structure of the wave is clear.

As these relatively warm and cold regions pass south of Australia, they often flood the Great Australian Bight and surround Tasmania. Consequently, when the southern Australian States experience winds off the Southern Ocean, these winds are slightly warmer than average when a warm region is present, and they also contain slightly more moisture than usual. Hence, warm regions cause winters (for example) to be warmer and wetter than average, and cold regions make them cooler and drier. During July 1998, it appeared that we were in the last stages of a cold region. A warm region is expected next year.

It now seems likely that these effects from the Antarctic Circumpolar Wave will be more important for rainfall in the southern states than El Niño. It is a recent realisation, but perhaps no real surprise, that events over our 'back fence' may be more important to us than distant events out in the central Pacific that have received more international attention.

A B S T R A C T

Australia's climate is affected by interactions between the ocean surface and the atmosphere in the Indian, Pacific and Southern Oceans. These interactions produce effects known as El Niño, the Indian Ocean Dipole and, the most recent discovery, the Antarctic Circumpolar Wave. The Climate Modelling Group at CSIRO Atmospheric Research is characterising the mechanics of the wave in order to better understand its influence on the climate of southern Australia, and to improve the accuracy of global climate models.

Keywords: **oceanography; mathematical modelling; climate; El Niño; Indian Ocean Dipole; Antarctic Circumpolar Wave.**

Dogged modelling

Three climate factors may not be entirely independent of each other. One means of exploring their mechanisms of operation, and their interactions, is to use large-scale numerical models that describe the behaviour of both the global atmosphere and the global ocean. The interactions between the atmosphere and ocean also need to be faithfully captured.

This is a complex and sophisticated exercise, requiring a dedicated team of scientists and many years' work to build the necessary models, carry out the experiments, and analyse the results. Such a program is under way at CSIRO Atmospheric Research, where our Mark 2 coupled atmosphere-ocean model has been used to reveal a number of previously unknown aspects of the climate of the Southern Hemisphere.

The new, higher resolution Mark 3 version of this model, with improved physics, will be ready next year, and one of its foremost applications will be to analyse the joint effects of Niño, the Indian Ocean dipole and the Antarctic Circumpolar Wave, and the interactions between them. With the general improvement in oceanic research the science of long-term forecasting promises some exciting developments.

More about oceans and climate

O'Neill G (1995) Coping with climate. *Ecos* 84:11-26.

White WB and Peterson RG (1996) An Antarctic circumpolar wave in surface pressure, wind, temperature and sea-ice extent. *Nature* 380:699-702.

Wright B (1992/93) Climate models – for clues to the future. *Ecos* 74:14-17.

Going to extremes, *Ecos* 94:17-18.