Havoc surrounds a wave called Kelvin

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Wind erosion: one of the devastating consequences of drought. Understanding the global processes that affect climate variability is vital to improving the management of Australia's fragile landscapes.

IN 1994 a French/US satellite produced the first images of long, low waves undulating across the Pacific Ocean at the equator. These gravity-driven waves are the pulse of El Niño and understanding them is central to predicting climate on both sides of the Pacific.

Dr Tony Hirst from CSIRO's Division of Atmospheric Research helped establish the link between these strange, planetary-scale waves and the climatic phases known as El Niño and La Niña six years ago. Back then the waves existed only in theory, but satellite imaging now confirms their presence.

Hirst says the waves originate from an extensive pool of warm water that normally lies near Indonesia and New Guinea. Strong trade winds normally blow from east to west across the Pacific. These winds drag surface water westward, during which time it is steadily heated by the sun's rays. The water eventually accumulates in the Indonesia/New Guinea warm pool, which sits as a mound on a substrate of colder, denser water.

But if the easterly trade winds weaken, as in the event of an El Niño, this warm pool elongates and flows 'downhill' from the mound, eastward towards South America. It takes two to three months for the wave – known as a 'Kelvin wave' – to carry its cargo of warm, low-density water 10 000 kilometres across the Pacific.

Upon nearing the South American coast, the Kelvin wave overrides the cold, dense waters of the Humboldt Current. Fish, such as anchovetta, and other marine organisms, which rely on the rich nutrients of the Humboldt, are unable to feed. Consequently they migrate or die. The loss of anchovetta stocks can be disastrous for the Peruvian fishing industry.

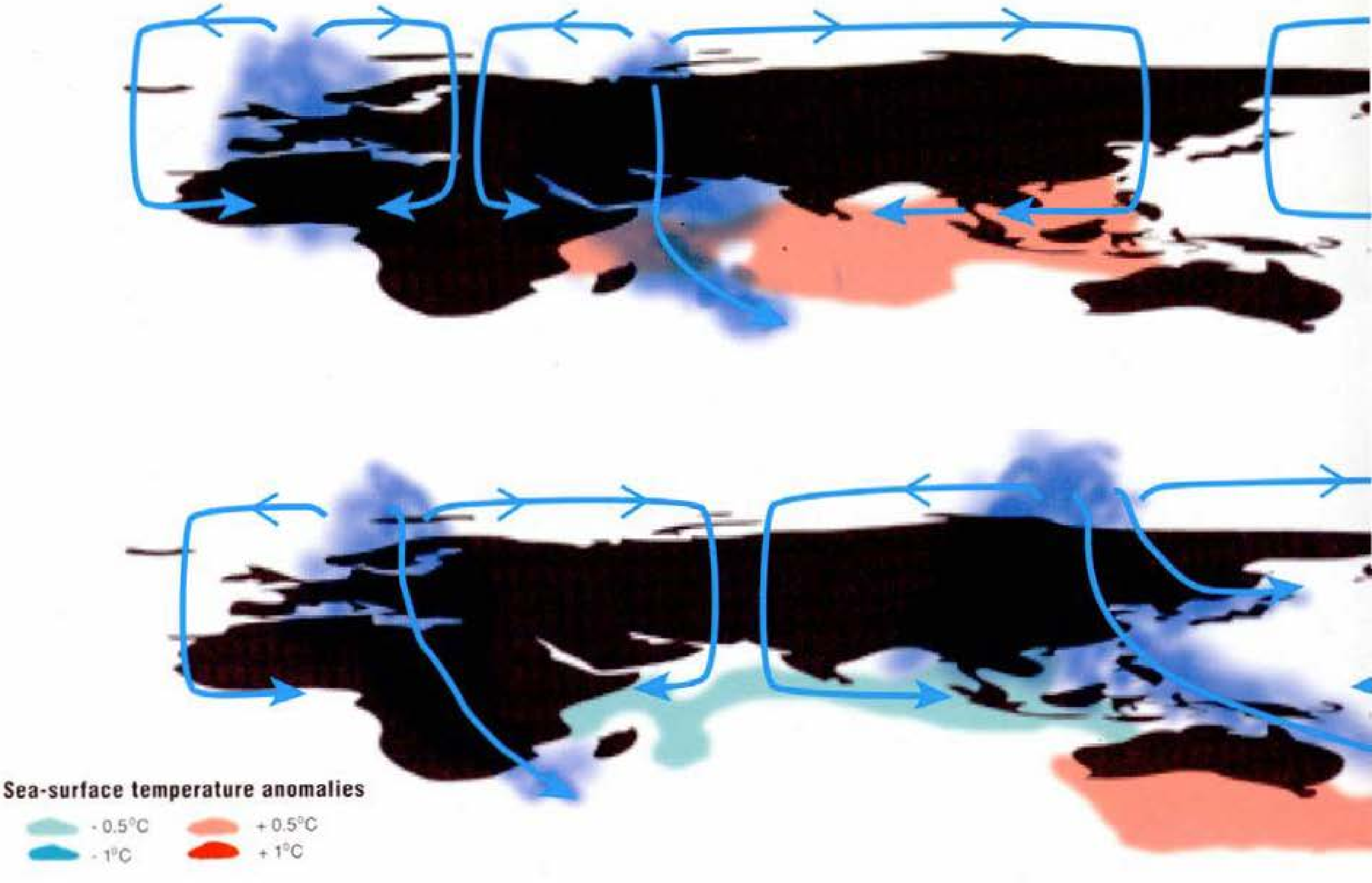
The eastward shift in warm water has a dramatic effect on rainfall patterns. In the tropics, rainfall usually occurs near where the ocean and surface air are warmest. The warming of the eastern Pacific during El Niño leads to tropical deluges over the usually arid west coast of South America, causing flooding and mudslides.

In the wake of a Kelvin wave, the consequences are equally drastic. The warm surface layer in the western Pacific thins out, and colder water is able to mix with the ocean surface. The sea surface cools, slowing evaporation and reducing rainfall. The climate of the western Pacific becomes drier, and the eastern two-thirds of Australia enter drought.

The Kelvin wave in the east Pacific splits into two upon reaching the South American coast, with one branch travelling north along the coast towards California, and the other travelling south towards Chile. The northern branch is known to affect marine life and ocean temperatures as far north as Vancouver before it dissipates. With the Kelvin wave having left the tropical eastern Pacific, the warm surface layer there thins and cools, and the trade winds begin rebuilding the Indonesia/New Guinea warm pool. The El Niño is over.

Drought and flooding rain

Hirst says that sometimes a receding El Niño episode is followed by an upwelling of abnormally cold water in the central and eastern Pacific, while in the western Pacific, sea-surface temperatures become unusually high. This phase, the opposite of El Niño, is called La Niña. Tropical rain is now centred over Indonesia and northern Australia, and further systems may spin off this region to



Riding the climate see-saw

THE El Niño-Southern Oscillation (ENSO) see-saws between two extremes: El Niño and La Niña. The top world diagram summarises an El Niño episode, the lower, a La Niña.

During ENSO extremes, changes in sea-surface temperature are linked to changes in atmospheric circulation. Sea-surface temperature anomalies (differences from the long-term average) are represented in the diagrams by the red and blue shaded areas. The red patterns indicate warmer than average sea-surface temperatures and the blue areas are cooler than average.

The blue arrows represent shifts in atmospheric circulation, which in turn reflect changes in the winds and vertical movement of air masses. These changes alter the typical positions of cloud masses (shown in mauve).

During an El Niño, rain-bearing systems are moved away from Australia and into the Pacific. During a La Niña, the rain-bearing clouds are typically found over Australia, resulting in wetter than normal years. The diagrams highlight the fact that ENSO extends across both the Pacific and Indian Oceans.

give eastern Australia torrential rain and flooding.

Occasionally, as in 1991/95, there is a succession of weak or moderate El Niño episodes with only short breaks in between. Such a pattern, or sequence, can produce prolonged or recurring drought, in the most recent case over parts of Queensland.

La Niña and El Niño episodes may be separated by long periods of near-normal conditions. Alternatively, the climate system may swing between La Niña and El Niño for several cycles, with either episode returning every few years. This swinging effect in the atmosphere is called the Southern Oscillation: the climatic phenomenon usually linked to El Niño and La Niña extremes.

Each extreme of the Southern Oscillation is associated with a particular pressure pattern. During an El Niño, sea-level air pressure is higher over Australasia, and lower over the South-east Pacific. In a La Niña phase, the reverse is true. Fluctuations in this pressure pattern can warn of impending El Niño or La Niña events and are monitored by the Southern Oscillation Index. The most commonly used version of the index is simply the difference in pressure at Darwin and Tahiti.

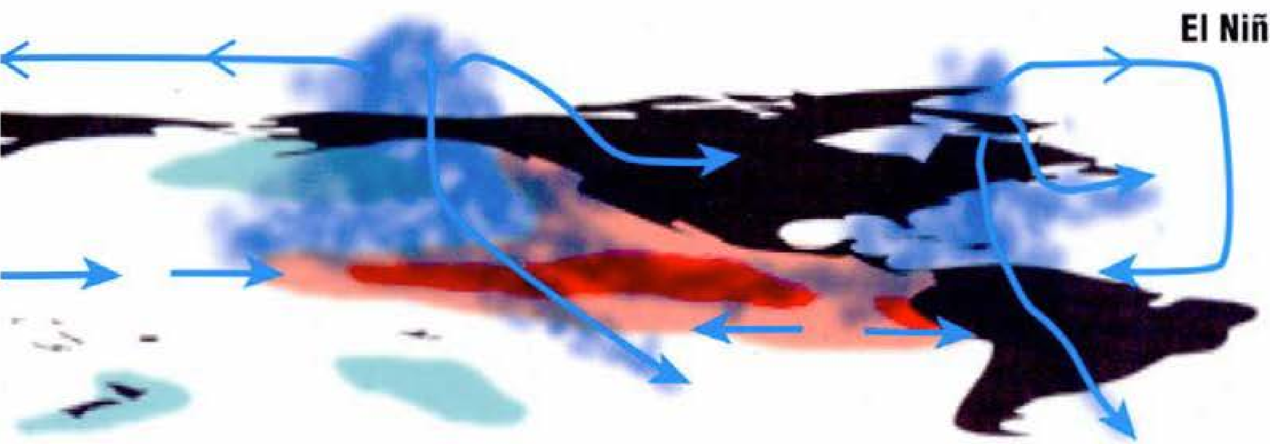
For example, the index fell to -15 during April/June 1994, indicating incipient El Niño conditions months before the full signature of the east Pacific warming became apparent (see graph opposite). The index is also affected by short-term pressure fluctuations, which sometimes reduce its interpretive value.

The term ENSO (El Niño-Southern Oscillation) is often used in relation to this Indo-Pacific climate system and its components. The phrase 'ENSO episode' may refer to either an El Niño or a La Niña, or both.

Unmasking Kelvin

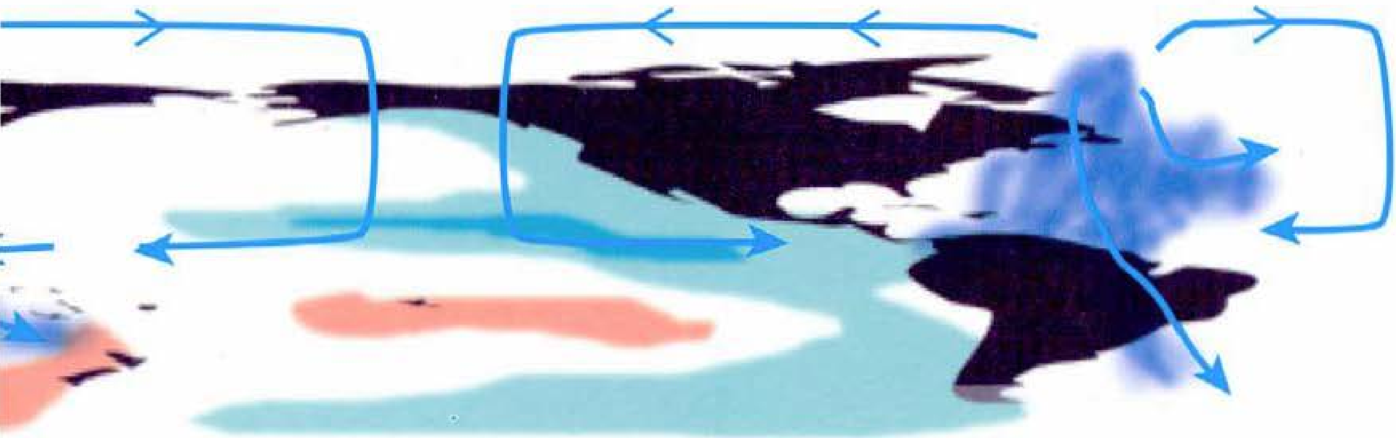
Scientists at the Division of Atmospheric Research, the Division of Oceanography and the Bureau of Meteorology Research Centre are working to develop an ocean-atmosphere model that simulates the ENSO system (the Australian Community Ocean Model).

Dr Steve Wilson, a member of the project team,



El Niño

La Niña



says that while ENSO manifests itself through the atmosphere – through marked changes in patterns of barometric pressure, wind fields and precipitation – the ocean is ENSO's 'memory'.

'The behaviour of the atmosphere is not predictable beyond a month or two,' Wilson says. 'However, it is influenced by the ocean, sea ice, and land surfaces. Because the ocean varies on longer timescales, typically a year or more, the ocean's influence on the atmosphere is the key to forecasting ENSO events.'

The Indian Ocean also experiences fluctuations in surface temperature which can affect rainfall across central and south-east Australia. The pattern of surface water temperatures in the Indian Ocean is linked with the Pacific ENSO. Dr Gary Meyers from the Division of Oceanography has confirmed that other parts of the Indian Ocean pattern, which evolve independently, can affect the impact of the Pacific ENSO on Australia.

'In 1993 we had an El Niño and drought in northern NSW and Queensland and, but conditions in Victoria were generally good because the drought was mitigated by conditions in the Indian Ocean,' Meyers says.

'The surface waters of the Indian Ocean off north-western Australia were warm and fed a band of rain-bearing cloud over the continent from the north-west to the south-east. This band interacted with a sequence of low-pressure systems and westerly winds to relieve the drought in Victoria.'

Meyers says these conditions show that the Indian Ocean system can act independently of the Pacific El Niño. When the Pacific ENSO and the Indian Ocean phenomenon conspire, however, trouble may result.

For example, during the 1982/83 drought, the Indian Ocean pattern was in a 'drought-favorable' phase. This reinforced the drought in south-eastern Australia.

This happened again late in the 1991/95 drought. In mid-1994 the sea surface off north-western Australia began to cool, and the widespread drought in Queensland and northern NSW extended from NSW to Victoria and Tasmania.

Meyers and his colleagues suspect the Indian Ocean pattern is linked to the Pacific ENSO via a powerful oceanic current called the Indonesian throughflow.

As easterly trade winds across the Pacific pile up warm surface waters in the western Pacific around Indonesia and northern Australia, gravity causes some of the surplus to drain south-westwards through the Indonesian archipelago into the Indian Ocean.

This throughflow is the source of the warm Leeuwin current that flows down the Western Australian coast and into southern near-coastal waters. Meyers and his colleagues are able to use their model of the Indian and Pacific Oceans in order to better understand such interactions.

More about ENSO

Bell A (1986) El Niño and prospects for drought prediction. *Ecos* 49: 12-18.

Brett D (1990) Oceans, atmosphere and climate prediction. *Ecos* 63: 21-27.

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