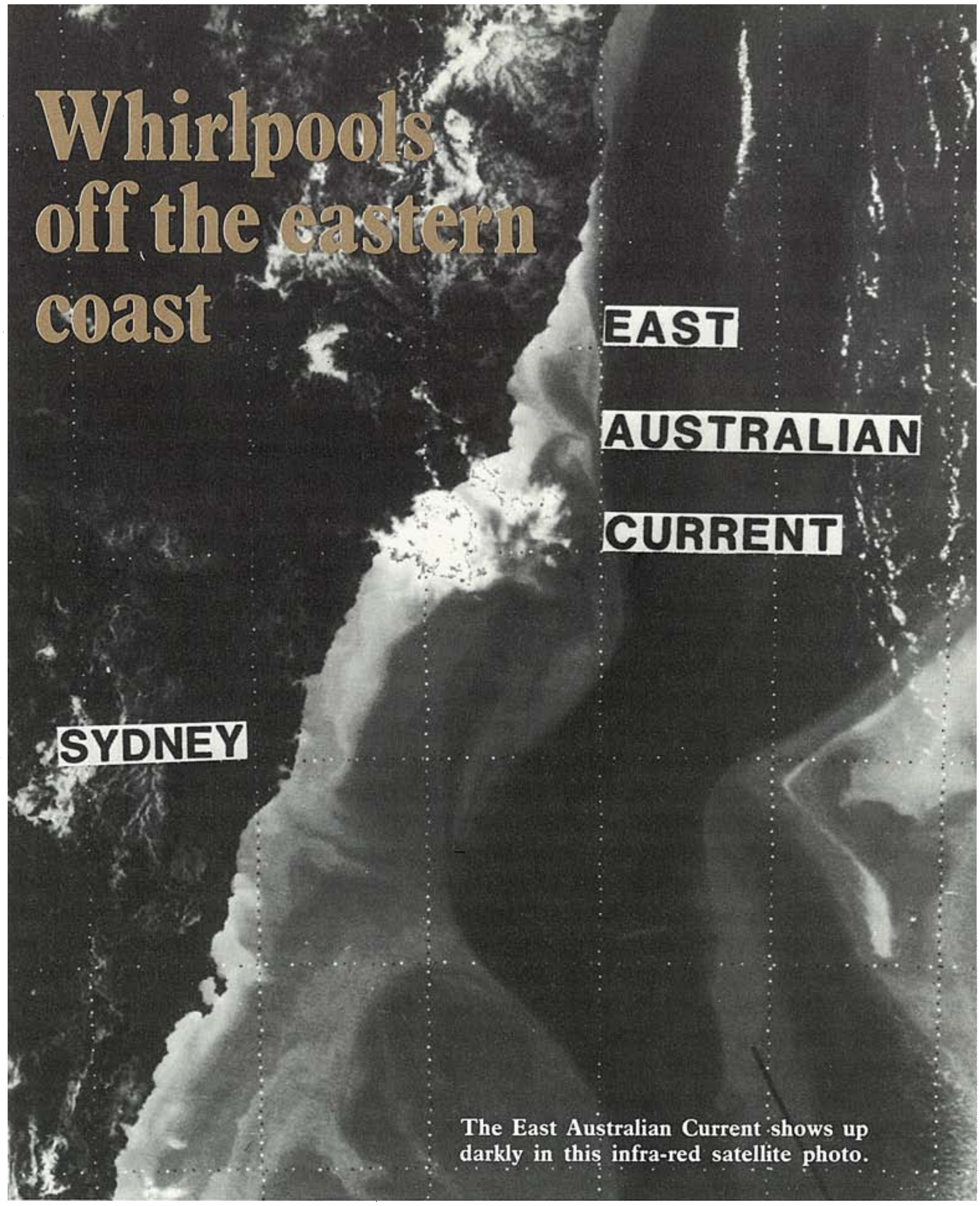
Whirlpools off the eastern coast



The East Australian Current shows up darkly in this infra-red satellite photo.

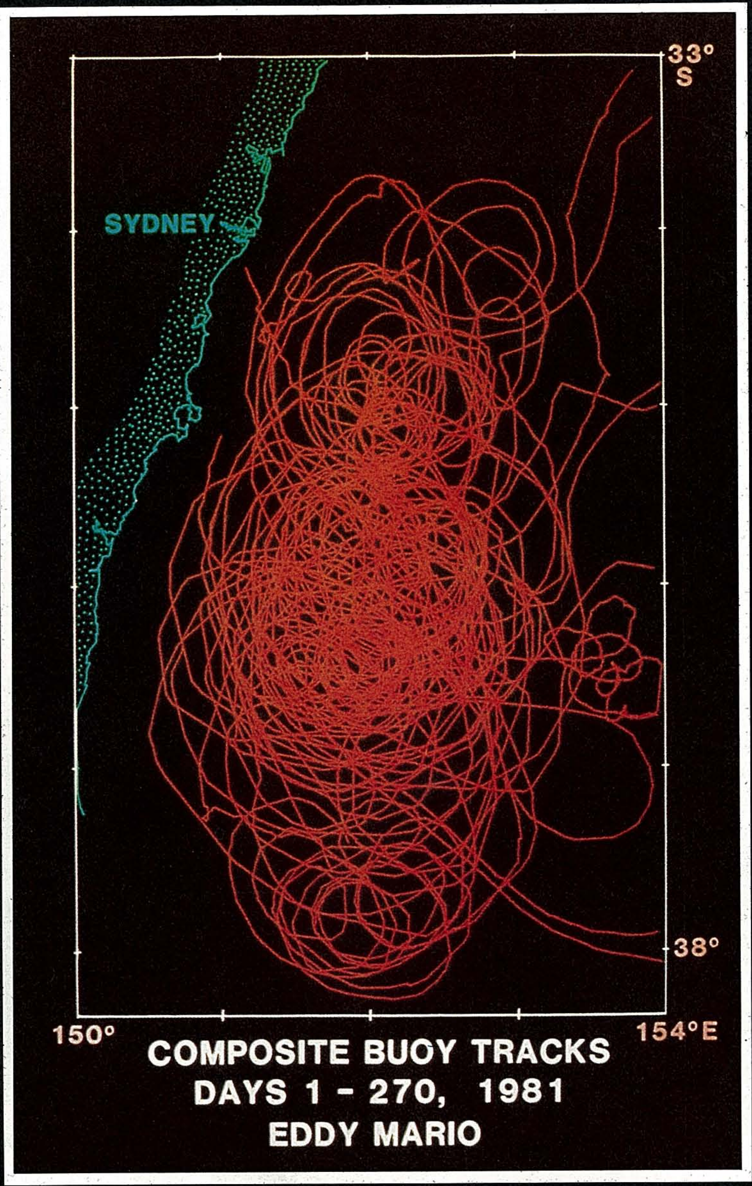
Scientists are beginning to understand a remarkable play of ocean hydrodynamics being staged in the Tasman Sea. They are observing giant whirlpools, rather similar to the diminutive ones seen peeling off an oar when it's drawn through the water.

The whirlpools, some as large as Tasmania, wander like spinning tops through the waters off Australia's eastern coast, moving as if they had minds of their own. Sometimes alone, sometimes in concert with one or two others, the rotating bodies of water persist for months — in some cases, more than a year. Floating buoys trapped within them will perform a circuit in from 5 to 20 days. The speed of surface currents at the periphery may be as high as 5 knots (2·5 metres per second).

Scientists from the CSIRO Marine Laboratories and the Royal Australian Navy Research Laboratory believe they now have a good idea of what's behind the warm-core eddies, as they call them. (The Marine Laboratories comprise the Division of Oceanography and the Division of Fisheries Research.)

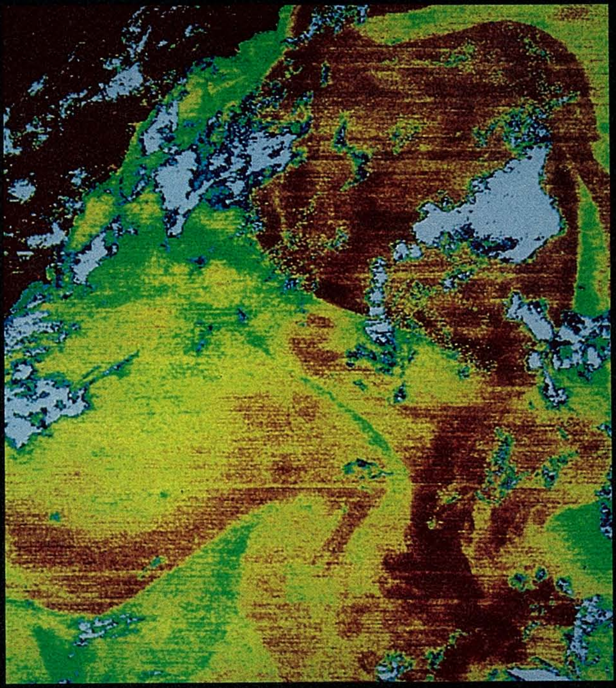
Their studies have enabled a dynamic picture of the eddies' behaviour to be drawn up. A glance along the series of frames at the bottom of the next page will give the reader a feel for what's happening. It can be seen that the eddies are offspring of the East Australian Current, which flows south along the coast of Australia. The current carries warm Coral Sea water southwards, and then veers east at about 30°S latitude to skirt Lord Howe Island before continuing on towards New Zealand.

Significantly, as it tries to turn the corner from a southward heading to an eastward one it appears to overshoot, and a



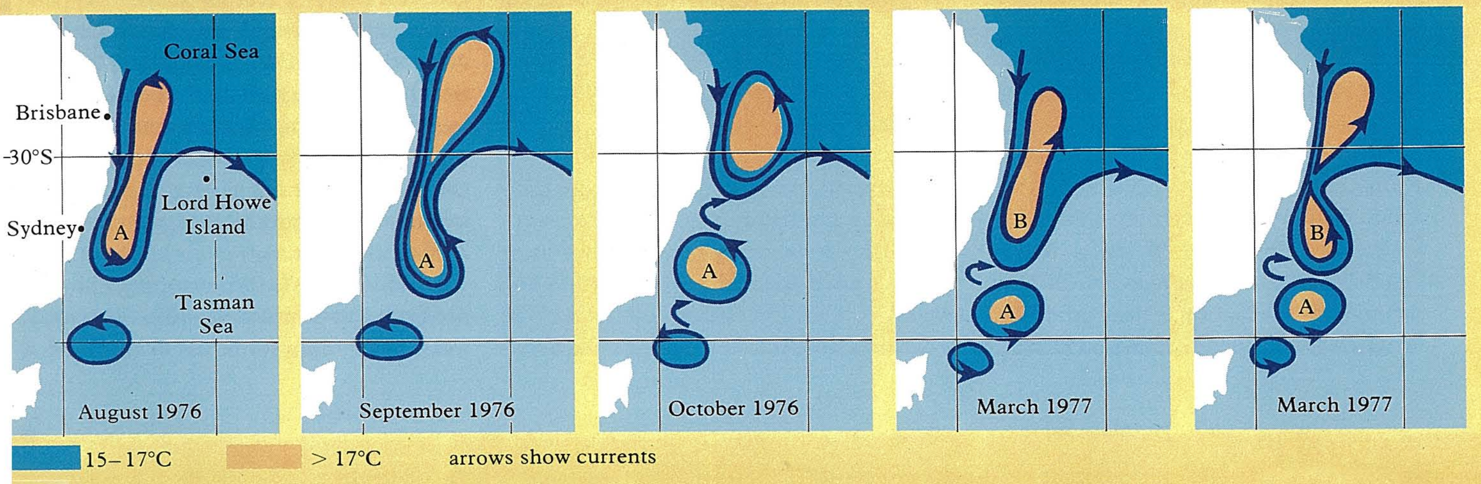
Caught in whirlpools, buoys trace out circular paths. The tracks show the movement of four buoys over 270 days in 1981.

Buoys like this one, tracked by satellite, are set adrift in the eddies.



This infra-red image of Eddy J (top right) off Sydney was captured by the Heat Capacity Mapping Mission satellite on 24 February 1979. The dark area is land and cloud appears light blue.

How eddies form



large meander protrudes down — often beyond Sydney.

The meander regularly pinches off, and the resulting 'billabongs' are the eddies we observe. Observations indicate that two or three eddies a year form in this way. It is tempting to view these as separating like drips from a dripping tap, but that's not quite right because about two-thirds of the eddies return to the mother current and become reabsorbed. The remainder may die out in the Tasman Sea, ricochet off one another, or coalesce. Sometimes an eddy may split into two.

The erratic movements of the eddies, and of the darting tongue of the parent current, explain why the currents experienced by shipping off Sydney are so variable. However, observations by Mr Fred Boland of the Division of Oceanography that sea level and sea temperature fluctuations off Sydney appear to recur most strongly at intervals of 3–4 months suggest an underlying regularity.

Ever since the earliest days of settlement, mariners have made use of the generally southward set of currents near the shore. Commander J. Lort Stokes of H.M.S. *Beagle* recorded in 1838 (2 years after the vessel had brought Charles Darwin to Australia):

> 'We sailed from Hobarton on the 19th of July and carried a strong fair wind to within a few days' sail of Sydney, when we experienced a current that set us 40 miles S.E. in 24 hours; this was the more extraordinary as we did not feel it before, and scarcely afterwards; and our course being parallel to the shore, was not likely to have brought us suddenly within the influence of the currents said to prevail along the coast. The ship's position was 40 miles east of Jervis Bay when we first met it.'

Why did the current often peter out so quickly, and why is a northerly counterpart regularly encountered further off shore? Oceanographers have only recently come up with the answer.

The latest observations — brought together by Dr Carl Nilsson and Dr George Cresswell, of the Division of Oceanography — show that mariners were travelling at some times on the outer edges of eddies and at others in a meandering but otherwise continuous current.

New tools

New technological tools are greatly assisting oceanographers to uncover the 'toing and froing' in the Tasman. Instrumented buoys are now tracked by satellite, and satellites can produce infra-red images of the ocean waters from which surface temperature can be deduced.

The history of the eddy remains written in the core.

Research vessels such as the CSIRO *Sprightly* and *Soela* and the Navy's *Kimbla* also carry modern instrumentation that allows precise and continuous measurement of surface water properties — temperature, salinity, turbidity, nutrient levels, phytoplankton content, and so on — to be made. Data on water properties at depth can also be obtained, so that profiles of water bodies can be drawn up.

As the picture begins to build up, scientists other than physical oceanographers are seeing what a unique opportunity for research these ocean eddies present.

An eddy is recognizably distinct from the surrounding sea. Here is a discrete parcel of water than can be followed for long periods, and can even be revisited.

Dr Nilsson and Dr Cresswell have found that as one crosses an eddy boundary the water temperature can change quickly — by 1 to 3°C. Observations of a number of eddies have shown that they cool during the winter, and their temperature at the end of the cold season depends on their latitude at that time. Dr Doris Airey of the same Division has substantiated this finding for 30 or more eddies. During cooling, a core is produced that can extend, by convection, to a depth of 370 m.

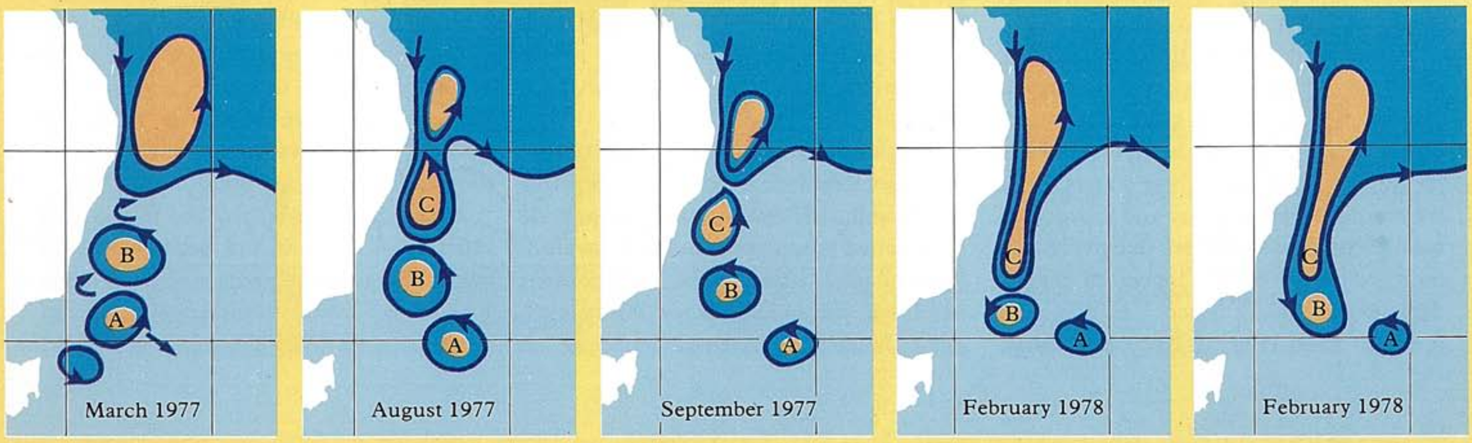
Come the summer, the surface waters warm up but the submerged core still retains its characteristic winter temperature and salinity. The history of the eddy remains written in the core; and the few eddies that have survived two winters show the more recent winter temperature–latitude signature overlying the older one at greater depth.

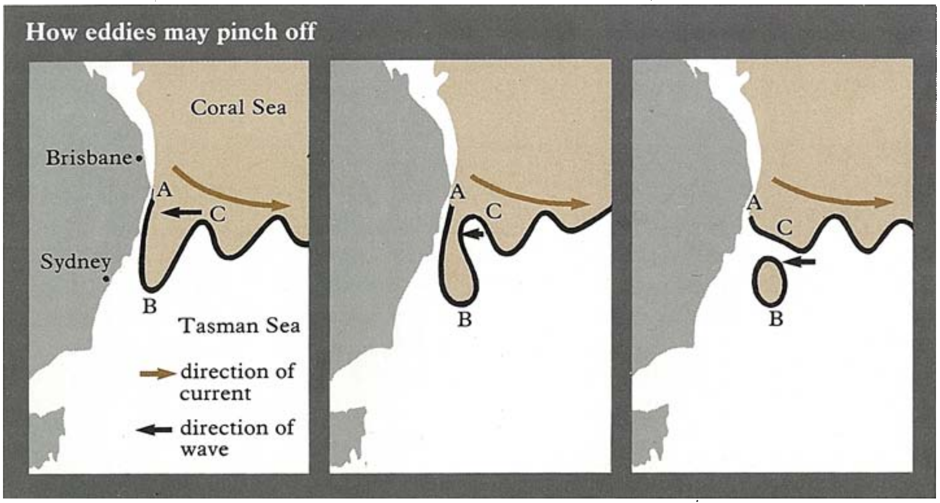
In recognition of their marked individuality, eddies are now given names like cyclones — the first one of this year was Eddy Angus. (As yet we haven't had an Eddy Eddy.)

For the biologist, an eddy is a microcosm of the parent water's environment, and lends itself to studies of how the marine life caught up in it copes with being expatriated to a new location and exposed to a new environment as a result of winter cooling. The interaction of species across the eddy boundary is particularly intriguing: how do the locals outside the eddy react to the invading foreigners inside, and what effects do the sharp changes in temperature, salinity, and nutrients at the boundary have on border crossings?

Each eddy is virtually a self-contained ecosystem, and it offers the biologist a chance to separate the effects of the physical and chemical surroundings on an oceanic community from the effects of biological interaction. Eddies may help us to understand the factors that limit the distribution of fish and micro-organisms

Dr Nilsson and Dr Cresswell present this picture of how the darting tongue of the East Australian Current can both produce new eddies and sweep up existing ones. The series combines observations from August 1976 to February 1978 with some guesswork.





Dr Nilsson and Dr Cresswell suggest that meanders on the boundary of the East Australian Current travel slowly westwards, and get pinched off against the coast.

such as plankton. For example, how do the Coral Sea fish that are occasionally found in Sydney Harbour get there?

Whirlpools of the world

Eddies are found not only in the Tasman Sea. They occur wherever fast currents are flowing, most notably in the Gulf Stream in the western North Atlantic, and the Kuroshio in the western North Pacific off Japan.

The currents themselves are parts of huge gyres — rotating bodies of water that fill the world's ocean basins. For reasons to do with the rotation of the earth, the gyres rotate clockwise in the Northern Hemisphere and anticlockwise in the Southern.

The rotation is driven by the sun. Like the atmosphere's weather systems, ocean currents carry heat energy from equator to pole. As Britons know well, currents are important in moderating climate at high latitudes.

However, like the weather, the energy flow in the oceans is not uniform, but comprises a turbulent complex of fluctuating currents, eddies, and meanders. Yet, just as the weather allows some degree of prediction, scientists hope that it will prove possible to forecast the appearance and movement of eddies.

In a sense, eddies are the ocean's 'high' and 'low' pressure systems. The surface of a warm-core eddy in colder surroundings in fact rises perhaps half a metre above the surface of its encircling waters. This is because its temperature and salinity are such as to give it a lesser density. Similarly, cold-core eddies appear as depressions in the ocean surface. The mean sea levels at Lord Howe Island show variations of up to 60 cm as 'highs' and 'lows' pass by.

As you would expect from a 'high', warm-core eddies invariably rotate anticlockwise in this Hemisphere, and current speed is related to the steepness of the surface slope. Cold-core eddies are the 'lows', and they rotate clockwise.

Eddies form at the boundaries of ocean currents. And so warm-core eddies form in the cold Tasman Sea from the warm waters of the Coral Sea; in addition, some cold-core eddies are formed in the Coral Sea from waters of the Tasman. Scientists know little about the latter, mainly because such eddies are well out in the Tasman, away from their laboratories.

The interaction of species across the eddy boundary is particularly intriguing.

Warm-core eddies, by comparison, appear right at our doorstep, and this article highlights some of the discoveries that have come from studies of the warm-core variety.

Prediction of eddies, if it proves possible, could have major implications for fishery operations. Thermal fronts — sharp changes in temperature between bodies of water — are known to have high productivity. For some years the fish cannery at Eden, N.S.W., has been making regular aerial surveys to guide the southern bluefin tuna boats to fish at these fronts.

Continuing studies by the Division of Fisheries Research are making it clear that eddies and their associated fronts provide heightened productivity at many levels of the food chain. The Division's scientists have observed an abundance of nutrients, phytoplankton, and zooplankton at an eddy's edge. Unexpectedly, the abundance of mid-water fishes, crustaceans, and squid higher up on the chain doesn't seem to show the same increase. However, the presence of tuna at fronts suggests these food items should be more abundant at an eddy.

The possibility of eddy prediction, and the importance of eddies for fish biology, were among the questions considered by scientists from Australia, New Zealand, and the United States when they attended a workshop last year to pool their knowledge. The meeting was held at the New Zealand Oceanographic Institute in Wellington. Most of the remainder of this article will draw upon the knowledge exchanged at the workshop, although it will restrict itself to Australian eddies (the Americans call theirs 'rings').

How eddies form

As mentioned earlier, much of the knowledge of the movement of eddies has come from research by Dr Nilsson and Dr Cresswell and their colleagues in CSIRO and the Navy. Dr Nilsson did much of his work with Dr John Andrews (now at the Australian Institute of Marine Science) while with the Royal Australian Navy Research Laboratory before joining CSIRO in 1982. The mechanism of eddy formation bears on the question of the predictability of eddies, and from their studies of eddies from 1976 to 1978, and those of Mr Fred Boland and Dr John Church, of the same Division, they have constructed the following picture.

About once a year the East Australian Current makes a particularly strong excursion southwards, and leaves behind an eddy at about 36°S, or even further south, when the Current retreats. While doing so, it sweeps up any old eddies that may be lying in its path. On subsequent excursions (about two per year) more eddies may be formed, although it is possible for the Current to advance as far as Sydney (latitude 33°S) and then retreat without forming an eddy.

Buoy tracks show that eddies move about irregularly. They can drift erratically — up to 20 km per day — or they can stay put for months on end. The researchers believe that the earlier notion that eddies continually drift south (reported in *Ecos* 3) was an incorrect impression based on scanty data.

Most eddies are reabsorbed by the East Australian Current, but perhaps once a year one may entirely escape it. If left alone an eddy is likely to continue spinning and wandering for 500–800 days. As it ages, it gradually gets smaller, and Dr Nilsson believes it acts like a turning ice-skater drawing in her arms: there is some evidence the spin rate increases.

Maximum spin is likely to be reached at an age of about 11 months, after which the speed declines. Eddies are generally lens-shaped, with rotation extending down to 300 (and sometimes 500) metres at the centre. Mr Bruce Hamon while at the Division of Oceanography (he is now retired) has observed rotation at even greater depths.

In winter, the temperature of an eddy slowly drops as it loses heat from the surface. In summer, however, the surface water warms up and the eddy core becomes insulated from the surface. The temperature of the deep cool core remains remarkably constant (within tenths of a degree). The insulating process can happen in two ways. Firstly, the eddy can begin to sink as it enters lighter, warmer water; this water floods over the eddy, submerging the core. Alternatively, the sun will warm the surface waters, leading to the formation of a 'cap' (just like a meteorologist's inversion layer).

If an eddy encounters and merges with another eddy, as occasionally happens, the new entity retains the old cores with their characteristic temperatures.

Marine billabongs

If, as the researchers have proposed, eddies are caused by pinching off of the East Australian Current, what causes the pinching off?

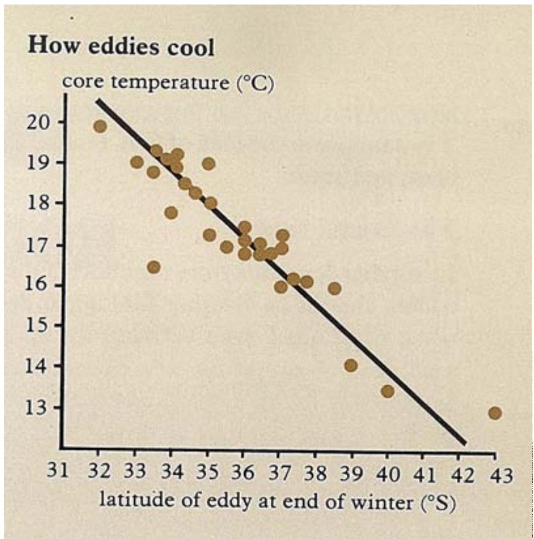
The suggested explanation calls for a moving wave in the boundary of the East Australian Current as it heads east towards New Zealand, as shown in the diagram on page 10. At times, Mr Boland has observed a wave-like appearance in the Current, but whether the wave moves as the theory predicts will require more study. Dr Nilsson and Dr Cresswell propose that, because of the earth's rotation, a wave 300 km long should be induced in the Current, and this Rossby wave (as it is known in hydrodynamics) should move slowly westwards in the opposite direction from the Current. Calculations suggest a speed of 2 cm per second.

It takes 170 days for a wave moving at that speed to cover 300 km; and this period is about the time Mr Boland has observed between one eddy and the next. In other words, there are indications that, one by one, loops in the Current do get pinched off against the coast by Rossby waves, as the theory demands.

Perhaps eddies can be predicted.

Such a process has an effect like waves breaking on a beach, with the result that the closer to the coast the eddies separate, the more intense they will be. Observations so far indicate that this is so. Further, the Rossby wave hypothesis calls for alternating periods of rapid change and quiet interludes; again, these have been seen.

The researchers have found that the focal region for loop formation is Sugarloaf Point (at 32·5°S). Sediment studies in the area indicate that the East Australian Current has been separating from the coast at this latitude for the best part of 5000 years, suggesting that the phenomenon is stable and regular.



Eddies become cooler the further south they drift during winter. The cool core temperature is preserved when the surface later warms up, and can be used to identify an eddy.

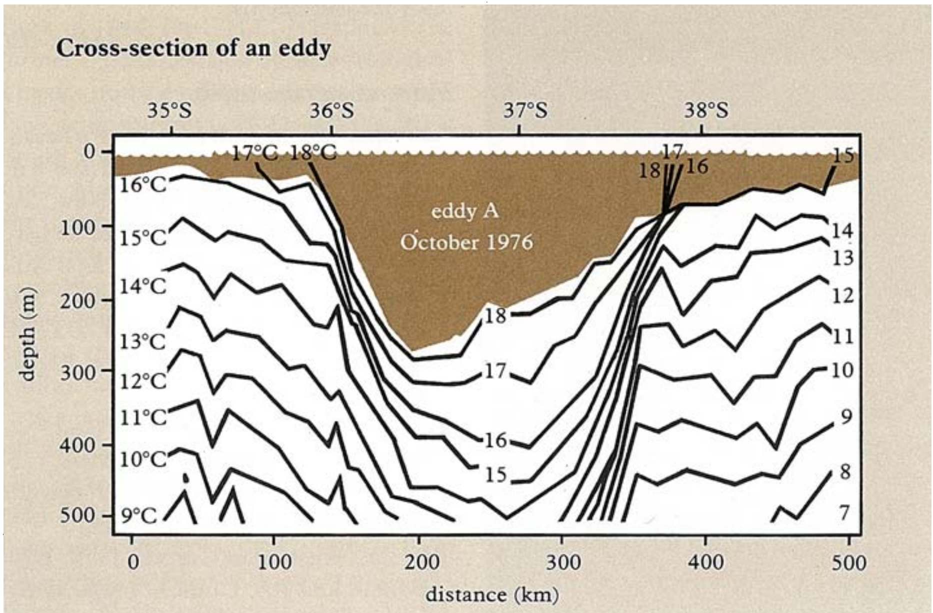
If the mechanism and major formation area are both known, perhaps eddies can be predicted. There is a clear difference in water temperature between the East Australian Current and the Tasman Sea. Satellite infra-red pictures may therefore make it possible to map the meanders and predict the next pinching-off — an exciting prospect.

Floating deserts?

Since the water making up an eddy originates from the open ocean of the Coral Sea, it is, like that Sea, very low in nutrients. We might expect, therefore, that the biological productivity of the eddy would be correspondingly low. Observed departures from this reasoning make eddies a great source of interest to fisheries scientists as well as oceanographers.

It is true that, in winter, the phytoplankton concentration inside an eddy is less than that outside. Dr David Tranter, Dr Shirley Jeffrey, and their colleagues in the Division of Fisheries Research have studied the phytoplankton levels of a number of eddies and found that by early summer the situation is sometimes reversed, and the ring stands out as a centre of biological activity. The eddy is the site of a phytoplankton 'bloom'. The bloom is caused by high-nutrient water brought up into the surface layers of the eddy by deep convective mixing. The colder the eddy becomes during its winter cooling phase, the deeper the mixing.

Dr Andrew Heron of the same Division has found that these blooms are succeeded by great swarms of herbivorous



The core of this eddy has a constant temperature (18·4 ± 0·1°C) from the surface to a depth of more than 250 m. Temperatures in the surrounding water are some degrees lower.

zooplankton — the very fast-growing salps. The salps form the food of fish, including tuna, and squid.

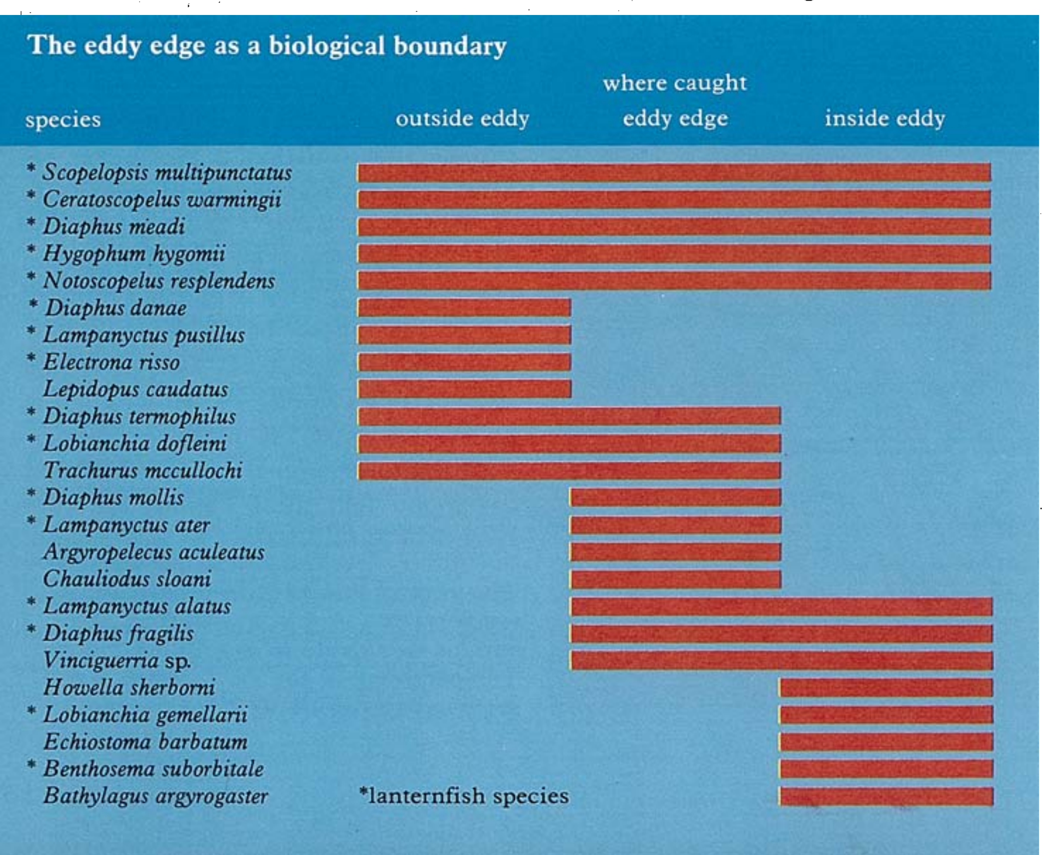
The frontal zone

In another departure from the concept that eddies should be floating biological deserts, the frontal zone between the eddy and the surrounding sea sometimes abounds with life. Dr Tranter has observed significant nutrient enrichment at this zone.

Dr Stephen Brandt (now in America) and his then colleagues in CSIRO have studied the abundance and distribution of fish caught on 195 trawls made in the vicinity of warm-core eddies. The distribution of the catch is shown in the diagram. It can be seen that only five fish species were found both inside and outside the eddy, and the fish community within the eddy had a structure recognizably distinct from that in surrounding waters. Some species of fish were more likely to be found at fronts, he found, and others avoided crossing frontal barriers. In all cases, temperature seemed to be the factor controlling the distribution of fish. There was no indication of obvious concentrations of fish at the fronts, as expected.

Few fish were caught during the day; at night, variable numbers of fish were landed and more than 80% of them were lanternfish, representing more than 40 species. Lanternfish are small (usually less than 10 cm long), and their silver and black bodies are patterned with luminous tissue and light organs, which emit a bright blue light. Each species carries a unique pattern of light organs.

The diagram shows how the fish population differs outside an eddy, at its edge, and inside.

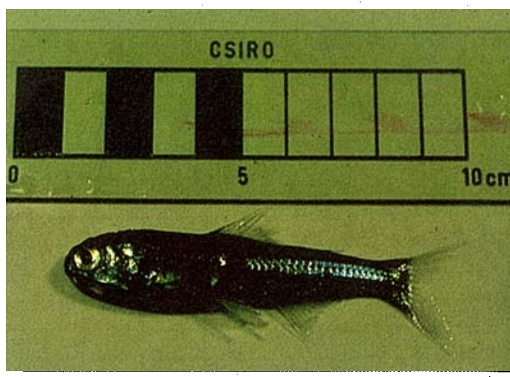


The fish rarely venture above 300 m during the day, preferring to live in the perpetual twilight of the middle ocean depths. Occasionally they go as deep as 2000 m. At night they migrate to the upper 200 m to feed, and this is when the scientists caught them. The preferences that fish have for particular water temperatures imply that fish populations are likely to vary according to the location of eddies. Dr Brandt observed a dramatic change in fish types when Eddy J coalesced with Eddy I in late 1979 and early 1980, probably because the two had different core temperatures, and consequently a different fish species complement.

Dr Brandt believes lanternfish have a commercial potential that is worth investigating. They belong to the most abundant family of fish in the world. Up to half of all fish larvae in the open ocean are lanternfish, and some researchers have suggested that these species may have the greatest biomass of any vertebrate family. The potential annual yield could be about 100 million tonnes — greater than the present world fish catch.

Lanternfish have a high oil content and their greatest use may lie in the production of fish meal, oil, and silage. However, Russian scientists have reported that one Antarctic species is suitable for human consumption.

The difficulty is that they are hard to catch. The ones near the surface don't congregate in schools and, with present fishing techniques, catches will usually be small. The CSIRO vessel *Soela* caught a maximum of 25 kg of them in an hour.



A lanternfish (*Diaphus* sp.).

Perhaps if the net had been aimed at the concentrations of fish indicated by the echo sounder, larger catches would have been obtained.

Regardless of whether lanternfish ever become a commercial proposition, the important fact is that they play a major role in the food chain of the open ocean. They are a food source for commercial fish species such as redfish, hake, Jack mackerel, yellow-fin tuna, skipjack tuna, and bluefin tuna. They are also eaten by squid, fur seals, and dolphins.

Obviously more research needs to be done on the association between fish and fronts. One of the techniques being applied by Mr Marshall Hall and colleagues at the Naval Research Laboratory is a specialized form of sonar called volume reverberation. Explosives are used to send a range of sound frequencies into the water, and the technique looks at how strongly fish scatter the signal at each frequency. A fish's air-filled swim bladder scatters sound strongly at its resonant frequency, which depends on its size and depth. In this way, scientists can determine the size and number of fish with swim bladders — such as lanternfish — in the waters below, speeding the abundance measurements.

Andrew Bell

More about the topic

Australian Journal of Marine and Freshwater Research, 1983, **34** (4). (This issue contains the proceedings of the New Zealand workshop on 'Warm-Core Rings'.)

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The East Australian Current 1978. F.M. Boland and J.A. Church. *Deep-Sea Research*, 1981, **28A**, 937–57.