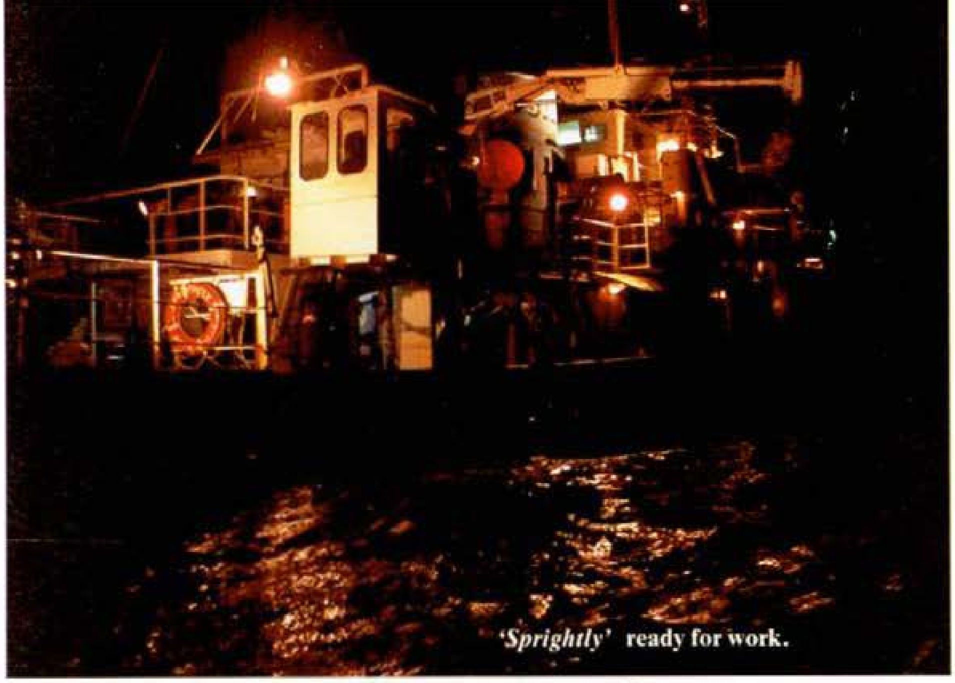


'Sprightly' ready for work.

Snaring the elusive trapped wave

Those studying nutrients, pollutants, and fisheries off Sydney should be aware that currents there are affected by oceanographic phenomena called coastal trapped waves that may be generated in Bass Strait or even in the Great Australian Bight.

Over recent years oceanographers have come to place credence in the presence of these waves despite the lack of conclusive experimental evidence. Now a major experiment off the New South Wales coast has provided conclusive proof of their existence.

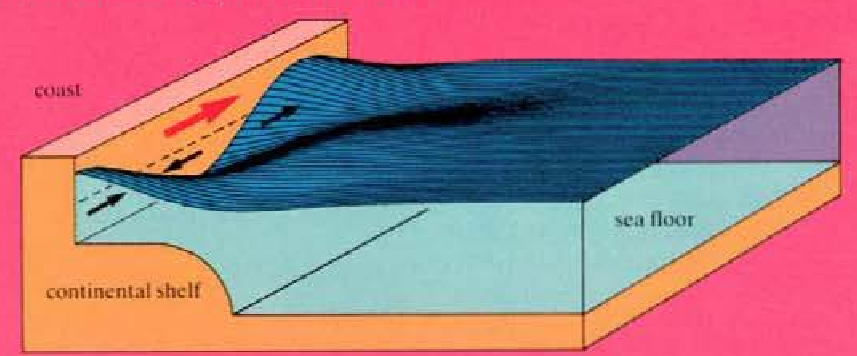
Coastal trapped waves are thought to inhabit all the world's coastlines. They have been invoked to explain diverse observations involving currents, fisheries, and weather — even aspects of the El Nino phenomenon. A CSIRO oceanographer, Dr John Church, thinks skippers in the Sydney–Hobart yacht race who headed offshore might have gained the edge over their rivals because they avoided these north-travelling waves (and their associated currents), as well as getting a southward push from the East Australian Current.

According to present oceanographic thought, the waves are bound intimately to the coastal shelf (which acts as a 'wave guide') and travel along it like the undulations on the edge of a fluttering flag (see the diagram). They also create an oscillating along-shore current. Both the sea-level changes and currents are generally strongest near the shore-line. In the Southern Hemisphere, the waves travel with the coastline on their left; in the Northern Hemisphere it's on their right.

The oceanographers' faith in their theory has now been justified. A 6-month observational net along the New South Wales coast has proved the existence of coastal trapped waves. Oceanographers involved in the Australian Coastal Experiment (ACE) isolated their quarry from the vast array of data collected.

This computer drawing shows the simplest first-mode wave. The red arrow shows the direction of travel in the Southern Hemisphere. Oscillating currents are also produced near the coast (small arrows).

What a coastal trapped wave looks like



ACE was a collaborative experiment involving the CSIRO Division of Oceanography, the Canadian Institute of Ocean Sciences, and the Departments of Oceanography at Oregon State University and Florida State University.

A balance of air and water

Speculation about coastal trapped waves sprang from observations in the 1960s by Mr Bruce Hamon of the former CSIRO Division of Fisheries and Oceanography. He was examining the effect of atmospheric pressure on the height of the ocean's surface. He reasoned that, if the ocean were in balance with the atmosphere, then an increase in barometric pressure of 10 millibars should cause the surface of the ocean to be depressed by 10 cm.

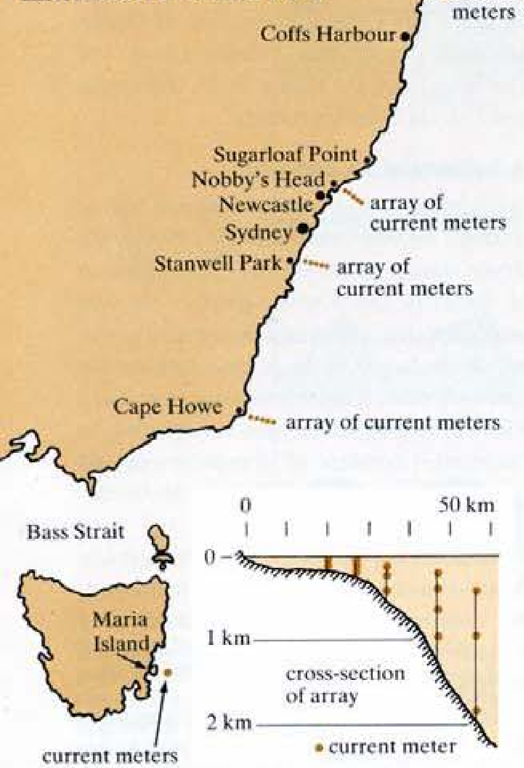
He gathered tide-height data from many Australian coastal stations and corresponding weather data from the Bureau of Meteorology, and looked for the expected correlation.

Some stations — Hobart for example — did show the expected balance. But to his surprise, many stations were distinctly out of balance. Data from Sydney showed only half the expected response, whereas data from Geraldton on the Western Australian coast showed a response twice that expected. Furthermore, there was a clear suggestion that the deviation from equilibrium propagated northwards along the eastern coast at a speed of about 4 metres per second (15 km per hour).

In other words, the ocean was behaving dynamically — more like a bowl of water than a barometer. Perturbed by variations in atmospheric pressure, the shelf waters seemed to be responding by sending out waves. The physics of this situation called for the existence of associated currents as well.

Soon scientists from countries around the world were finding suggestions of non-equilibrium behaviour in many sea-level and current anomalies, and the term

Instruments to catch a wave



The Australian Coastal Experiment relied for most of its data on dozens of current meters each set to take a reading every 30 minutes for 6 months. Other data came from tide gauges, weather stations, an oceanographic vessel, and other sources.

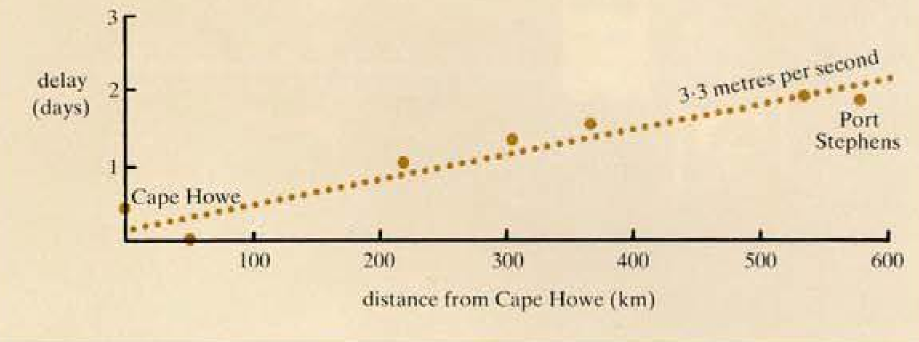
'coastal trapped wave' was coined by theoreticians. The importance attributed to these waves in ocean dynamics has steadily increased, and a good deal of theoretical work has been done in understanding their properties.

The continental shelf profile, and the stratification of ocean waters into layers of different densities, are essential ingredients for coastal trapped waves to exist. In effect, the continental shelf is the wave-guide, allowing the transmission of energy — the coastal trapped wave — along the coast.

It is now accepted that wind stress — the force of wind blowing across the ocean surface — is more important in generating the waves than direct atmospheric pressure. If the ocean's and the atmosphere's time and space scales are in tune, a resonance occurs, and coastal trapped waves are easily generated.

We are talking of waves with a period of days, and (recognizing the speeds mentioned above) wave lengths of several thousand kilometres. Such time and space scales are able to 'lock' into the scales of the weather patterns that pass overhead. Tides, which have a much shorter period (two per day), don't play a significant role in initiating the phenomenon.

How a wave travels up the coast



Despite considerable theoretical and observational detail, until ACE no clear-cut verification of the dynamics of coastal trapped waves had emerged.

Planning for ACE began in 1981, but it wasn't until September 1983 that equipment was deployed off the New South Wales coast and recording of data began.

One of the factors favouring the coastline between Eden and Newcastle was the uniformity of its continental shelf. Along those 500 km it has no large canyons, few islands, and no strong fronts (abrupt changes in water density). Also, no strong currents affect the area — the East Australian Current usually leaves the coast further north, at Sugarloaf Point. And, of course, there was evidence that coastal trapped waves lurk here, and nearby were oceanographers keen enough to search them out.

Fishing for a wave

To detect them, the ACE experimenters relied most on three lines of current meters, each with 15 instruments, arranged perpendicular to the coast.

One line was off Cape Howe, another off Stanwell Park (near Sydney), and the third off Nobby's Head (near Newcastle). Each line extended from 8 km out from the coast to nearly 60 km off-shore, and measurements were taken from near the surface to a depth of 1900 metres.

Five additional current meters were moored off-shore — three near Coff's Harbour, and the other two near Maria Island on the eastern coast of Tasmania. Each current meter was programmed to record the current every half-hour for 6 months.

After a current surge is detected at Cape Howe, current meters further north detect it at successively longer delays. The speed of propagation is 3·3 metres per second.

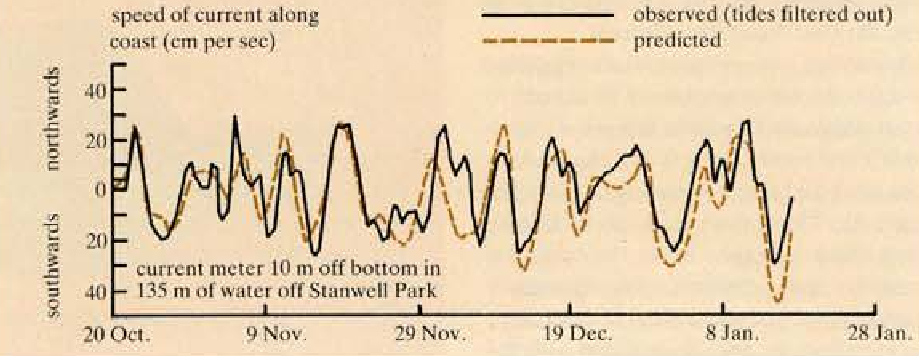
Other instruments in the observing net included tide gauges set on the sea floor and meteorological buoys to record surface winds. Data were also collected from coastal meteorological stations and tide-gauge stations. Satellite-tracked buoys and infrared satellite photos also helped the researchers keep watch on the East Australian Current, particularly eddies from it that might perturb coastal waters.

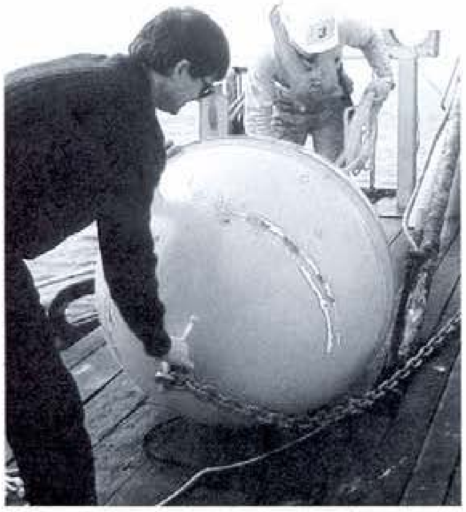
The CSIRO research vessel *'Sprightly'* made seven 2-week cruises during ACE, sounding the waters with expendable bathythermographs (XBTs), which measured profiles of temperature with depth, and a conductivity–temperature–depth (CTD) meter, which took more than 600 density profiles. The RAAF helped by dropping airborne XBTs during patrols of the area.

The idea, then, was to see whether a current (and a corresponding change in sea

Using the theory of coastal trapped waves, the scientists can predict currents off Stanwell Park very well from the currents at Cape Howe. In other words, most of the near-shore currents off Sydney are due to coastal trapped waves.

How currents at Cape Howe determine currents near Sydney





A buoy about to go overboard.

level), detected at the southern line of instruments, would show up later at the central and northern lines.

Theoretical predictions made before the experiment began suggested that wind-forced coastal trapped waves, with a near-shore current of 10–20 cm per second, should propagate northwards at 4–5 metres per second. Since Mr Hamon had found that sea levels at Eden were almost in balance with the atmosphere, the researchers expected little wave activity at the first line of instruments. But they thought that it would build up to reach pronounced levels at the second and third lines.

Caught!

Happily for theory, the observations matched most of the expectations. The researchers found a good correlation (a correlation coefficient of up to 70%) between instrument readings at Cape Howe and those further north. The delay between a movement at Cape Howe and its response at Stanwell Park 300 km away was 1·3 days, corresponding to a speed of 3·3 m per sec. This is somewhat lower than expected due to a surprisingly small contribution to the wave energy by local winds. The predominant period of the waves turned out to be about 6 days, corresponding to a wavelength of 1–2 thousand kilometres!

The data showed that coastal trapped waves propagate in three dominant modes. Mode 1, the simplest, which is depicted on page 13, propagates at 3·5 m per sec. However, two other modes with more complicated water particle movements were clearly seen. The along-shore velocities associated with the first three modes are shown in the diagram above right. Mode 3 waves are relatively weak, but as much energy is carried by mode 2 as by mode 1 waves.

Maximum wave amplitudes, found at coastal tide-gauge stations, were vertical displacements of 10–20 cm, and maximum along-shore currents of 50 cm per sec. were measured by the moored current meters.

Contrary to expectations, the data showed large wave activity at Cape Howe — implying that wave energy (calculations suggest some 200 megawatts) was entering the region from the south. This is a real puzzle, since comparatively little energy was found off the eastern coast of Tasmania. There are two possible explanations. Firstly, the waves could be generated in Bass Strait by winds there. Secondly, a recently proposed theory allows coastal trapped waves generated along the coastline of the Great Australian Bight to be somehow coupled to those on the eastern coast through an oscillation in Bass Strait.

The large wave activity found at Cape Howe also apparently contradicts Mr Hamon's finding of sea levels near there being in balance with the atmosphere. However, when the scientists looked more closely at the data, they found that the statistics on which his earlier findings were based weren't strong enough to definitely support his conclusion.

Another surprising finding of ACE was that the energy levels of the coastal trapped waves changed very little between the first line of instruments and the second. This shows that winds off the eastern coast play only a very small part in exciting the waves, and it means that the apparent propagation speed of the waves is lower than would be observed if local wind forcing was dominant. The scientists presume that the waves keep going, only slightly diminished, past Newcastle and are probably stopped by large changes in the width of the shelf at the southern end of the Great Barrier Reef.

On a number of occasions, they observed eddies from the East Australian Current coming inshore and interfering with the generally stable conditions there. Indeed, on one occasion an eddy caused damage to two of the equipment moorings.

ACE scientists

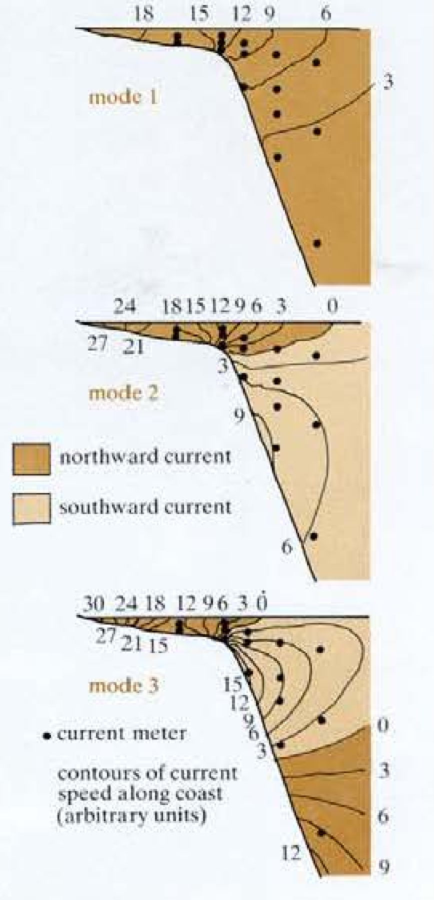
CSIRO Division of Oceanography
Mr Frederick Boland, Dr John Church, Mr Andrew Forbes, Dr Rory Thompson (now retired), and Dr Neil White

Institute of Ocean Sciences, Canada
Dr Howard Freeland

Department of Oceanography, Oregon State University
Dr Robert Smith and Dr Jane Huyer

Department of Oceanography, Florida State University
Dr Allan Clarke

Coastal trapped waves travel in three modes



As data from the current meters placed off Stanwell Park showed, coastal trapped waves travel in three dominant modes simultaneously. Mode 3 is relatively weak, but mode 2 is as strong as mode 1.

Nevertheless, if you rule out the occasions when eddies disturb matters, then it turns out that coastal trapped waves are the predominant feature governing currents close to the southern coast of New South Wales. Tides give the largest changes in water level, but tidal currents are negligible here. Currents associated with coastal trapped waves can reach 50 cm per sec. (about 1 knot) near the coast.

The ACE group has used the theory of coastal trapped waves to predict the currents at Stanwell Park from the observed winds and currents at Cape Howe. A comparison of the predicted and measured currents for a period when no eddies were present in the region is shown on page 14. The fit is quite good, and statistically shows a correlation coefficient of 77%.

Andrew Bell

More about the topic

The Australian Coastal Experiment: a search for coastal trapped waves. H.J. Freeland, F.M. Boland, J.A. Church, A.J. Clarke, A. Forbes, A. Huyer, R.L. Smith, R.O.R.Y. Thompson, and N.J. White. *Journal of Physical Oceanography*, 1985, **15** (in press).