EAST AUSTRALIAN CURRENT

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The East Australian Current

The East Australian Current (EAC) is a strong western boundary current akin to the Gulf Stream, the Brazil and the Agulhas Currents, and the Kuroshio. Its maximum speed exceeds 2 $m\,s^{-1}$ near the surface and its effects extend down several thousand meters. It has a distinct surface core of warm water with a trough-shaped cross-section that is about 100 km wide and 100 m deep. There is a northward undercurrent beneath the EAC that extends from the upper continental slope down to the abyssal plane at 4500 m. The EAC plays a pivotal role in the life cycles of marine fauna and flora of eastern Australia and weather systems respond to the patterns of warm water that it creates.

The strength of the EAC came as a surprise to explorer Captain James Cook: "Winds southerly, a fresh gale", he wrote in his log at sunset on 15 May 1770 as he neared Cape Byron. Seeking more sea-room for the night, he headed offshore until, "having increased our soundings to 78 fathoms, we wore and lay with her head in shore… At daylight we were surprised by finding ourselves farther to the southward than we were in the evening, and yet it had blown strong all night". The EAC had carried his ship, *Endeavour*, southward into the strong winds.

The EAC has two main sources (**Figure 1**): One is the Pacific Ocean South Equatorial Current that flows westward into the Coral Sea between the Solomon Islands at 11°S and northern New Caledonia at 19°S. As this current nears Australia's Great Barrier Reef it splits at 14°–18°S, with part going NW to the Gulf of Papua and part going SE as the first 'tributary' of the East Australian Current. The other source is the near-surface layer of salty waters of the central Tasman Sea that are linked to the central Pacific Ocean. North of 25°S the salty layer slips beneath the fresher and warmer waters of the tropics. Near Australia, as we will see, the salty waters are taken south to Tasmania by the EAC.

What is it that drives the EAC? The curl of the wind stress over much of the South Pacific Ocean moves its waters northward. The southward return flow in a narrow band against the western boundary is consequently very strong. At the same time, the westward propagation of Rossby waves accumulates energy against eastern Australia. As a result there is a band several hundred kilometers

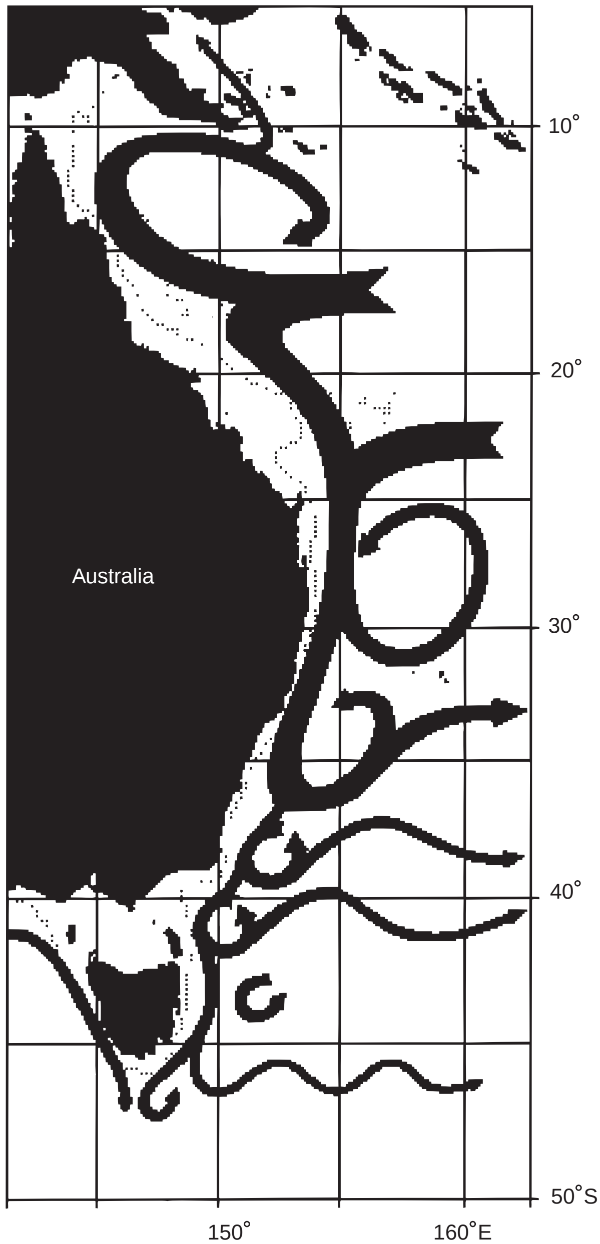


Figure 1 A schematic diagram of the East Australian Current showing its inflows and the eddies that are associated with it. The current off western Tasmania has been named the Zeehan Current.

wide off central eastern Australia where the subsurface water structure of the upper kilometer has been depressed by up to 300 meters. This means that the temperature at any depth in the band is higher, by as much 5°C, than that at the same depth in the neighbouring Tasman Sea. It follows that these waters, down to a 'depth of no motion', have lower density and, since a low-density water column will be taller than a high density one, the sea surface in the band stands as a ridge about one meter higher than its surroundings (**Figure 2**). In other words, it has a greater steric height. Surface currents are controlled by the shape and slope of the sea surface topography in the same way as winds are controlled by

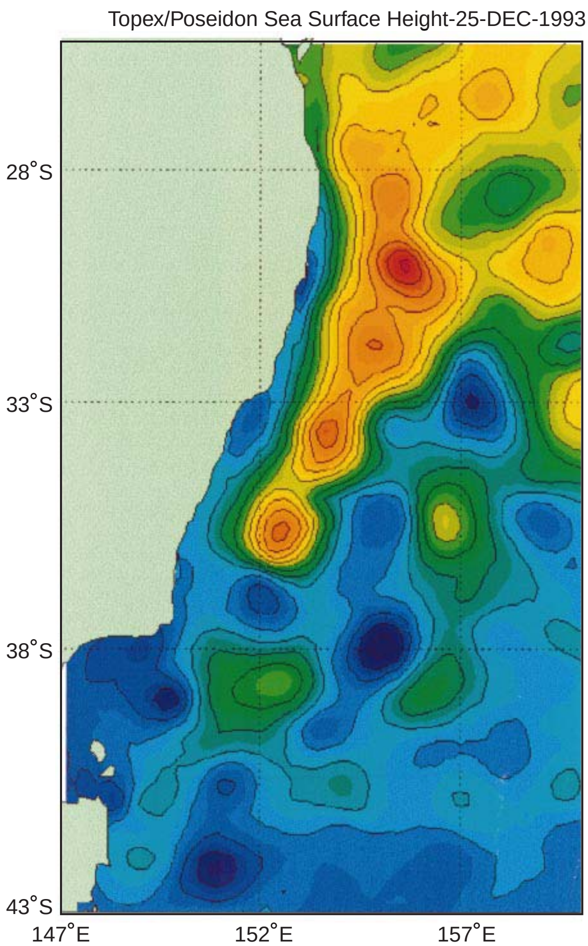


Figure 2 An image of sea surface topography prepared from radar altimeter data from the French-US satellite TOPEX/POSEIDON. The image was formed from satellite passes over a 17-day period centered on 25 December 1993. The passes were 300 km apart on the ground and the measurements along them were effectively 6 km apart. The data are contoured, but unless a pass goes, for example, over the center of an eddy its peak height will be an underestimate. The contour spacing is 10 cm; it is a little over a meter from the highest to the lowest parts of the sea surface. The EAC flowed down the western side of the ridge in this image. On 28 December, yachts in the Sydney to Hobart race encountered a southerly storm that drove waves into the opposing EAC. The waves steepened, the distance between crests decreased, and 67 of the 104 yachts sought safety in nearby ports owing to failures of rigging, hulls, and crew. Image provided by K. Ridgway, CSIRO.

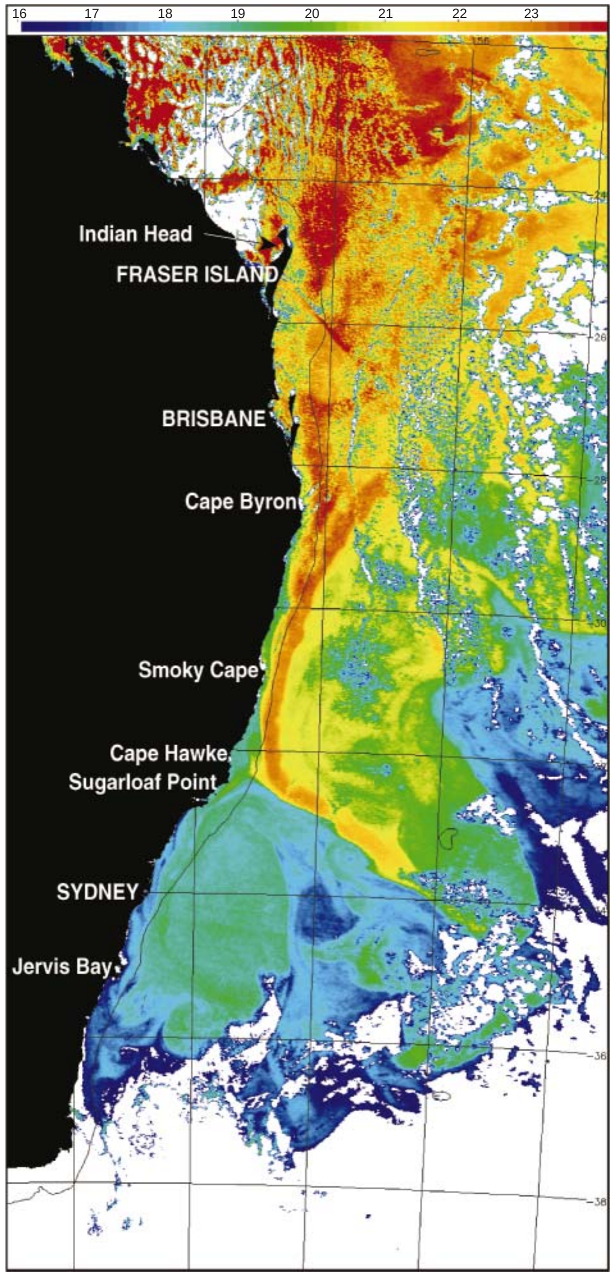


Figure 3 A NOAA satellite sea surface temperature image of the East Australian Current on 18 November 1991. The temperature scale is at the top of the image. There is a $2° \times 2°$ latitude–longitude grid and the 200 m isobath (roughly the edge of the continental shelf edge) is marked as a black line. The white areas are cloud. Note the two streams converging at 30°S. A concurrent ship section (**Figure 4**) suggests that the eastern stream was of high salinity while the stream from the Coral Sea was low salinity.

atmospheric pressure patterns. The currents follow contours of elevation and are strongest where the slopes of the sea surface are steepest. Similarly, deeper currents respond to patterns of subsurface steric height.

The low-salinity tributary from the Coral Sea, which is strongest in late summer, flows toward the western side of the ridge at about 25°S, where it joins high-salinity inflow from the east (**Figures 3** and **4**). The resulting EAC flows southward along the western side of the ridge, with higher sea surface elevation on its left (eastern) side. Peaks and saddles along the ridge force the current to meander, accelerate, and decelerate. The western edge of the EAC can spread in across the narrow continental shelf to influence the near-shore waters, while at the same time, as we will discuss later, driving intrusions of continental slope water onto the shelf. When the EAC reaches the southern end of the ridge, commonly near 33°S, it turns anticyclonically (anticlockwise in the southern hemisphere) until it has reversed direction and is running northward several hundred kilometers offshore. Part of it completes a circuit, rejoining the parent EAC, while the remainder meanders eastward along the Tasman Front toward New Zealand.

Various estimates have been made of the volume transport in the various components of the EAC system. From the surface to 2000 m depth the South Equatorial Current carries 50 Sverdrups into the Coral Sea. Of this, half flows southward into the

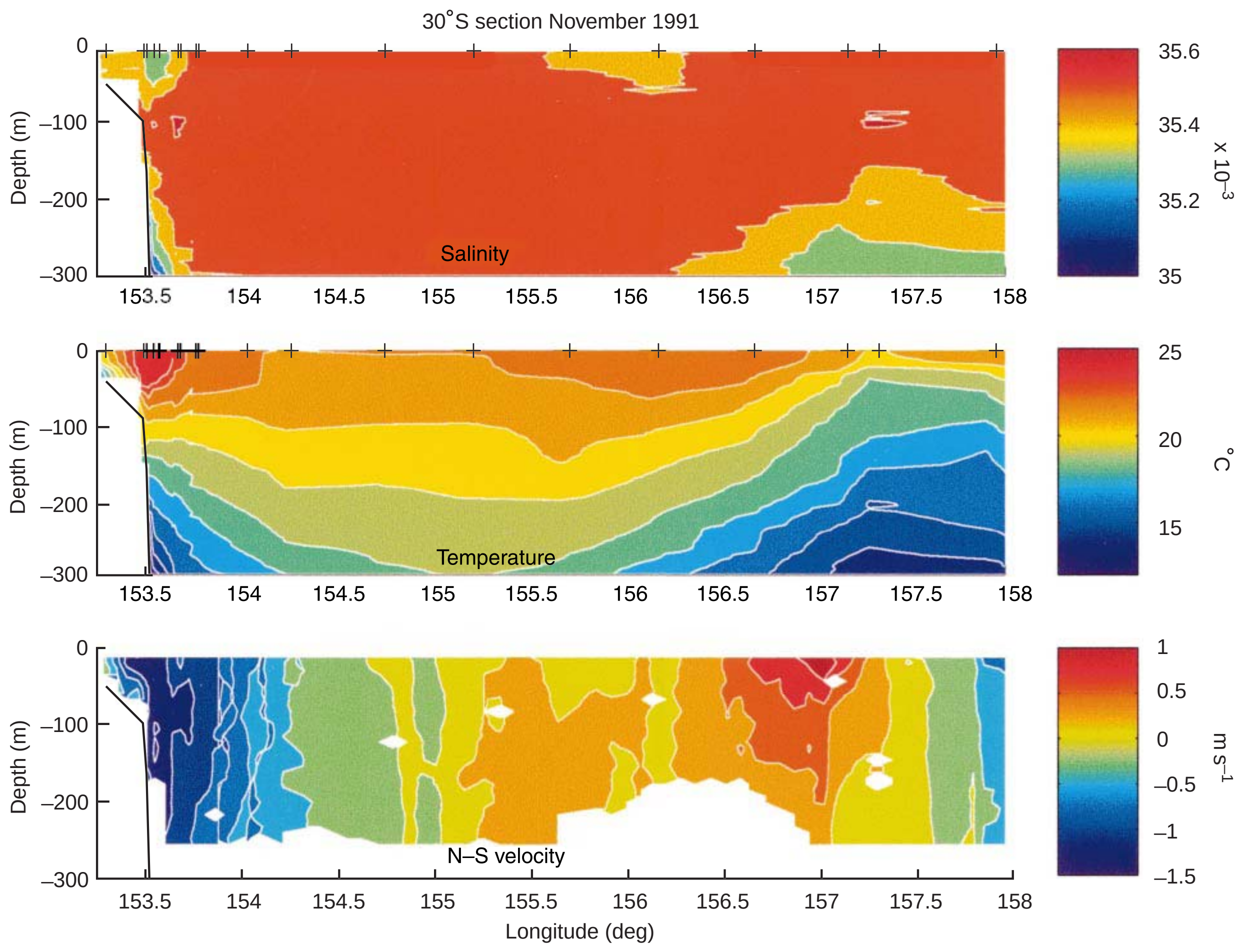


Figure 4 A ship section along 30°S out from Australia of salinity, temperature, and north–south velocity component (measured with an acoustic Doppler current profiler, ADCP). Note the warm, low-salinity feature with the trough-shaped section at the edge of the continental shelf. This is the fastest part of the EAC, but the ADCP data show this current to be much broader and deeper and to be carrying mainly higher-salinity west central Pacific water. The current measurements show the reverse (northward) flow of the EAC meander where the subsurface temperature structure has its greatest slope. On this section the maximum southward speed of the EAC was 1.2 m s^{-1} and the maximum reverse speed was 1.16 m s^{-1}. The innermost station on this section was at the 50 m isobath and suggested that a slope intrusion had upwelled to the surface because the surface and bottom water temperatures were 20°C and 17°C, respectively. Near and down from the shelf edge these temperatures were encountered at 100 m and 190 m, respectively.

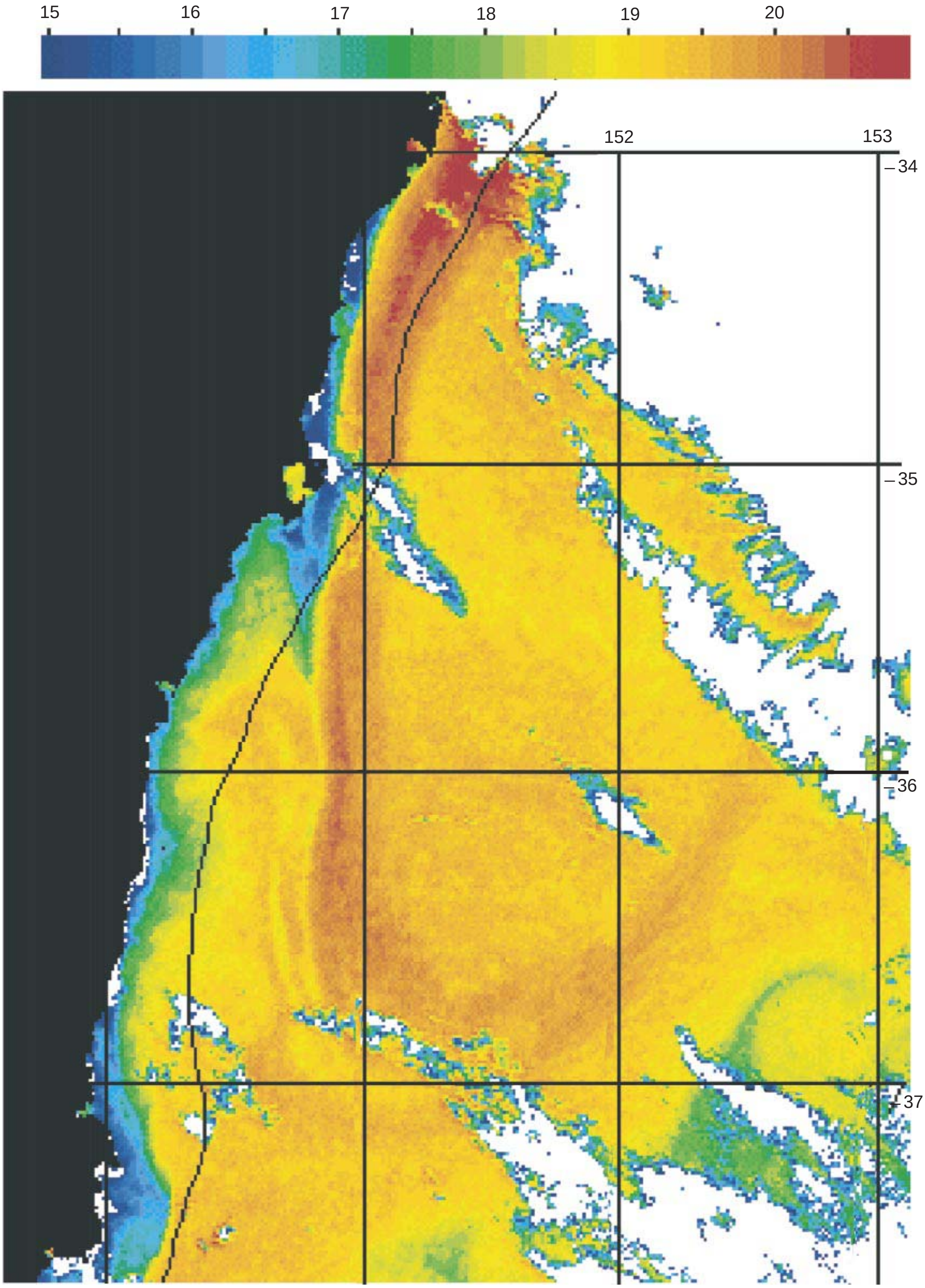


Figure 5 A NOAA sea surface temperature image of an eddy near Jervis Bay (35°S) in early December 1989. There is a 1° × 1° latitude–longitude grid and the 200 m isobath (roughly the edge of the continental shelf edge) is marked as a black line. The white areas are cloud. Note the warm band going around the elliptical eddy, the coastal upwelling, and a small cyclonic eddy centered near the intersection of 36°S and the shelf edge. (NOAA 11 Tm 45 S 2 Dec. 1989 15172. © 1998 CSIRO.)

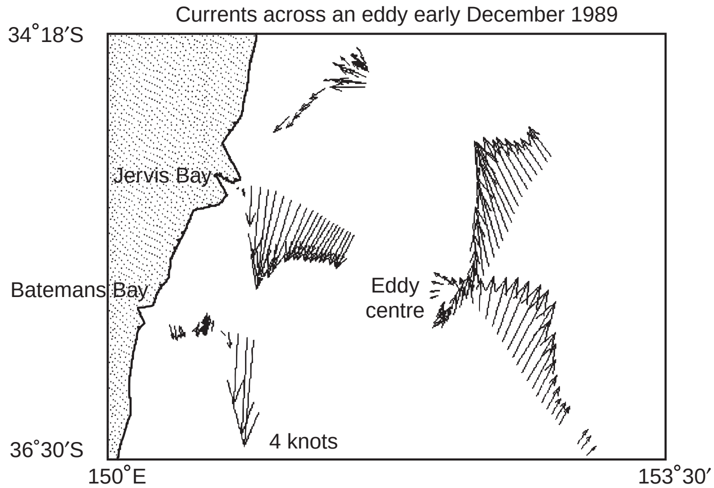


Figure 6 Current measurements with a shipboard ADCP around the time of the satellite image in **Figure 5**. Note that the current speed reaches almost $2\,\mathrm{m\,s^{-1}}$ on the western side of the elongated eddy.

EAC, which, at 30°S carries 55 Sv. After meandering to the north, 30 Sv recirculates back into the EAC and 25 Sv moves along the Tasman Front. The transport around a large anticyclonic eddy (next section) is about 55 Sv. Recent work suggests that up to 40 Sv can flow northward just south of the separation point of the EAC, perhaps on the western side of a cyclonic eddy.

Eddies

South of the ridge are 'warm-core' anticyclonic eddies that are 250 km in diameter with edge speeds of over $1\,\mathrm{m\,s^{-1}}$ (**Figures 5** and **6**). Just as Captain Cook had been surprised by the EAC, so was Commander J. Lort Stokes on HMS *Beagle* in July 1838 surprised by the currents in an eddy: "…from Hobarton we carried a strong fair wind to 40 miles east of Jervis Bay 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".

The subsurface structure in the eddies is depressed by several hundred meters, such that at 400 m their temperature can be 8°C warmer than at the same depth in the surrounding southern Tasman Sea. The

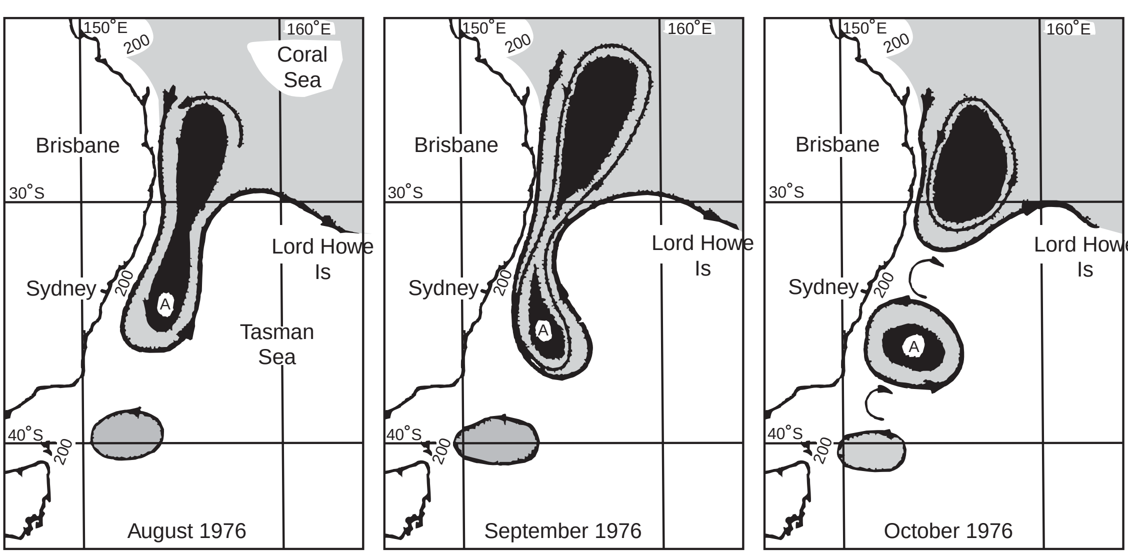


Figure 7 A cartoon showing how the westward propagation of an undulation on the Tasman Front causes the ridge of high sea surface elevation, around which flows the EAC, to pinch off to form a new anticyclonic eddy. (From Nilsson and Cresswell, 1986.)

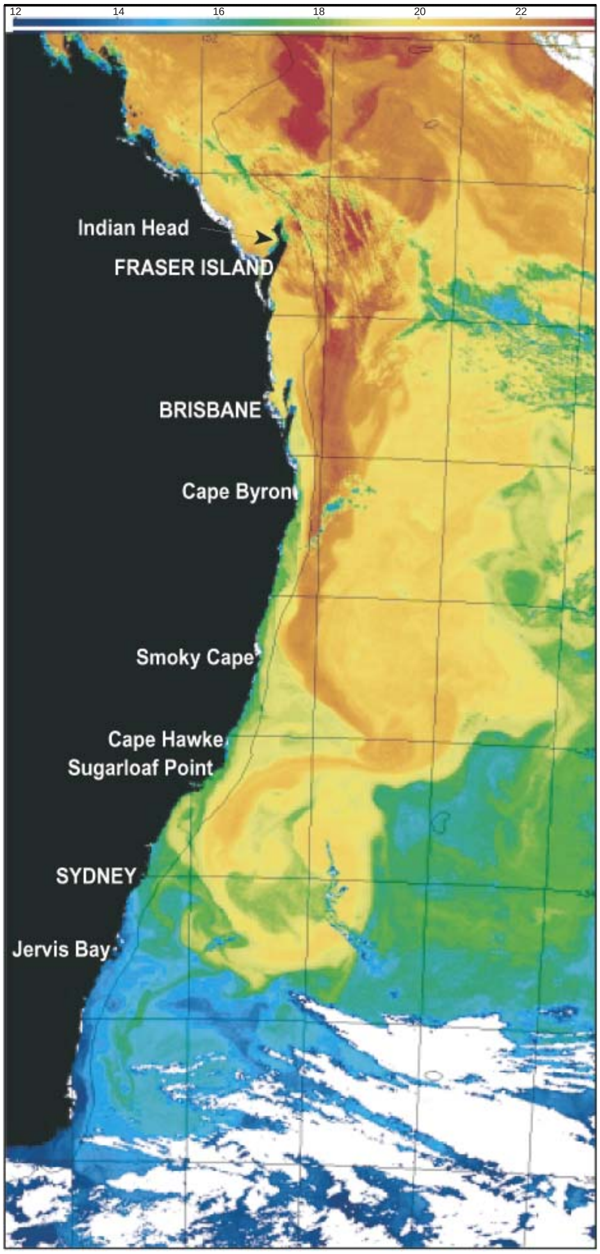


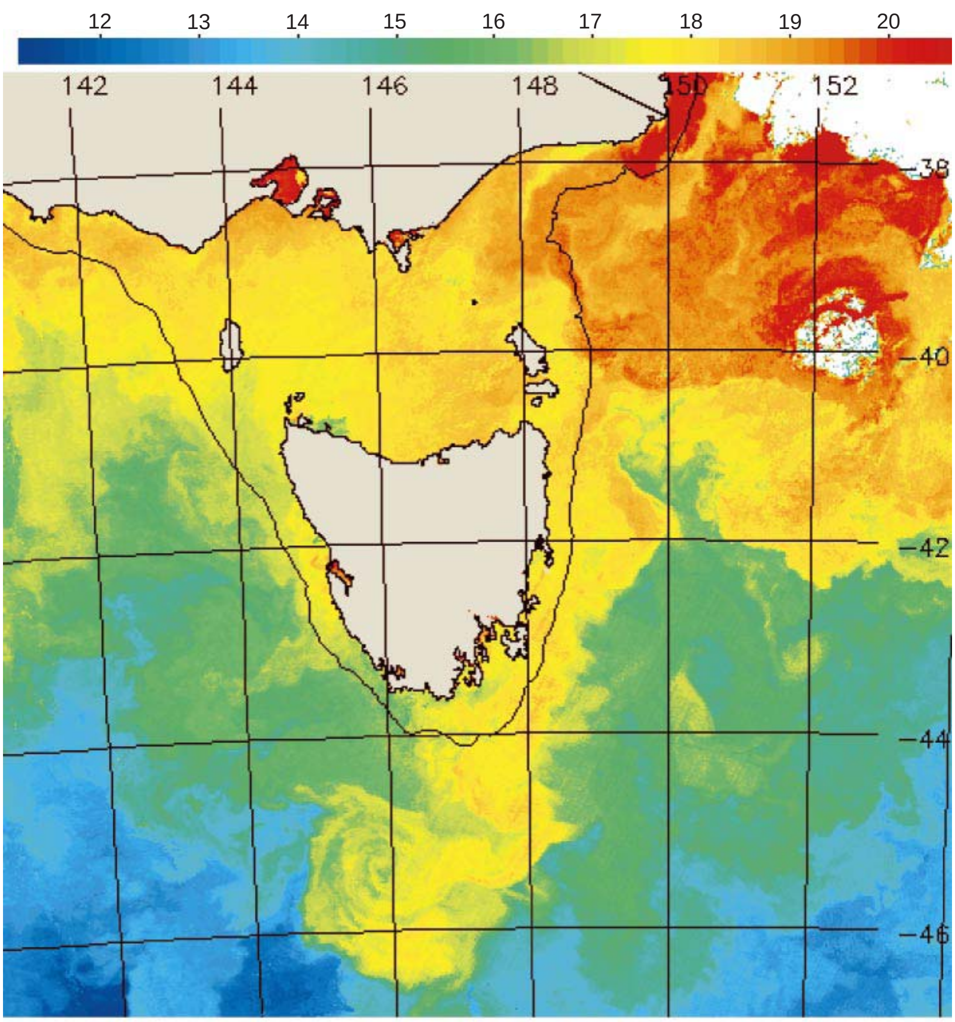
Figure 8 A NOAA satellite sea surface temperature image of the East Australian Current running southward and then out to sea on 29 September 1991. There is a $2^\circ \times 2^\circ$ latitude–longitude grid and the 200 m isobath (roughly the edge of the continental shelf edge) is marked as a black line. The white areas are cloud. There are two anti-cyclonic eddies south of this meander. Note the cascade of warm water from the meander to one eddy and then to the next, as well as the small cyclonic eddies produced by current shear at the edges of all three features. (NOAA 11 TMS 45S 29 Sep. 1991 1615z. 1999 © CSIRO.)

primary eddy formation process is linked to the westward propagation of Rossby Waves along the Tasman Front. These move its meanders and associated thermocline undulations towards Australia, even though the net flow along the Front is eastward. Several times each year a Rossby Wave reaches the ridge in the sea surface against Australia, initially constricting it and then causing it to pinch off a new eddy (**Figure 7**). These drift slowly southward. The eddies usually become isolated peaks in the sea surface topography that are not encircled by the surface core of the EAC. However, a transient saddle can form between an eddy and the ridge and this allows the warm EAC to 'reach' across to the eddy and encircle it (**Figure 8**). Part of this warm water may spread inward to cover the surface of the eddy, while part may escape the eddy's influence after encircling it several times. In summer, when the EAC is strongest, the ridge steps its way southward, successively coalescing with eddies, until it reaches the SE corner of the Australian continent at 38°S. These eddies retain their identities, with the ridge then consisting of a chain of eddy peaks and saddles. The elongated ridge opens a pathway for the EAC to cascade southward. The strength of this cascade progressively decreases because part of the EAC that encircles each eddy is lost to the northeast. Remnants of the EAC reach southern Tasmania at 43°S via smaller eddies and then overshoot by 200 km into the Southern Ocean (**Figure 9**). Each day in the fishing season fleets of 20–30 Japanese vessels follow parallel paths several kilometers apart across such eddies as they stream their 100 km long lines to catch tuna.

When the ridge retracts to the north it can spawn two or three eddies that are either new or rejuvenated in that the introduction of the new warm EAC water has increased their height above the surrounding sea surface. The eddies have lifetimes of over one year. The speeds in them increase from zero at the center to over $1\,\mathrm{m\,s^{-1}}$ at the perimeter. An eddy disk does not rotate stiffly: the rotation period decreases from 5 days at the perimeter to 1–2 days near the center (**Figure 10**). The eddies move along complex paths at speeds ranging from near-stationary up to $30\,\mathrm{km\,d^{-1}}$. The paths followed by their centers include anticlockwise loops about 200 km across that are described in about one month and these can cause eddies to collide with the continental slope. Such a collision distorts a circular eddy into an ellipse, around which the flow appears to conserve angular momentum, giving highest speeds ($>1.5\,\mathrm{m\,s^{-1}}$) near the minor axes and lowest speeds ($\sim 1\,\mathrm{m\,s^{-1}}$) near the major axes. While an eddy is against the continental slope its southward currents can extend in across the shelf. Eddies regain their near-circular shapes once they move out to sea.

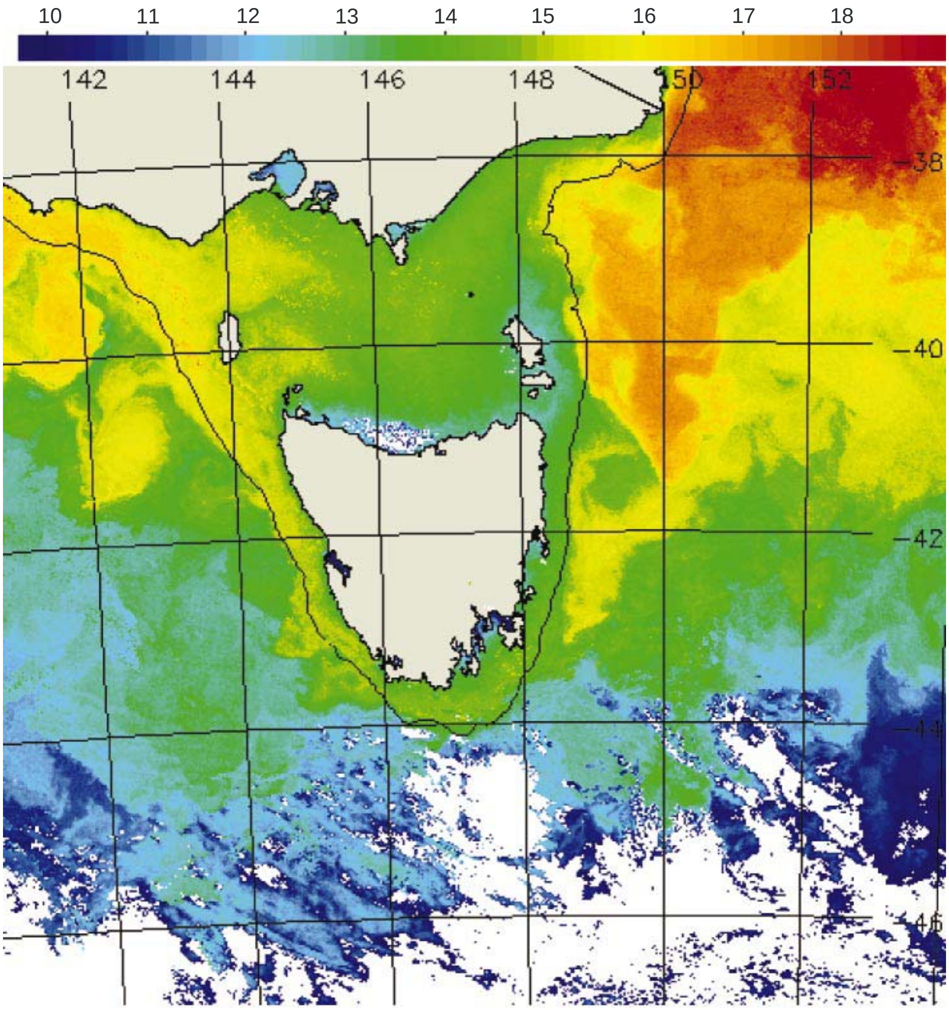
Not all eddies rotate anticyclonically. Between the ridge and the nearest warm-core eddy to the south – and between warm-core eddies themselves – can be depressions in the sea surface that are cold-core cyclonic eddies. On their inshore (western) sides these drive northward currents of up to $1\,\mathrm{m\,s^{-1}}$ near the shelf edge. Also, as the EAC separates from the shelf and slope at the southern end of the ridge it often develops instabilities that are carried along its edge. Each starts as a small meander to the west from which a warm plume then reaches back and around a growing cyclonic eddy. The instabilities can form every five days and are spaced at intervals of about 100 km. Similar small eddies form from the shear at the edges of large anticyclonic eddies. The continual formation of the small cyclonic eddies, each with doming of the water structure in its interior, lifts richer water into the photic zone where it can photosynthesize. Satellite color measurements reveal the widespread effects of this (**Figure 11**).

Occasionally the southward migration of the ridge will force two anti-cyclonic eddies together so that both are affected: they move several times anticlockwise around one another until they coalesce into a large eddy. The process takes several weeks, during which the current speeds in the pair reach $2\,\mathrm{m\,s^{-1}}$. The product highlights an interesting property of the anticyclonic eddies: Because their waters, like those of the ridge, are warmer down to several hundred meters than the surrounding waters, in winter they lose



(A)

Figure 9 Winter and summer satellite sea surface temperature images from the NOAA11 satellite. The temperature scale is across the top of the images. Clouds are white. The shelf edge (200 m isobath) is marked as a thin black line. The winter image (A) shows the EAC apparently arrested off eastern Tasmania, while warm water of the Zeehan Current comes down the west coast and part way up the east coast of Tasmania. The summer image (B) shows the EAC to overshoot Tasmania by about 200 km. It entrains Zeehan Current water as it does this.



(B)

Figure 9 *Continued*

heat at the surface more rapidly and they mix down to more than 400 m depth. The near-constant salinity and temperature in the mixed layer together serve as a unique signature for an eddy once it acquires a summer 'cap' owing to insolation and flooding by the EAC. When eddies coalesce, the new eddy has parts of their signature layers one above the other, according to their relative densities.

Effects on the Continental Shelf

We have already mentioned that the EAC (and its eddies) can influence the currents on the continental shelf of eastern Australia. The shelf is narrow, with a width of about 25 km, and its depth at mid-shelf is 60–80 m. The edge of the EAC can reach in to drive southward currents in excess of $0.5\,\mathrm{m\,s^{-1}}$ at promontories like Indian Head on Fraser Island, Cape Byron, Smoky Cape, Cape Hawke, Sugarloaf Point, and Jervis Bay. This means that it may be more of an influence on the circulation of the Australian shelf than is the Gulf Stream on the 70–120 km wide US eastern shelf with a typical depth of 30 m. Incursions of the EAC onto the shelf quickly overwhelm existing current patterns, replace large parts of the shelf waters, and appear to be a mechanism for driving cold, nutrient-rich intrusions of slope water from 200–300 m depth in towards the coast. The stress by the EAC on the bottom sets up a bottom boundary layer that moves in across the shelf at a slight angle. Near the coast, and notably downstream of headlands (perhaps because of cyclonic motion that they induce), the intrusions may upwell to the surface. This process can be

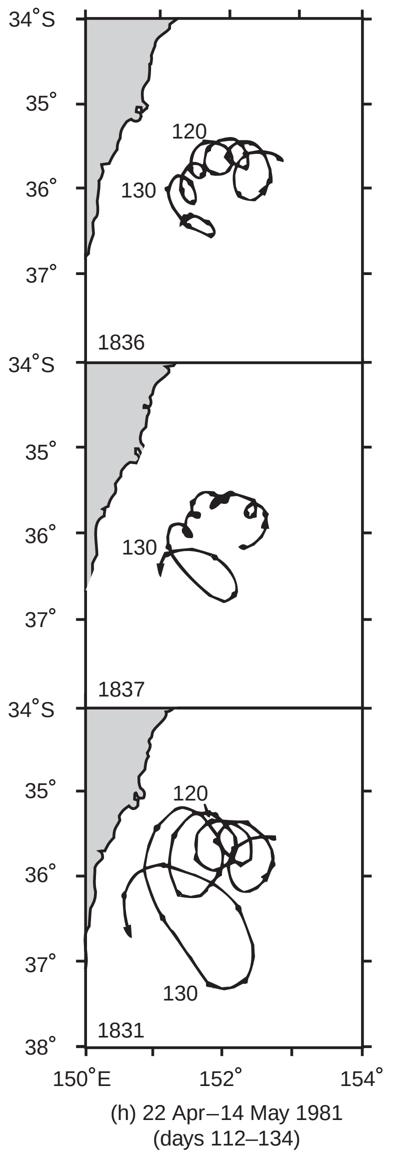


Figure 10 The paths followed by three satellite-tracked drifters in an eddy that became distorted into an ellipse after it collided with the continental slope of SE Australia. The dots on the tracks indicate daily intervals. Note the short rotation periods for drifter nearest the eddy center. (From Cresswell and Legeckis (1986) *Deep-Sea Research*.)

greatly assisted by northerly winds that drive the surface waters offshore in an Ekman layer, to be replaced by the upwelling of the slope intrusions near the shore. The upwelled waters photosynthesize, producing a peak in productivity at about 20–50 m that is a balance between light, nutrients, and grazing by zooplankton. The green waters are known to mariners and their spectacular patterns are clearly evident in color satellite imagery, contrasting with the transparent deep blue of the nutrient-poor EAC (**Figure 11**). The edge of the EAC can be seen in the images to carry the chlorophyll-rich waters along the shelf and well out to sea.

Summary

The near-surface core of the East Australian Current draws water both from the South Equatorial Current via the Coral Sea and from the central Tasman Sea. It flows southward to about 33°S, where it separates from the continent and executes a meander to the north. Part recirculates and part proceeds along the Tasman Front toward New Zealand. The meander spawns 250 km diameter anticyclonic eddies several times each year and these migrate southward. Smaller cyclonic eddies are found throughout the region. The separation point occurs near the southern end of a ridge in the sea surface topography. This ridge moves south and north, coalescing with the anticyclonic eddies that are also highs in the surface topography. The East Australian Current cascades southward along and around these structures, ultimately entering the Southern Ocean south of Tasmania each summer. The waters and currents of the East Australian Current and its eddies can extend in across the narrow continental shelf to the shore. Bottom friction can establish a bottom boundary layer that lifts continental slope water onto the shelf to upwell near the coast, particularly when the winds are northerly.

Glossary

Ekman layer The wind-driven component of transport in the Ekman or surface boundary layer is directed to the left (right) of the mean wind stress in the southern (northern) hemisphere.

Rossby waves Rossby waves occur in the atmosphere and the ocean. In the atmosphere they are high and low pressure cells that, while being carried eastward by strong westerly winds, they in fact propagate westward relative to the mean air flow. In the ocean the mean flow is weaker and undulations in the steric height propagate westward as Rossby waves.

Steric height and depth of no motion Measurements of temperature, salinity and pressure are needed to calculate steric height, which is the depth difference in the ocean between two surfaces of constant pressure. The deeper of these is often chosen to be a 'depth of no motion' which lies on a constant pressure surface and thus the currents are zero. Steric height differences at the ocean surface across the East Australian Current are about 1 m.

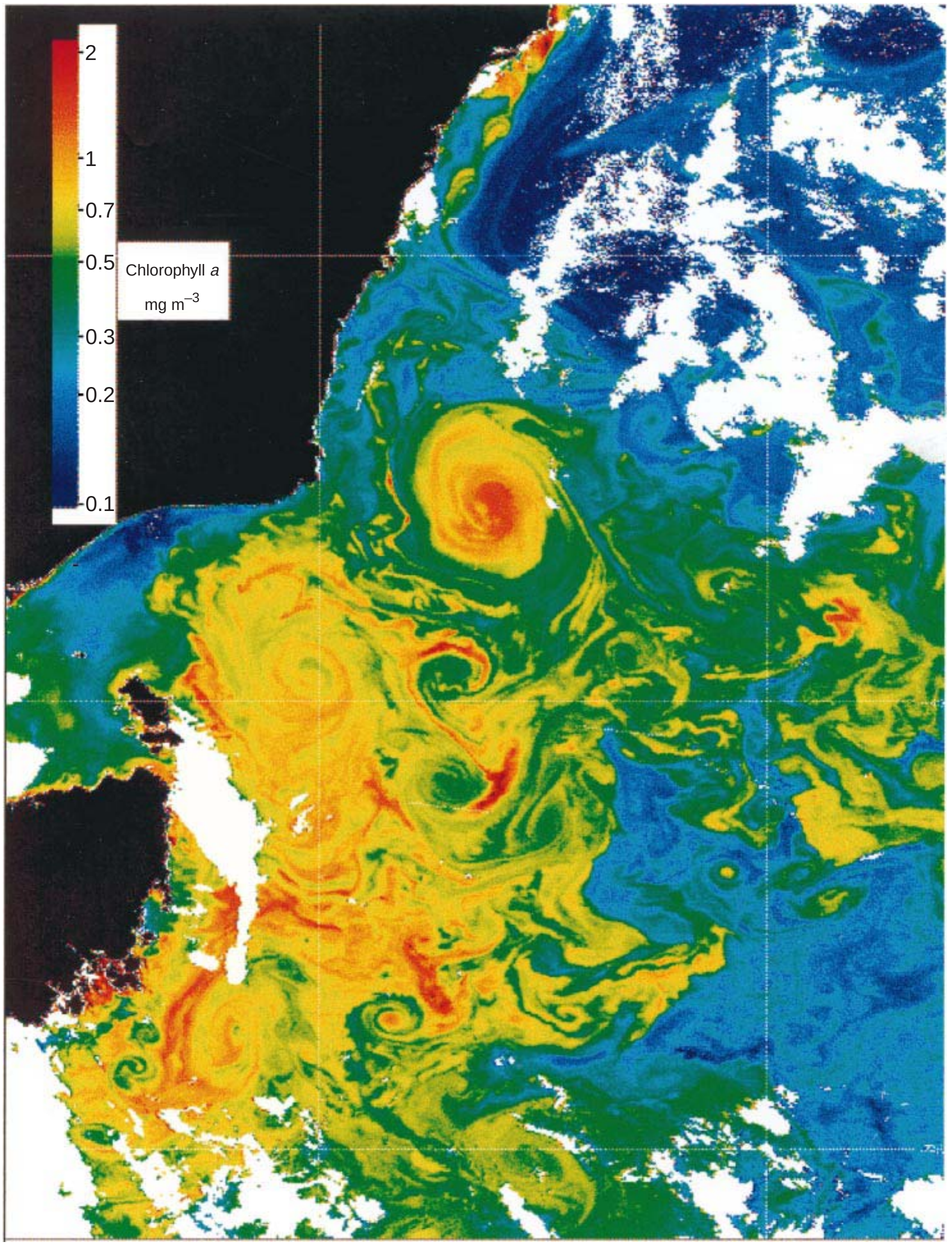


Figure 11 An image of chlorophyll concentration in the SW Tasman Sea inferred from color measurements from the SeaWIFS satellite on 22 November 1997. Clouds are white. In the top right the blue color marks the unproductive waters of the EAC. Inshore of those is a coastal upwelling from which two slugs of chlorophyll-rich waters are carried ~ 200 km southward along the continental shelf. There is an anticyclonic eddy at 38°S that has high chlorophyll concentrations, which is hard to understand without knowing the eddy's recent history. Southward from the mainland to southern Tasmania the chlorophyll concentrations are high, perhaps owing to the confluence and mixing of subantarctic and subtropical waters.

See also

East Australian Current. Ekman Transport and Pumping. Mesoscale Eddies. Ocean Color from Satellites. Pacific Ocean Equatorial Currents. Rossby Waves.

Further Reading

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