The Structure of the East Australian Current

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Summary

The surface dynamic topographies obtained on a number of cruises off the east Australian coast between latitudes 30 and 37°S. are presented. In general, these topographies indicate a southerly current within 60 miles of the edge of the continental shelf, and a northerly or north-easterly countercurrent further offshore. On many occasions these two currents appeared to be parts of the same current system, being connected by an easterly current in the latitude of Sydney (34°S.).

The volume transports in the upper 1000 m are tabulated, and the variation of relative current with depth is shown.

I. Introduction

Between 1954 and 1959, F.R.V. *Derwent Hunter* made a number of cruises within about 500 miles of the east Australian coast, and between latitudes 30 and 37°S. In this paper the dynamical results of this work are summarized.

The earlier *Derwent Hunter* cruises were single sections along bearings of 090 or 110° from Sydney. Later, two parallel sections 60 miles apart were planned for each cruise. Between August 1958 and May 1959, five cruises were made in which the area covered extended as far north as the line joining Coff's Harbour and Lord Howe Island. The spacing between stations was usually planned to be about 20 miles for the stations nearest the edge of the continental shelf, and was increased to about 75 miles further offshore. The small size and limited range of the vessel led to frequent changes in cruise plans, and bad weather prevented many stations being occupied.

In addition to the *Derwent Hunter* cruise, a section to the east from Sydney by R.R.S. *Discovery II* in October 1950 has been included. Some observations from the cruise of H.M.A.S. *Queenborough* in April 1958 have also been used for comparison with the *Derwent Hunter* observations in the same month.

II. Dynamic Topography

The calculation of dynamic heights at each station was carried out by standard methods, but was based on thermosteric anomalies (Montgomery and Wooster 1954) instead of specific volume anomalies. For all except four of the cruises, the calculations were made relative to the 1000 decibar surface.

The main results are presented in Figures 1(*a*) and 1(*b*). Whenever the station positions permitted, contours of dynamic height of the sea surface have been drawn at intervals of 10 dynamic cm. Except where otherwise marked on Figure 1(*a*), these contours are relative to the 1000 decibar surface. For uniformity, single-line sections

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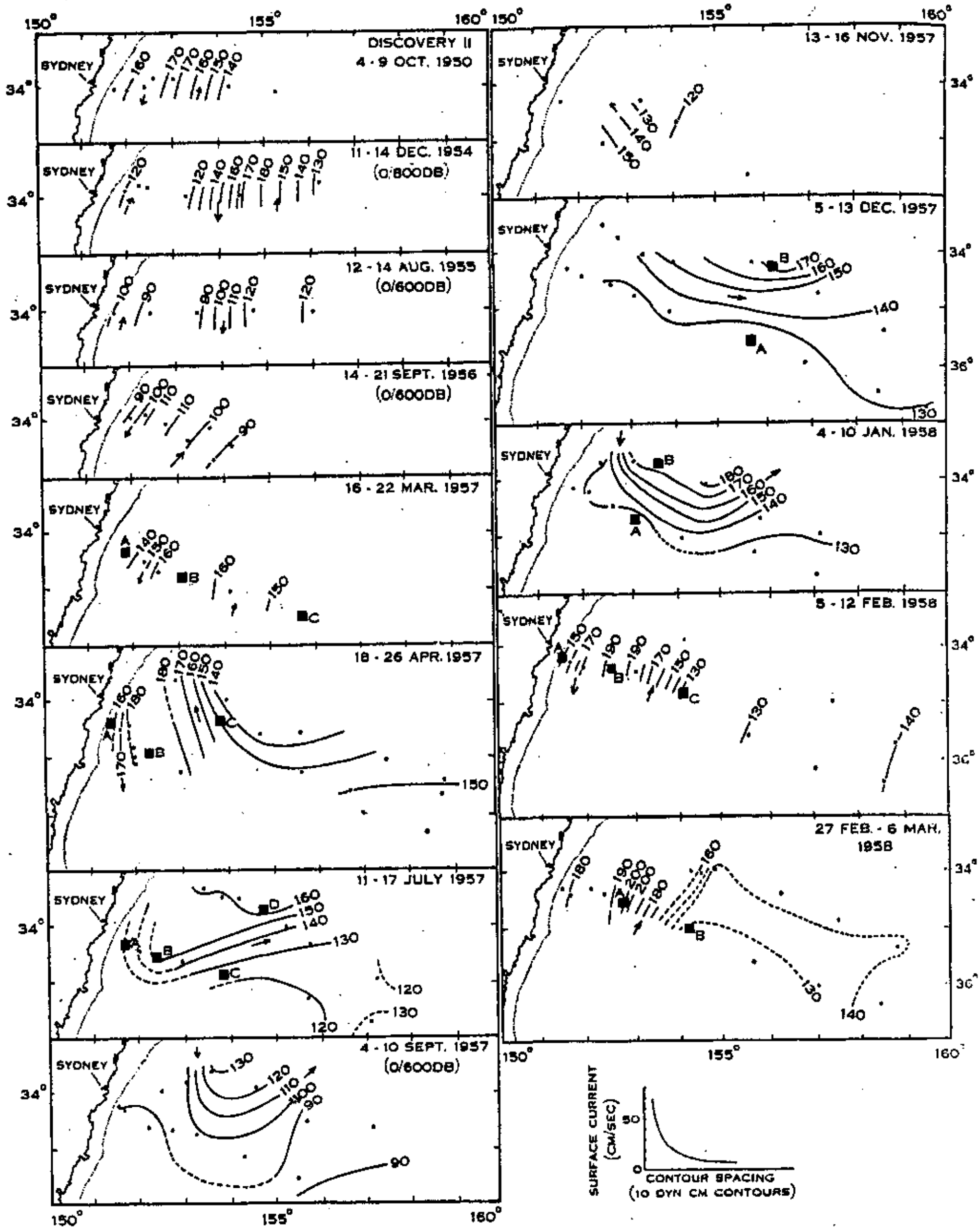

Fig. 1(*a*)

Figs. 1(*a*), 1(*b*).—Contours of dynamic height for 21 cruises off Eastern Australia, 1950–1959. Unless otherwise marked, dynamic heights are relative to the 1000 decibar level. The contour interval is 10 dynamic cm.

● Position of stations with observations down to at least the reference level

○ Position of shallower stations, whose dynamic heights were taken into account in contouring

[*For continuation see opposite page*]

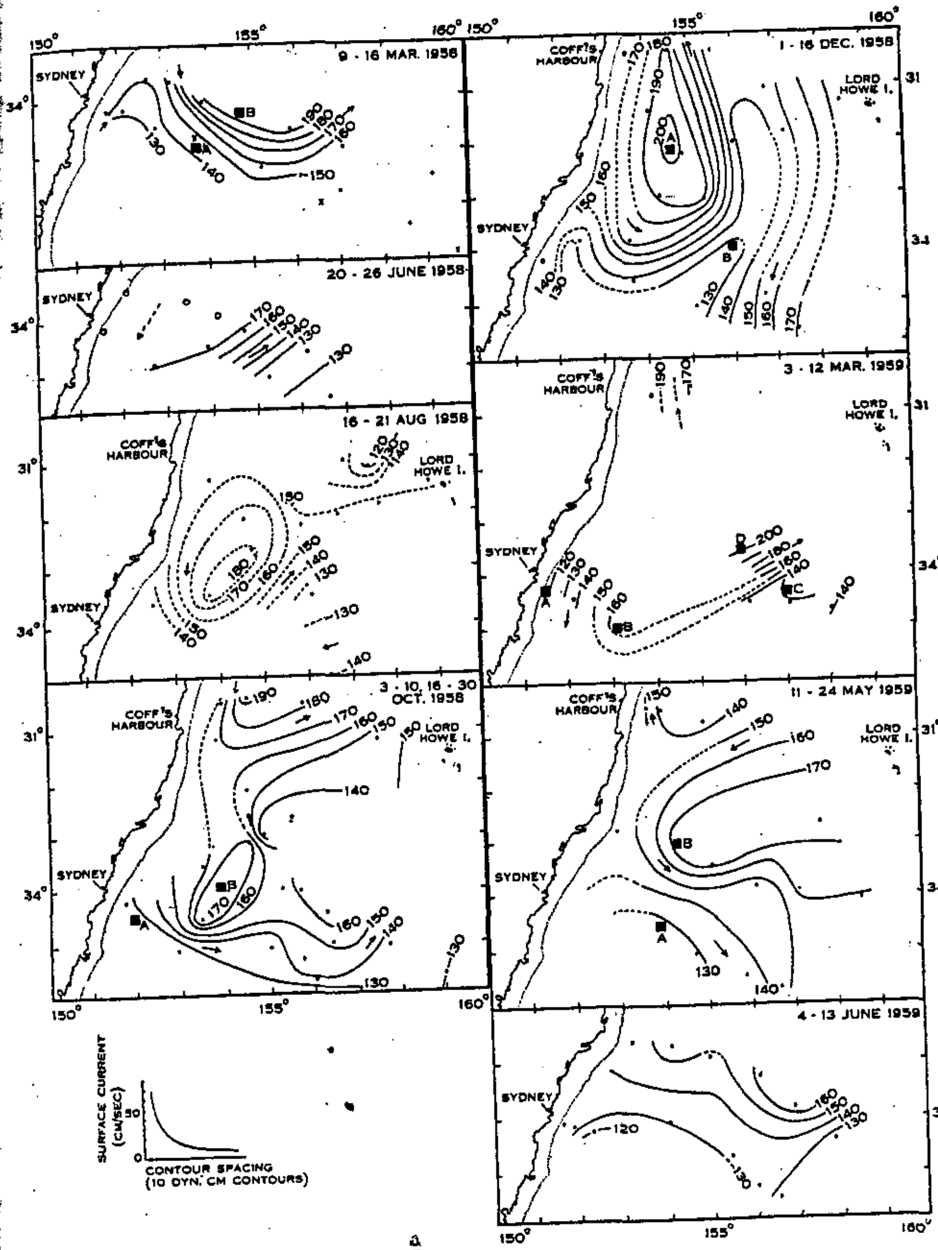

Fig. 1(*b*)

Figs. 1(*a*), 1(*b*) (*Continued*)

■ Stations for which the calculations of volume transport were made

× *Queenborough* stations (April 25, 1958)

The arrows show the directions of the main surface currents. The edge of the continental shelf (100 fm depth) is shown dotted.

have also been included in Figures 1(*a*) and 1(*b*) in plan form, with short lines at 10 dynamic cm spacing drawn perpendicular to the ship's track, or parallel to the coast.

The direction of the surface current is such that the higher dynamic heights are on the left of the current when looking down stream. At least for the major branches of the currents these directions have been indicated in the figures by arrows. The surface velocities are inversely proportional to the spacing between the contours of dynamic height; a scale of surface velocities has been included in Figures 1(*a*) and 1(*b*).

Figures 1(*a*) and 1(*b*) show that the dynamic topography, and hence the strength and direction of the surface currents, are complicated and variable in this area.

The two main features of the surface circulation, as revealed by the dynamic topography, are as follows:

(1) A southerly or south-easterly current usually just beyond the edge of the continental shelf. In accordance with established usage, this will be referred to as the "East Australian Current". This current sometimes crosses the southernmost section in the area studied (the section along a bearing of 090 or 110° from Sydney), but in many cases turns east just north of this line. The current is usually within about 60 miles of the edge of the shelf but on two occasions (December 1954 and August 1955) was between 80 and 110 miles from the edge. On these occasions, there appeared to be a weak northward countercurrent between the East Australian Current and the edge of the shelf.

(2) A northerly or north-easterly current, here called the "countercurrent", whose axis is from 70 to 200 miles to the east of the axis of the East Australian Current. Perhaps the most interesting result of this study is the demonstration of the magnitude and persistence of this countercurrent.

On several cruises (September, December 1957; January, April, October, December 1958; May, June 1959) a connection between the south-flowing East Australian Current and the northerly or north-easterly countercurrent appears as an easterly current. The results of these cruises suggest that the East Australian Current and countercurrent are continuous, being the two sides of a roughly U-shaped current system. In view of the restricted coverage by most cruises in the north-south direction, it is surprising how often the easterly component of this current system was found almost due east of Sydney.

The results of two cruises (August 1958, December 1958) suggest that the current system might be at least partly a closed anticyclonic eddy, but the contours for the August 1958 cruise are perhaps the least reliable, and the December 1958 cruise did not extend far enough to the north.

In October 1950, February–March 1958, and June 1958, the dynamic height contours of Figures 1(*a*) and 1(*b*) suggest that the countercurrent was stronger than the East Australian Current. For the June 1958 cruise, an examination of the σ_t sections shows that the East Australian Current was probably better developed than is indicated in Figure 1(*b*) where contours near the shore could not be drawn for lack of deep observations. In October 1950 and February–March 1958, however, the East Australian Current appears to have been definitely less than the countercurrent.

(*a*) *Variation of Current with Depth, and Volume Transports*

Figure 2 shows the variation with depth of the difference in dynamic height, relative to 1000 decibars, for selected pairs of stations on five cruises. At any such depth, the velocity relative to 1000 decibars, and perpendicular to the line joining the two stations of each pair is proportional to the abscissa at that depth, and inversely proportional to the distance between the stations. The horizontal volume transport in any depth interval is proportional to the area bounded by the curve, the ordinate axis, and the two depths.

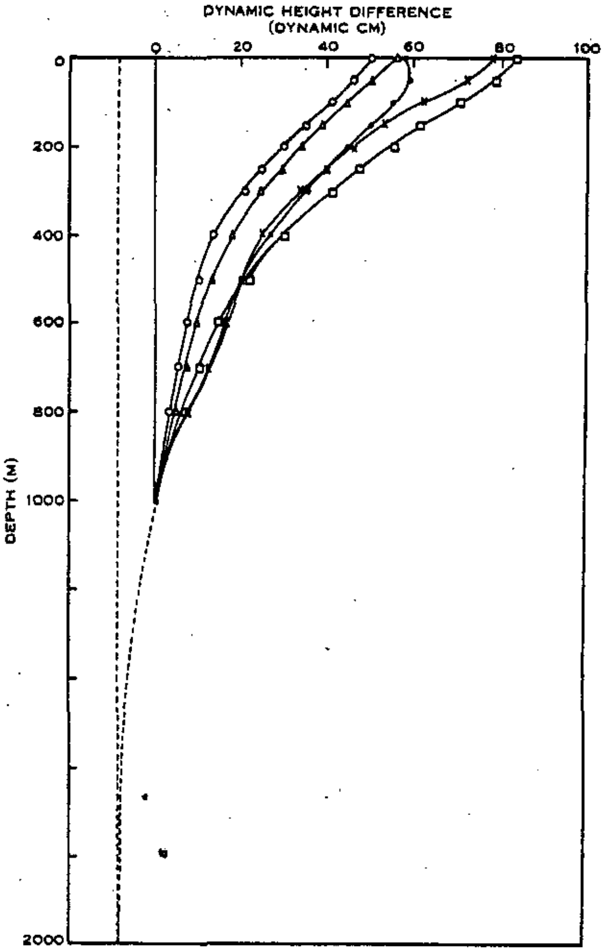

Fig. 2.—Differences in dynamic heights between pairs of stations to the right and left of the current, as a function of depth. The stations are indicated by letters in Figure 1.

△ Stations A, B, Dec. 1957
● Stations A, B, Apr. 1958
+ Stations A, B, Feb.–Mar. 1958
○ Stations A, B, Oct. 1958
□ Stations A, B, Dec. 1958

The 1000 decibar level was chosen as reference level only because it was the deepest reference level common to the majority of stations. Examination of the densities (σ_t) at 1000 m for the station pairs for which Figure 2 was drawn showed that in all cases there was still a density difference at this depth, of the same sign as at shallower depths. The mean value of this difference in σ_t for five pairs of stations was 0·16. If it is assumed that this difference decreases linearly to zero at a depth of 2000 m an estimate can be made of the effect of calculating volume transports relative to 2000 decibars, instead of 1000 decibars. The effect would be to move the ordinate axis of Figure 2 approximately to the position shown by the vertical dashed line, and to extend the curves downwards as shown. Volume transports would now be represented by the area between the curve and the new ordinate axis. Calculation shows that such a change in reference level would increase the estimates of total volume transport by between 30 and 40%.

Table 1

VOLUME TRANSPORTS ABOVE 1000 DECIBARS

Cruise	Date	Station Pair	Volume Transport ($10^6 m^3/sec$)	Direction
1/57	Mar. 1957	A, B	12	S.
		B, C	5	N.
3/57	Apr. 1957	A, B	13	S.
		B, C	14	N.
5/57	July 1957	A, B	11	SSW.
		B, C	14	NNE.
		C, D	16	E.
16/57	Dec. 1957	A, B	22	E.
1/58	Jan. 1958	A, B	18	ESE.
2/58	Feb. 1958	A, B	20	S.
		B, C	28	N.
4/58	Feb.–Mar. 1958	A, B	31	N.
6/58	Apr. 1958	A, B	30	SE.
16–17/58	Oct. 1958	A, B	19	SE.
20/58	Dec. 1958	A, B	35	NE.
2/59	Mar. 1959	A, B	10	SW.
		C, D	32	NE.
6/59	May 1959	A, B	20	E.

The volume transports between the surface and the 1000 decibar level for a number of pairs of stations, including those for which Figure 2 was drawn, are shown in Table 1. In most cases, the figures given will underestimate the volume transports of the complete current system, since there were not enough stations to locate the maxima and minima of dynamic heights. For the same reason, it is not worthwhile to study the seasonal variation in volume transports, except to point out that values over 20×10^6 m^3/sec were found only between December and April, when the East Australian Current is known to be best developed (Wyrtki 1960).

(*b*) *Time Variations in Dynamic Topography*

Some estimates of the rate at which the dynamic topography changes can be obtained from Figures 1(*a*) and 1(*b*) by examining the occasions when two cruises were made in successive months.

Between March and April 1957, the maximum dynamic height increased by about 20 dynamic cm on a section bearing 110° from Sydney.

Between November and December 1957, there was apparently a complete reversal in current direction 100 miles east of Sydney.

In 1958, the pattern of dynamic topography moved about 50 miles to the south between the January and February cruises. This movement was reversed between March and early April. Results of a cruise by H.M.A.S. *Queenborough* later in April showed that the pattern had apparently moved south again, by at least 30 miles in 2 weeks.

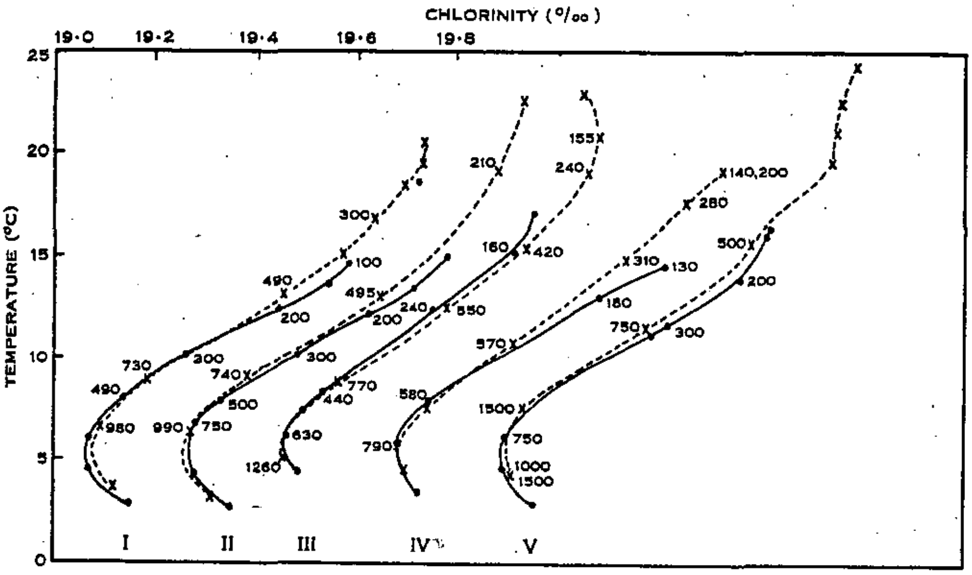

Fig. 3.—Temperature–chlorinity diagrams at five pairs of stations. ——Stations to the right of the current. - - - Stations to the left of the current. The stations are indicated by letters in Figure 1.
I Stations A, B, Dec. 1957 II Stations A, B, Feb.–Mar. 1958 III Stations A, B, Apr. 1958
IV Stations A, B, Oct. 1958 V Stations A, B, Dec. 1958
Each pair of curves is displaced 0·2‰ chlorinity to the right of the preceding pair. The numbers on the curves show the sampling depths (m).

(*c*) *Temperature–Chlorinity Diagrams*

Temperature–chlorinity diagrams for the five pairs of stations used for Figure 2 are shown in Figure 3. The two curves of each pair are similar, but a particular water type is found at a greater depth at a station to the left of the current than at one to the right. The uniformity of the temperature–chlorinity curves for stations in a particular area, even when large-scale currents are present, is well known (see, e.g. Stommel 1958, p. 63) and is taken as evidence of mixing along surfaces of equal potential density.

III. DISCUSSION

The maximum volume transport listed in Table 1 is greater than the volume transport of the Florida current (approximately 25×10^6 m^3/sec), and of the order of half the transport of the Kuroshio current or the Gulf Stream.

The present study shows that the East Australian Current is very frequently associated with a narrow northerly countercurrent of approximately equal strength, the whole system being practically confined to the western third of the Tasman Sea. To this extent the East Australian Current cannot be considered a "western boundary current", in the sense in which this term is applied to the Kuroshio and the Gulf Stream. In the latter, the current is a true boundary phenomenon, separating relatively large areas of warm water on the offshore side of the current from the colder (and therefore denser) waters on the inshore side (Stommel 1958, p. 21). There is no evidence for a similar structure in the case of the East Australian Current.

Again, to the extent that the current system is mainly U-shaped, its influence on the hydrological conditions in the Tasman sea as a whole must be restricted, since the greater part of the water carried south in the inshore region appears to return north again further offshore, and is not available for mixing with other waters to the south and east.

In discussing the countercurrent as revealed in surface current atlases, Wyrtki (1960) suggests that its formation is due to the influence of strong southerly winds. The evidence from the present study is that the countercurrent appears too frequently, and is too closely linked with the East Australian Current itself, to be due to local winds. It is suggested that the main reasons why the countercurrent appears so rarely in the current atlases are its narrowness and variability in position, and the fact that there are no regular north-south shipping routes through the region in which it occurs.

As has already been noted, Figures 1(*a*) and 1(*b*) suggest that the East Australian Current very frequently turns away from the coast east of Sydney, and returns to the north or north-east as the countercurrent. But it is well known that the influence of the east Australian Current extends as far south as Eden (37°S.), especially in Autumn (March, April) and also occasionally down to latitude 42°S. (Newell 1960). Such a southerly extension of the East Australian Current does not appear to conform with the countercurrent discussed here. More detailed work will be necessary to show the relation between the East Australian Current, as computed from the field of density, and the hydrological conditions in different parts of the western Tasman Sea.

There is no objective method for deciding on the reference level for the calculation of relative currents and transports. It might be argued that beneath the East Australian Current the reference level should be above the salinity minimum (600 to 1000 m, Fig. 3) since the salinity minimum is due to waters sinking at the Antarctic convergence and spreading northward. But the salinity minimum occurs throughout the whole Tasman and Coral Seas, and there is no reason to expect the northward spreading to be uniform throughout the whole area. It should not be regarded as inconsistent with the general northward spreading that the salinity minimum waters under the narrow East Australian Current have a small velocity to the south. Such a velocity is indicated if the reference level is chosen at or below 1000 m.

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