Eddies in the Pacific North Equatorial Current[1]

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ABSTRACT

Observations taken during the Hawaii to Tahiti Shuttle Experiment allow identification of eddies drifting westward with the North Equatorial Current. During 17 months only three eddies passed through the area and their individual residence time is about four months. They probably represent non-dispersive first-mode baroclinic Rossby waves. The eddies represent no real problem for monitoring the strength of the North Equatorial Current since they can be easily recognized in temperature sections and are located near the center of the current.

During the Hawaii to Tahiti Shuttle Experiment between February 1979 and June 1980 (Wyrtki *et al.*, 1981), several eddies were crossed south of Hawaii in the North Equatorial Current. The Shuttle Experiment was designed to observe the changing equatorial ocean structure and circulation and to develop the scientific basis for their monitoring by simple observations of thermal structure and sea level. Eddies represent disturbances of the mean structure and consequently it is important to determine the frequency of their occurrence and their effects in distorting the mean structure. Although the Shuttle Experiment was not designed to observe eddies in detail, nonetheless many were crossed and it seems worthwhile to discuss them.

The existence of eddies in the North Equatorial Current has been known at least since the Trade Wind Zone Study in 1964/65. The numerous temperature profiles (Seckel, 1969) obtained during this study between 10 and 26°N cross a number of these eddies. The discussion of the data by Seckel (1968), which centers around the mean conditions, mentions these eddies only briefly. A statistical analysis of the data by means of structure functions revealed a spectral peak at 200 km, indicating the presence of eddies (Wyrtki, 1967). With the use of the same data set, the westward migration of baroclinic eddies north of Hawaii was determined as about 5 km day^{-1} by Bernstein (1974). During the Test Shuttle Experiment between November 1977 and February 1978, when 26 high-density air-expendable-bathythermograph (AXBT) sections were taken between Hawaii and Tahiti, another eddy was repeatedly crossed (Patzert *et al.*, 1978a). This large eddy was ~300 km in diameter and it took about one month to cross the 150°W meridian, giving it a drift of ~10 km day^{-1} (Patzert *et al.*, 1978b).

During the 17 months of the Shuttle Experiment, the North Equatorial Current was crossed 35 times by AXBT sections along 150, 153 and 158°W and 16 times by hydrographic sections taken by research vessels along 158°W. The ships took hydrographic stations at every degree of latitude with a conductivity–temperature–depth recorder (CTD) and intermediate expendable-bathythermograph (XBT) casts at each half-degree of latitude (Taft and Kovala, 1981). The AXBT drops were spaced at one-

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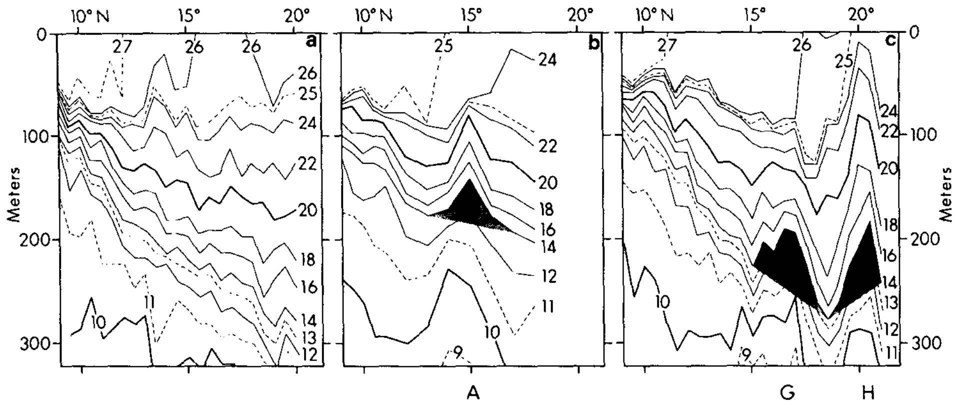

FIG. 1. Example of three temperature sections across the north equatorial current. The left section (cruise 6, July 1979) shows no eddy. The central section (flight 6, March 1979) shows eddy A. The right section (cruise 10, December 1979) shows eddy G at 17°N, and eddy H at 20°N.

degree intervals to the north of 12°N and at half-degree intervals south of 12°N (Stroup *et al.*, 1981). These sections allow the identification of synoptic-scale eddies with diameters between 200 and 300 km (Fig. 1). Crude but simple parameters of the eddies were determined from the excursions of the 14°C isotherm. This isotherm, situated in the center of the main thermocline, slopes from about 100 m at 10°N to 270 m at 20°N across the North Equatorial Current (Fig. 1a). The deepest positions of the 14°C isotherm north and south of any eddy feature were determined (Fig. 1b,c). Their distance can be considered a measure of eddy diameter. The difference between the highest position of the 14°C isotherm in the center of the eddy and the mean of the two deepest positions at its periphery was taken as a measure of eddy amplitude. Only if the amplitude exceeded 25 m was the feature considered an eddy. The root-mean-square "noise" in the depth of the 14°C isotherm is 6 m.

In the 51 temperature sections a total of 35 eddies was identified. Frequently the same eddy appeared at several successive sections and at several longitudes, allowing a determination of its mean speed of migration. The locations of the various eddies, labeled alphabetically in order of appearance, are displayed in Fig. 2. The three panels of Fig. 2 represent observations at the three longitudes, and the time and latitude of observed eddies is shown. Observations believed to represent the same eddy are connected by solid lines.

Two different types of eddies are present. Fre-

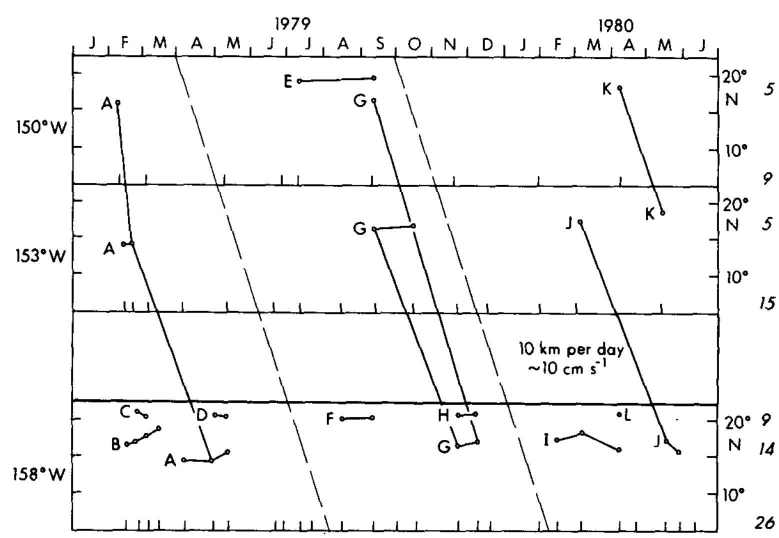

FIG. 2. Latitude and time of observation of eddies in the north equatorial current at the three longitudes 150, 153, and 158°W. Observations of the same eddy are connected by heavy lines. The dashed line gives a speed of migration of 10 km day^{-1}. On the right-hand side the numbers of eddy crossings and of sections are given.

quently, eddies appear at 158°W near 20°N to the south of Oahu (Fig. 1c). Five of these Hawaiian eddies were observed during the 17-month period (eddies C, D, F, H and L). They appear on nine of the 26 sections and one eddy passes across 158°W approximately every three months. These eddies are formed to the west of the island of Hawaii and have been extensively studied by Patzert (1969). They will not be discussed here.

The other, more important type of eddy appears in the North Equatorial Current between 14 and 19°N and these seem to drift west with the current (eddies A, G, J and K). Eddy A is observed in February at 150°W but has only an amplitude of 27 m. It appears almost simultaneously at 153°W, where its amplitude increases to 50 m. Its diameter of 350 km makes it a large eddy. It is subsequently observed in March at 156°W (Fig. 1b) and in April at 158°W with amplitudes between 35 and 50 m, and it disappears in June. Its average speed of migration is ~9 km per day.

Eddy B was observed at 158°W on four occasions during the early part of the experiment. Its amplitude decreased from 65 m in February to 40 m in March before it disappeared, obviously having drifted to the west out of the observation area. Its diameter was in excess of 250 km.

In July 1979 eddy E appeared at 18.5°N at 150°W. It had an amplitude of 50 m and a diameter of 250 km. It was observed a second time in September at 19°N and probably drifted northwestward, passing to the north of the Hawaiian Islands. Eddy E is probably the same eddy as the one observed near 18.5°N, 148.5°W in June 1979 by the circular trajectory of a satellite-tracked drifting buoy (Patzert and McNally, 1980).

Eddy G was observed almost simultaneously at 150 and 153°W at 16°N in September 1979. Its amplitude at both meridians was only 40 m and, if it was the same eddy, its center was probably between the two meridians. This in turn means that eddy G must have been strongly elliptical, but the three-dimensional structure of eddies in the north equatorial current has not yet been observed. In October, eddy G was still present at 153°W and in November it appeared at 158°W, where it reached a maximum amplitude of 60 m in early December (Fig. 1c) before it disappeared to the west. The diameter of eddy G was between 150 and 250 km; its mean speed of migration was 10 km day^{-1}. Fig. 1c shows the simultaneous occurrence of Eddy G at 17°N and Eddy H, a Hawaiian eddy, at 20.5°N.

Eddy I, seen first at 17°N, 158°W in February 1980, was a weak eddy that was observed three times until April. Its diameter was smaller than 250 km and its amplitude stayed at 40 m. It may have been locally formed as it was not observed previously at 150 or 153°W.

Eddy J appears first at 17°N and 153°W in March 1980 and is subsequently observed twice at 158°W in May. Its amplitude is between 35 and 45 m, and its diameter only 150 km; it is a weak eddy. Its average speed of migration from 153 to 158°W is ~8 km day^{-1}. The eddy probably formed near 153°W, since it was not observed at 150°W during the AXBT section in February.

In April 1980, eddy K is seen at 18°N, 150°W. It is again observed in May at 19°N, 153°W, having advanced with an average speed of ~9 km day^{-1}. The eddy is very weak; its amplitude is only 20–30 m but its diameter is more than 250 km. It is probably an old eddy in the final stages of decay.

During the Shuttle Experiment, six eddies were observed in the North Equatorial Current to the south of Hawaii (eddies A, B, G, I, J and K). Of those, three were weak (I, J, K) with amplitudes of 40 m or less. Two eddies, A and G, were moderately strong, with amplitudes reaching 50–60 m; eddy B appears to be the strongest, reaching an amplitude of 65 m. Diameters of the eddies were between 150 and 350 km, but there was no obvious relationship between amplitude and diameter. An eddy can be large either because it is strong or because it is in the process of disintegration. Such dilation of decaying eddies has been observed by Patzert (1969).

Not counting the Hawaiian eddies near 20°N, which are of different origin, one finds that 24 of the 51 sections show eddies in the North Equatorial Current. Consequently there is a probability of ~50% of observing such an eddy on any section crossing the area between 150 and 158°W. On the other hand, only four eddies were observed at 150 and 153°W during the entire 17 months. At 158°W five eddies appeared during the same period, but from May through October 1979 not a single eddy was found.

Judging from the very dense observations at 158°W, an eddy is present at a given longitude during ~50% of the time. Considering the entire region of the North Equatorial Current between 10 and 19°N and between 150 and 158°W, one concludes that there is an eddy present virtually all of the time. The only periods when no eddy was present during the Shuttle Experiment are June 1979 and January 1980. Looking from a different point of view, one can state that only three eddies (A, G and J) drifted through the area during the 17 months and that their individual residence time was ~4 months.

The speed of migration of these eddies, nearly uniform at ~10 km per day, is consistent with the mean geostrophic flow of the North Equatorial Current, which varies seasonally between 5 and 15 cm s^{-1} as determined by Seckel (1975). This annual variation was much less pronounced during the Shuttle Experiment. One could assume that the eddies are embedded in and drift with the mean flow which is concentrated above 250 m. The speed of migration is also very close to the speed of non-dispersive first-mode baroclinic Rossby waves, which is about 10 cm s^{-1} at 16°N. Consequently, the eddies might be expressions of such Rossby waves. Their constant speed of migration, apparently independent of the season, favors the latter explanation.

The cyclonic eddies observed in the North Equatorial Current are weak compared with those found in the North Atlantic to the east of the Gulf Stream (McCartney *et al.*, 1978), or in the North Pacific in the Kuroshio (Burkov and Pavlova, 1979); they have about the same diameter, but a much smaller amplitude. Nonetheless, the isotherm uplifting in their center not only involves the upper portions of the thermocline but extends to at least 800 m depth, indicating a deep-reaching disturbance in the density field, which penetrates far deeper than the geostrophic flow in the shallow North Equatorial Current (Taft and Kovala, 1981). This deep penetration is also indicative of their Rossby-wave character and would not exist if advection by the mean flow were the mechanism of their migration. The fact that the mean speed of the North Equatorial Current is the same as the speed of Rossby waves at 16°N seems to be entirely coincidental.

The eddies found in the North Equatorial Current represent no real problem to ocean monitoring. As long as the spacing of observations is at least one degree of latitude, and the section spans the entire width of the current, eddies can be easily recognized. The low-frequency variations of the North Equatorial Current are given by its mean slope between 10 and 20°N, and eddies occur chiefly near the center of the current near 16°N. Problems for monitoring exist only when isolated temperature profiles or stations located too far apart are used. None of the eddies in the North Equatorial Current has a signature in sea-surface temperature, indicating that the cold core did not penetrate the surface mixed layer. It is thus impossible to monitor these eddies by means of radiation measurements from satellites.

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