NOTES AND CORRESPONDENCE

Spatial Fluctuations North of the Hawaiian Ridge

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ABSTRACT

A closely spaced hydrographic section from Oahu, Hawaii to 28°N, 152°W and then north along 152°W shows strong eddy or current features with dynamic height signatures of about 30 dyn cm across 150 km and associated geostrophic surface velocities of approximately 60 cm s^{-1}. Two such features are found between Hawaii and the Subtropical Front, which is located at 32°N. Similar features have been observed on a number of other hydrographic and XBT sections perpendicular to the Hawaiian Ridge. It is hypothesized that the features are semipermanent, are due to the presence of the Ridge, and are related to the North Hawaiian Ridge Current of Mysak and Magaard.

1. Introduction

An eddy-resolving hydrographic and CTD section was made in May 1984 from Oahu, Hawaii to 28°N, 152°W and thence north along 152°W. The most intense flows, other than the Alaska Current, occurred just north of the Hawaiian Ridge, in an 800-km wide region which showed bands of alternating flow. It is not possible, solely from geostrophic computations along a single section, to ascertain definitively whether these flows are slices through a chain of eddies or whether they extend a long distance along the Ridge. However, previous surveys of the area on various sections perpendicular to the Ridge have found similar features, though the magnitude and precise location of the alternating flows varied. For instance, Roden's (1977, 1980) repeated hydrographic sections at 153° and 158°W showed reversing currents north of the Ridge. Price (1981) has found such features in the repeated XBT section from Honolulu to San Francisco, approximately along the line we sampled. Seckel's (1975) monthly hydrographic surveys of the region around Hawaii in 1964–65 showed hints of this structure, though they were too coarsely sampled to resolve the currents. Also, water-mass properties that we measured on the section strongly suggest that the reversing flows extend along the Ridge as a quasi-permanent feature and provide a means for determining their source.

A twelve-year average of XBT data in the region around Hawaii (White, 1983) shows reversing currents which are somewhat cellular in nature along the ridge and which are most developed north of Hawaii and Maui. The better development of the currents north of Hawaii suggests that the currents are time-dependent, since much less data was available for the average there. Time dependence may involve shifts of the currents away from the ridge and changes in amplitude rather than changes in meridional length scale. Most synoptic surveys examined show features with the same meridional scale. White (1983) and Mysak and Magaard (1983) dubbed the mean current just north of the ridge the North Hawaiian Ridge Current. (North of Oahu, it is not clear that there are mean currents with strong flow parallel to the ridge.)

Mysak and Magaard (1983) and Oh and Magaard (1984) developed a theory of the North Hawaiian Ridge Current. They hypothesized that westward-propagating, annual Rossby waves reflecting from the nonzonal boundary of the Hawaiian Ridge produce a disturbance which can be rectified into steady, Eulerian flow with the aid of vertical or horizontal friction. Their theoretical flows parallel to the ridge are quite similar to White's (1983) mean flow north of the main island of Hawaii. The predicted meridional scale of the currents is somewhat shorter than White's and our observations, although it agrees fairly well with Roden's (1980) observations.

In the following section, we present observations of the energetic flows, their dynamic height, geostrophic shear and geostrophic velocity. Oxygen and nutrients, which were also sampled on the section, provide valuable evidence of the possible long-term nature and large longitudinal extent of the currents. In section 3, our observations are compared with previous observations and theory.

2. Observations

The cruise track for the May 1984 hydrographic section is shown in Fig. 1. Between Oahu and 28°N, the section is nearly perpendicular to the Hawaiian Ridge. Stations along this track up to 32°N are used in the potential density section shown in Fig. 2. CTD data, which were calibrated with discrete salinity samples collected at 24 depths at each station, were used in Fig. 2. The temperature and conductivity data were filtered, lagged and block-averaged to a 1 sec time series, calibrated and pressure-sequenced to a 2 db series, and then block-averaged to a 10 db series upon which Fig. 2 is based. Just north of the ridge, there are several large fluctuations in the upper 1000 m. The distance between peaks and troughs is approximately 180 km. The fluctuations decrease in amplitude with depth.

Figure 3a shows temperature at the sea surface and four other levels, again based on CTD data. This figure shows clearly that the sea surface temperature does not reflect the large amplitude fluctuations in temperature below, possibly because of seasonal warming. Another possibility is that the fluctuations are related to Rossby waves with weak surface thermal signatures. The figure also shows the strong vertical coherence of the fluctuations.

Dynamic height at the sea surface and at four other levels relative to 1400 db is shown in Fig. 3b. Dynamic height at the first station is not included, since the depth at the first station is only about 750 m. (When dynamic

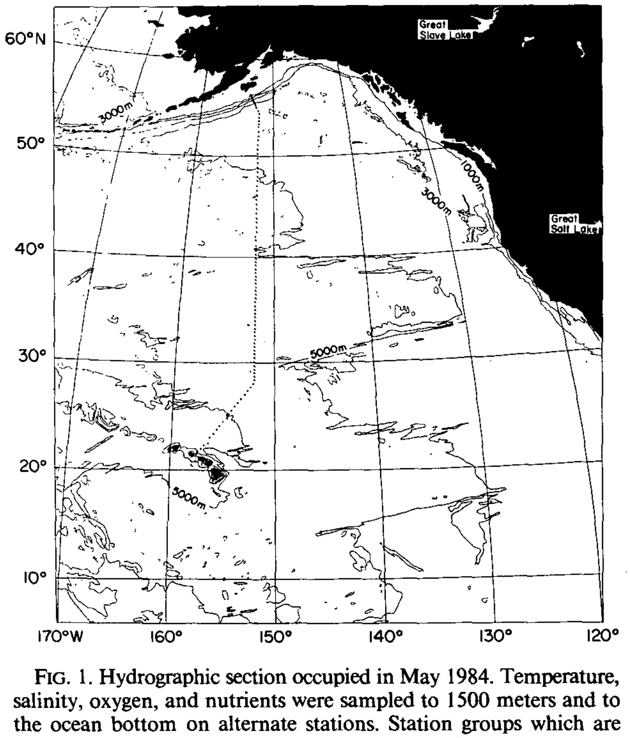

FIG. 1. Hydrographic section occupied in May 1984. Temperature, salinity, oxygen, and nutrients were sampled to 1500 meters and to the ocean bottom on alternate stations. Station groups which are used in Fig. 5 are indicated by symbols used in Fig. 5.

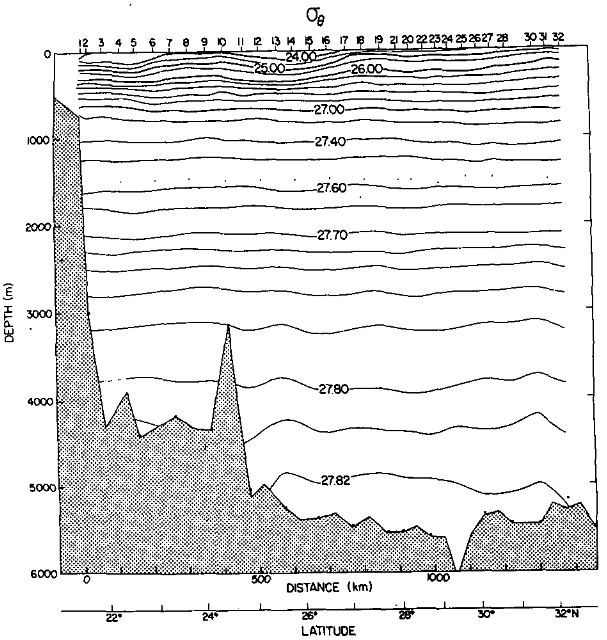

FIG. 2. Potential density at the southern end of the section. Dots indicate the maximum depth of each station.

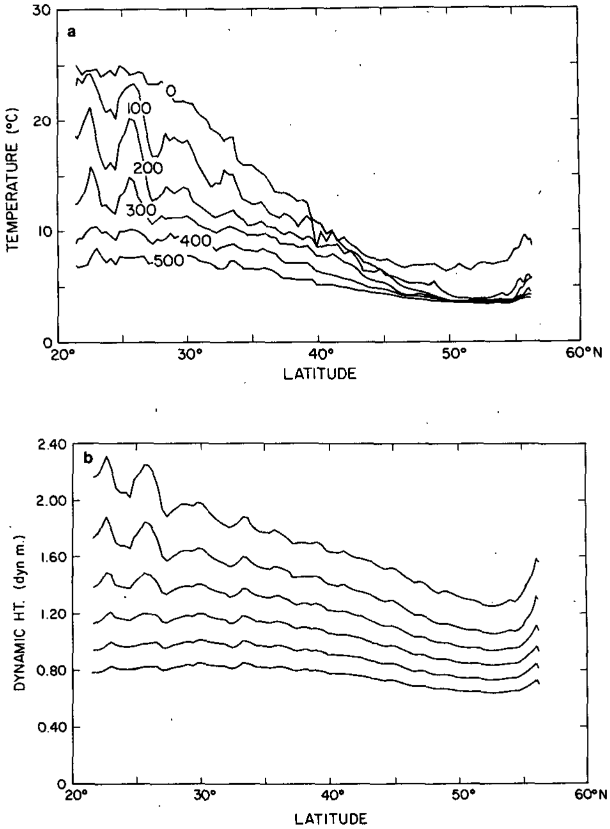

FIG. 3. (a) Temperature and (b) dynamic height relative to 1400 db at 0, 100, 200, 300 and 400 meters for the entire section.

height is calculated relative to 750 db, flow directions at the surface are unchanged: flow between the first two stations is to the east.) The entire section from Hawaii to Alaska is presented to show how energetic the regime near Hawaii is. The broad sweep of eastward flow between Hawaii and the Alaska Current is clear from the figure. It also appears that the subtropical gyre shifts northward with depth so that south of 32°N there is broad eastward flow at 0 to 200 m, while dynamic topography at 300 and 400 m indicates no flow or slightly westward flow. The dynamic height gradient of the fluctuations near Hawaii is matched only by the Alaska Current at the very northern end of the section. North of about 34°N, fluctuations are much weaker and have shorter meridional scales. Geostrophic velocity at the sea surface relative to 1400 db is shown in Fig. 4. Speeds in excess of 60 cm s^{-1} relative to 1400 m are found in the fluctuations near Hawaii.

Water property variations provide valuable information about the longitudinal extent of the reversing flows along the Hawaiian Ridge. Dynamic computations from the single hydrographic section, as mentioned above, do not distinguish whether flows observed denote constricted eddies or whether they denote currents extending far along the Ridge. However, in addition to CTD measurements and Nansen bottle salinities, oxygen and nutrients were sampled at many levels at each station. Property–property relations provide a useful method for assessing the sources of water in the reversing flows. Figure 5 shows oxygen versus salinity between Hawaii and 32°N. Well-defined boundaries in this relation and in σ_θ (S) occur at each peak and trough in potential density in Fig. 2. There is a surface layer, about 100 m thick, of highly oxygenated water which covers the entire region. Below this, down to about 300 m and in the density range 24.3 to 26.3 σ_θ, is a middle layer where O_2 (S) is quite different in eastward and westward flows. There is an abrupt decrease in oxygen below about 26.3 σ_θ and 34.2‰ which marks the bottom of the layer in question and is the bottom of the ventilated layer in the subtropical gyre (Talley, 1985). Water flows westward at stations 2–5 and 10–14 according to the geostrophic velocity of Fig. 4; the middle layer (above the abrupt decrease in oxygen at all stations) has lower oxygen in westward flow than water at stations 6–9 and 15–19, flowing eastward. (Temperature versus salinity, not shown here, indicates that this middle layer is also fresher in the westward flow.) The higher oxygen, higher salinity comes from the general area northwest of the Ridge, based on maps of the full subtropical gyre; lower oxygen, lower salinity comes from the northeastern part of the gyre. The two bands of lower oxygen and lower salinity are anomalous compared with the rest of the entire transect where general flow is eastward. Properties in these bands of westward flow are consistent with a source in the east while the source of water elsewhere on the section is generally the west. Thus property contrasts between eastward- and westward-flowing waters indicate that the currents are not merely recirculating eddies north of the Ridge, but rather extend a long distance along the Ridge.

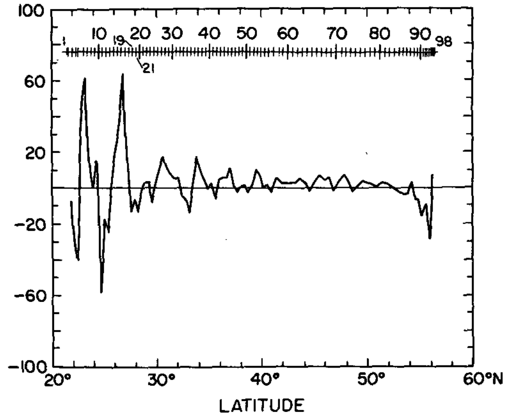

FIG. 4. Geostrophic velocity at the sea surface relative to 1400 db.

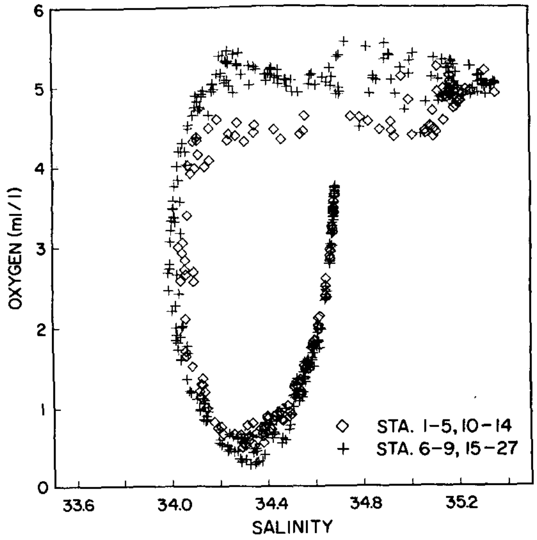

FIG. 5. Oxygen vs salinity for indicated station groups.

3. Discussion

As mentioned above, Roden (1977, 1980) and Price (1981) have both observed energetic jets similar to those reported here. Roden's pertinent sections were along 158°W and 153°W. At both longitudes, he found energetic jets with meridional scales of about 400 km just north of Hawaii, decreasing in amplitude to the north. Repeated sections at 158°W indicate that the strength of the fluctuations is time-dependent.

White (1983) averaged XBT data from 12 years in a region surrounding the Hawaiian Ridge. Northeast of the main island of Hawaii, where the data are unfortunately rather sparse, the averaged flow shows the sort of reversals seen on our synoptic section. The meridional scales are almost identical to ours, even though our section is from a different part of the ridge. White's averaged flows in the area we sampled do not show such mean currents. This may reflect the fact that, because there was much more data available near Oahu than near the main island, and because the flow is meandering and variable but with stable spatial scales, the reversing currents, moving in and out from the ridge, average to near zero in a long time series.

In summary, we found energetic flows in excess of 50 cm s^{-1} relative to 1400 db in reversing bands north of Hawaii; the length scale perpendicular to the ridge was about 390 km from peak to peak; they extended to at least 700 m depth and perhaps to 1000 m; oxygen–salinity and temperature–salinity relations indicated that the flows observed were not merely slices through compact eddies, but extended along the ridge. The Hawaiian Ridge appears to influence the circulation to approximately 800 km northeast of the ridge. It appears from comparison with other datasets that, while the flows may be time-dependent in amplitude and position relative to the ridge, the meridional length scale and northward decay of amplitude are robust features.

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