Eulerian Measurements in the Alaskan Stream near Kodiak Island[1]

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ABSTRACT

A current record during February–August 1980 over the continental slope off Kodiak Island provided the first Eulerian measurements in the high-speed region of the Alaskan Stream. The net flow at 980 m during the 6-month period was 6 cm s^{-1} at 235°, but there were major low-frequency variations in the current. These appeared to result from the occasional advection of meanders past the mooring, however, rather than from features such as planetary waves. The ratio of fluctuating to mean kinetic energy was much lower than reported values in the Kuroshio and Gulf Stream, probably as a result of important kinematic differences in these flows.

1. Introduction

The first reasonably complete description of the Alaskan Stream was provided by Favorite (1967). He concluded that the water driven northward into the Gulf of Alaska by wind-stress curl moves westward along the Alaska Peninsula and Aleutian Islands as a narrow, intense boundary flow whose characteristics are a result of vorticity conservation (see Fig. 1). This westward flow, the Alaskan Stream, has been studied since Favorite's work with hydrocast sections (see Favorite *et al.*, 1976; Reed *et al.*, 1980), but few direct current measurements were made. Four sets of Lagrangian measurements of one or two days duration were made from 1959 to 1969 (Reed and Taylor, 1965; Reed, 1971; Favorite *et al.*, 1972). These very limited data indicated that the flow was deep, intense and in approximate geostrophic balance. Pearson (1975) also reported a 2-day current-meter record in deep water near the head of the Gulf of Alaska. Since then the results from drifting buoys tracked by satellite in 1978 and 1979 (Reed, 1980) showed large-scale recirculation around the cyclonic Gulf of Alaska gyre, but they provided little detailed information on the high-speed core of the Stream. Eulerian measurements made as part of the Outer Continental Shelf Environmental Assessment Program were inshore of the Stream (Muench and Schumacher, 1980), but in 1980 we obtained results from a current mooring deployed for six months in the high-speed flow region off Kodiak Island. The results from these data permit a limited comparison with the baroclinic structure of the deep part of the Stream, they allow examination of temporal variations, and they provide estimates of the energetics of this flow.

During February–March 1980 a CTD (conductivity/temperature/depth) survey of the Alaskan Stream was made aboard the NOAA ship *Discoverer* from the head of the Gulf of Alaska (145°W) to the western Aleutian Islands (180°). On 14 February 1980, a current mooring was deployed off Kodiak Island in a water depth of 1670 m, and it was recovered on 14 August 1980. Complete data (current speed and direction, temperature and conductivity) were obtained at 980 m, and current direction and temperature (but no speed or valid conductivity data) were recorded at 480 m. Aanderaa RCM-4 rotor/vane current meters, with a sampling interval of 30 min, were used on a taut-wire mooring (constructed from Kevlar line) with a float ~ 10 m above the upper current meter. The data records were checked for errors, and the time series was filtered so that over 99% of the amplitude was passed at periods > 5.0 h, 50% at 2.9 h, and <0.5% at 2.0 h. This "2.9 h" filtered series was used in the following analyses except in Table 2. The current-meter and hydrographic data, with numerous maps and sections, were documented in a report by Wright (1981).

2. Comparison with geostrophic flow

The location of the current mooring and nearby CTD casts that spanned the Alaskan Stream are shown in Fig. 1. During deployment, the highest geostrophic speeds were approximately at the mooring site between casts 27 and 30, where computed surface speed (referred to 1500 db) exceeded 100 cm s^{-1}. (Estimates of ship drift at the mooring were

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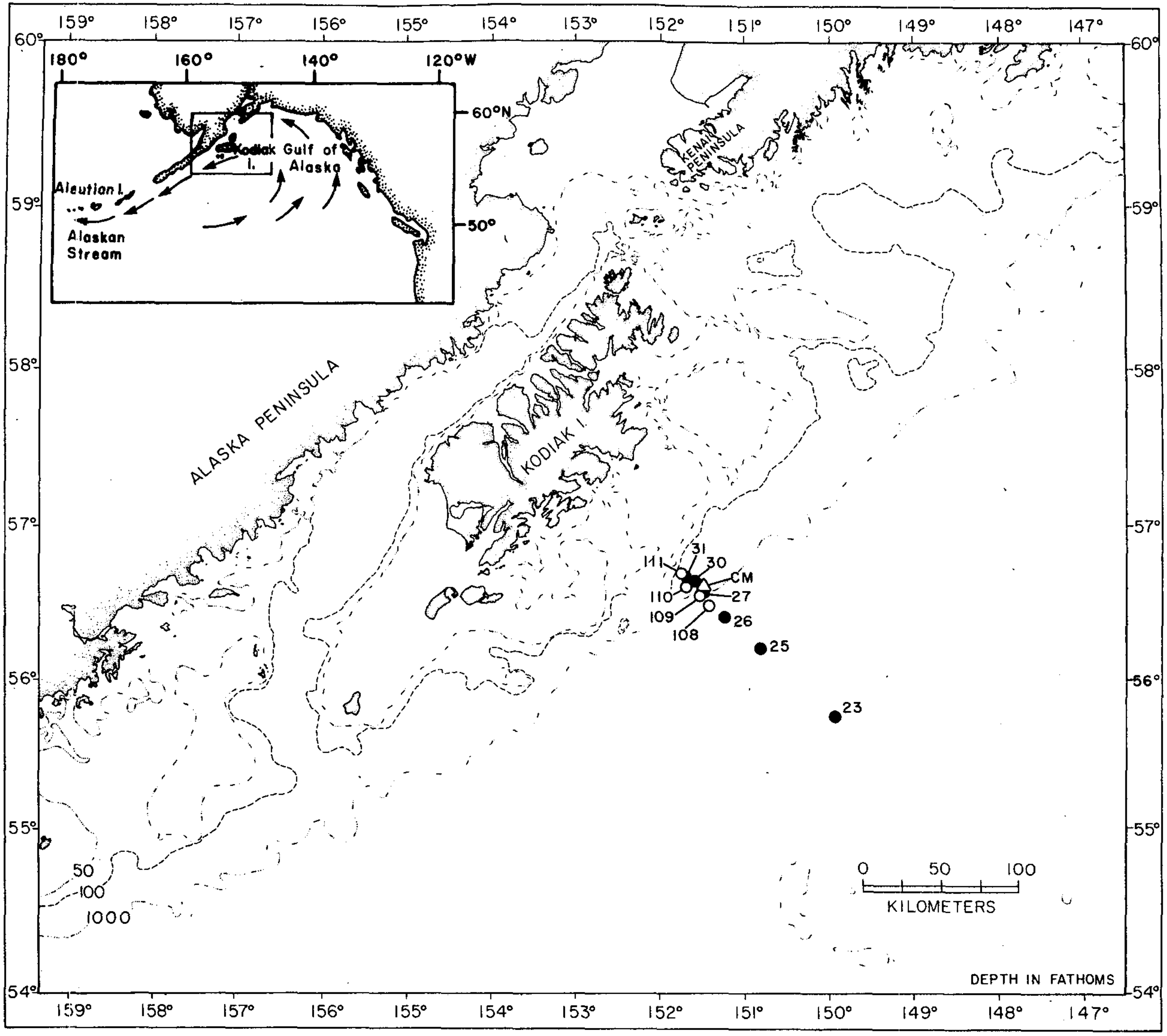

FIG. 1. Location of observations in the Alaskan Stream near Kodiak Island, February–August 1980. The open and closed circles indicate CTD casts, the triangle denotes the current mooring, and the isobaths are in fathoms (1 fathom = 1.829 m).

$\sim$100 cm s^{-1} to the southwest, but drift near the shelf break was only roughly 10 cm s^{-1}.) During occupation of casts 108–111 (about three weeks after deployment), the surface speed (60 cm s^{-1}) was greatest between casts 109 and 110, but subsurface speeds were slightly greater inshore of the mooring at casts 110–111. We do not have an adequate time series of CTD sections to examine the evolution of any changes in deep baroclinic flow, but the data are well situated for a general examination of the measured and computed deep flow.

A comparison of computed geostrophic flow for the two CTD sections and measured net velocities, rotated in the direction of geostrophic flow, is shown

TABLE 1. Comparison of geostrophic flow (referred to 1500 db) and measured net velocities at 980 m, February–March 1980.

Station	Date	Computed geostrophic velocity (cm s^{-1})	Measured velocity (cm s^{-1})	Date	Difference (measured − geostrophic)
27–30	14–15 Feb	14.6	13.7	15–24 Feb	−0.9
109–110	8 Mar	9.3	13.0	4–13 Mar	3.7

in Table 1. Measured net flow was determined over 10-day periods; Taft (1978) discussed the rationale for different averaging intervals, and he chose ten days for use in the Kuroshio. The agreement of computed and measured velocities for the first station pair in Table 1 is quite close but is less good for the second pair. Such comparisons are associated with errors, however, and there are too few values of computed flow to make statistically significant statements about the degree of geostrophy. In the absence of firm evidence to the contrary, we will assume that the deep flow here is approximately geostrophic and that the deep waters probably experience changes in baroclinic structure, although lack of data prevents its demonstration.

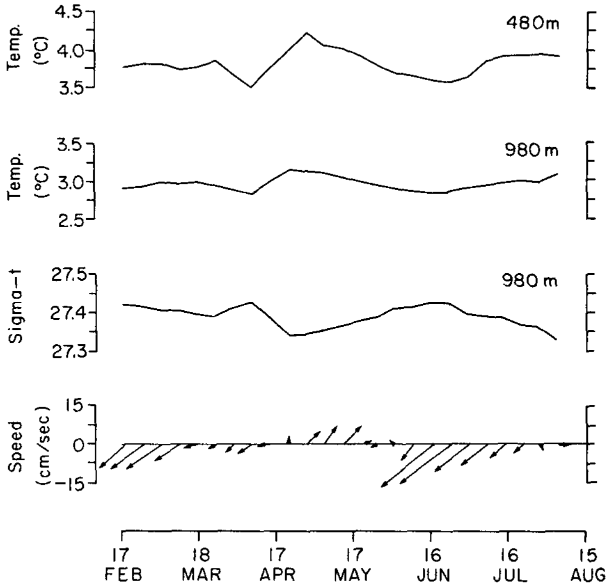

FIG. 2. Weekly net current vectors at 980 m, weekly mean sigma-*t* density at 980 m, and weekly mean temperature at 980 and 480 m from the current mooring near Kodiak Island, 15 February–14 August 1980. 2.9 h filtered data were used to prepare these plots.

3. Temporal variations

The weekly net flow at 980 m during the 6-month period is shown in Fig. 2. The record is typified by low-frequency variability; during the first month the flow was of moderate intensity toward the southwest, for the next three months it was relatively weak with the suggestion of a clockwise rotation of the vectors, for the next month it was strong and steady toward the southwest, and the last month had weak and variable velocities. Appreciable changes also occur in temperature at both levels, and the density at 980 m undergoes similar oscillations.

The possibility of planetary waves being a mechanism for the observed variations was investigated. Such waves in flows along continental slopes should be controlled by topographic effects (rather than variations of the Coriolis parameter with latitude), and appropriate expressions for the behavior of these waves were given by Garrett (1979). Using a period of about 90 days as suggested by Fig. 2, the Coriolis parameter, the bottom slope, and the measured net flow during the entire series (5.9 cm s^{-1}) along an axis parallel to the continental slope, we computed an alongshore wavenumber. The wavelength obtained was only 20 km, however, which is typically over an order of magnitude less than the scale of features that have been clearly identified as resulting from topographic planetary waves (see, e.g., Garrett, 1979). In addition, the oscillations in temperature at 480 and 980 m in Fig. 2 are quite similar (correlation coefficient = 0.88), but they should not be in phase if they were caused by a long-wave propagating and being advected in flows that are appreciably different at the two levels as indicated by the geostrophic calculations. Hence the variations in Fig. 2 do not appear likely to have resulted from organized, periodic, long waves. Another argument against the likely importance of planetary waves here is given below.

The large oscillations seen in the current, density, and temperature records seem to us most likely to have resulted from aperiodic meanders in the flow that were advected past the mooring. (We consider meanders to be regions of highly curved flow that are not regularly occurring or repeatable; thus they are different from *periodic* planetary waves even though both might be caused by similar mechanisms.) Although the Alaskan Stream off Kodiak Island is frequently a rather straight flow, Reed *et al.* (1980) reported an area of marked anticyclonic curvature on one cruise ~ 200 km upstream of our mooring. A feature such as that reported could account for the clockwise rotation and marked warming seen in Fig. 2 in March and April, whereby warm (low-density) water laterally followed the offshore trend in the streamlines; as this perturbed feature was advected past the mooring, streamlines would presumably straighten and speeds should increase as observed. Furthermore, use of the net flow during the period of weak, variable velocity, with its duration, gives a length of 150 km for a meander, which is similar to that suggested by the observations of Reed *et al.* (1980). Thus we have presented a rationale for the observed oscillations, but we have little additional information. Reed *et al.* (1980) did not find a mechanism for these meanders, but Reed (1979) found evidence for inshore-offshore migrations of the Stream edge which could induce such features through interactions with the topography of the continental slope.

We examined the weekly mean deviations in sea level, after adjustment for variations in atmospheric pressure, recorded at the National Ocean Survey

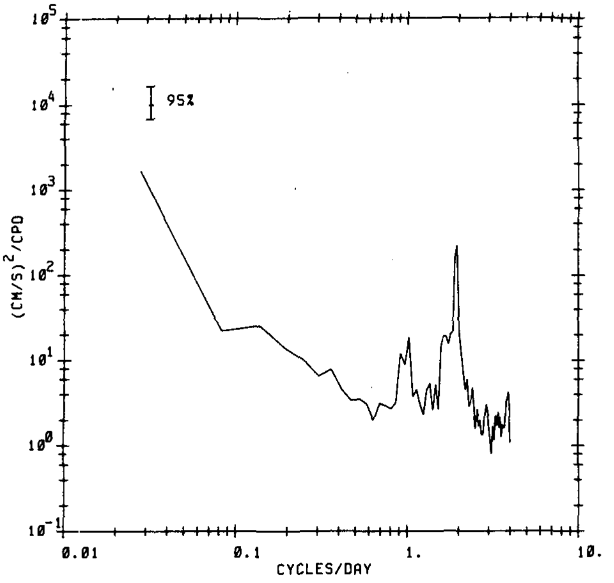

FIG. 3. Variance spectrum of 2.9 h filtered velocities at 980 m, 15 February–14 August 1980.

tide gage on Kodiak Island but were not able to find any obvious correspondence with the velocity record in Fig. 2. Thus the velocity fluctuations in deep water over the slope did not seem to have large effects that were transmitted over the shelf and were readily apparent at the coast. Similar results were found by Brooks and Bane (1981) off North Carolina.

4. Energy levels

A spectrum of the energy density computed from the 2.9 h filtered current record at 980 m is given in Fig. 3. It is apparent that much of the energy is in periods of two weeks or longer, which was inferred from the data in Fig. 2. The energy density at the semidiurnal period dominates the higher-frequency end of the spectrum; the energy densities at the diurnal and inertial (14.3 h) periods are only about a tenth that at the semidiurnal. The semidiurnal tidal currents here have an amplitude of ~5 cm s^{-1}, which is less than other estimates (10–25 cm s^{-1}) of tidal currents in deep water of the Alaskan Stream (Reed and Taylor, 1965; Reed, 1971; Favorite *et al.*, 1972).

Table 2 presents data on the net flow and kinetic energy of the Alaskan Stream averaged over 30-day segments of the record after the data were passed through a 35 h filter to eliminate tidal motion. Taft (1978) performed a similar analysis for the Kuroshio and reported other results obtained for the Gulf Stream. Nowlin *et al.* (1981) also gave comparable results for the Antarctic Circumpolar Current. (It must be stressed that these analyses for other currents were based on numerous moorings, whereas our results for the Alaskan Stream are from a single meter.) The mean kinetic energy in Table 2 is greater than the values given by Taft (1978) and Nowlin *et al.* (1981), but the measurements they listed were in water depths of 2–4 km, not 1 km as here. On the other hand, the fluctuating kinetic energy in the Alaskan Stream, insofar as results from this meter are typical of this flow, is about the same as for the Kuroshio but generally less than for the Gulf Stream and the Antarctic Circumpolar Current. Thus the ratios $KE'/\overline{KE}$ that we obtained are roughly an order of magnitude less than the ratios in these other currents. (The two ratios greater than one in Table 2 are based on very weak net flows, and the values are probably not reliable.) Even though we have stressed the low-frequency variability of the Alaskan Stream, its fluctuating energy levels in relation to the mean energy appear to be much lower than those in the Kuroshio, Gulf Stream, and Circumpolar Current.

Why does the Alaskan Stream appear to be more stable than these other boundary currents? We suspect that it results from differences in direction of these flows in relation to the underwater topography. Holton (1972) described the generation of multiple, wavelike meanders in eastward flow over a barrier; for westward flow, however, vorticity conservation creates only a single disturbance which does not propagate as a wave downstream. The latter situation was much like that found by Reed *et al.* (1980) off Kodiak Island. Thus the Alaskan Stream is a retrograde flow (Johnson, 1978) which should not be characterized by multiple meanders like the Kuroshio and Gulf Stream. The relatively low levels of fluctuating kinetic energy in the Alaskan Stream suggest that these arguments have validity, and the characteristics of this flow appear to have significant differences from those of the major western boundary currents.

TABLE 2. Basic statistics of low-pass (35 h) filtered velocity measurements in the Alaskan Stream at 980 m, 17 February–12 August 1980. $\overline{KE}$ is the mean kinetic energy per unit mass [$\overline{KE} = 1/2(\bar{u}^2 + \bar{v}^2)$], and KE' is the fluctuating kinetic energy per unit mass [$KE' = 1/2(\sigma_u^2 + \sigma_v^2)$]. The velocity components u and v were derived for axes of 325 and 235° respectively, and σ_u^2 and σ_v^2 are the variances of the u and v component velocities.

	Net flow		Energy (cm^2 s^{-2})		
Period	Speed (cm s^{-1})	Direction (° true)	$\overline{KE}$	KE'	$KE'/\overline{KE}$
17 Feb–17 Mar	14	235	99	7	0.1
18 Mar–16 Apr	5	240	12	3	0.2
17 Apr–16 May	6	35	20	2	0.1
17 May–15 Jun	2	235	6	32	5.3
16 Jun–15 Jul	19	230	172	26	0.2
13 Jul–12 Aug	1	175	1	15	15.0
17 Feb–12 Aug	6	235	52	14	0.3

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