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The recent return of the Alaskan Stream to Near Strait

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ABSTRACT

A hydrocast survey was conducted near the western Aleutian Islands and in the Bering Sea in September 1992. Presence of the Alaskan Stream was indicated by temperatures $>4°C$ to depths in excess of 200 m. Geopotential topography showed the Alaskan Stream flowing through Near Strait into the Bering Sea, with branches also flowing northward through Amchitka and Buldir passes. Satellite-tracked drifter paths were in general agreement with these features. Transport through Near Strait was $\sim 5 \times 10^6$ m^3 s^{-1}. Previous research indicated that the Stream had been absent from the Strait for more than a year. Data from three current moorings (13-mo duration), however, suggested that the Alaskan Stream started flowing through Near Strait in October 1991 and continued into September 1992. This inflow had periods of both steady and variable flow.

1. Introduction

The Alaskan Stream, the northern boundary of the Pacific subarctic gyre, flows westward just south of the Aleutian Islands. Normally, a major part of it turns northward into the Bering Sea through Near Strait, the wide passage between Attu Island and the Komandorski Islands (Favorite, 1974; see Fig. 1). Stabeno and Reed (1992), however, reported a circulation anomaly whereby the Stream turned to the south off Attu Island and eventually moved eastward. That is, no pure Alaskan Stream water was flowing through Near Strait. This lack of inflow apparently started in summer 1990 and persisted through at least late 1991. The results reported here show the end of this circulation anomaly and a return to normal inflow through Near Strait.

The observations analyzed here were part of NOAA's Fisheries Oceanography Coordinated Investigations (FOCI). The goal of FOCI is to gain understanding of the effects of the abiotic and biotic environments on commercially important fisheries. FOCI field work in the Bering Sea started in August 1991 with an emphasis on circulation in the western and central parts of the region. The data used in the present study are from a hydrocast survey aboard the NOAA ship *Miller Freeman* in September 1992, a set of satellite-tracked drifters deployed during the cruise, and

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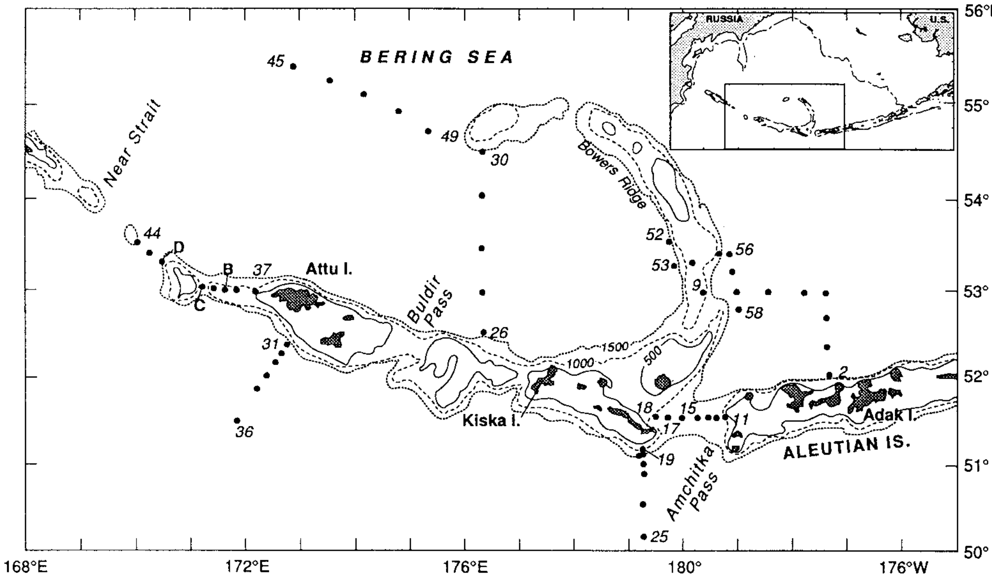

Figure 1. Location of CTD casts, 13–25 September 1992, and current moorings in Near Strait. The 500-, 1000- and 1500-m isobaths are also shown.

three subsurface current moorings in Near Strait. We describe the observations, examine water properties and geostrophic flow, analyze drifter trajectories and current time series, and summarize results in light of knowledge of the circulation in the region.

2. Observations

During 13–25 September 1992, a total of 53 CTD (conductivity/temperature/depth) casts were taken in the area shown in Figure 1. Observations were confined to the U.S. economic zone, whose western boundary is ~5 km west of the line between stations 44 and 45 (Fig. 1). A Seabird SBE-9 CTD was used, and the data were recorded during the downcast on disk in a minicomputer. Casts were made to near bottom or a maximum depth of 1500 m. A salinity correction (−0.002‰) was derived from samples taken on each cast at various depths. Temperature and salinity were averaged over 1-m intervals; these values were used to compute density and geopotential anomaly.

During September 1992, seven satellite-tracked drifting buoys were launched and provided reliable data. They were obtained from Oceanroutes Seimac and employed a tristar drogue centered at 40 m. An average of ~10 satellite fixes were obtained each day, with a standard position error of ~0.2 km. Processing of the data was similar to the methods reported by Stabeno and Reed (1991).

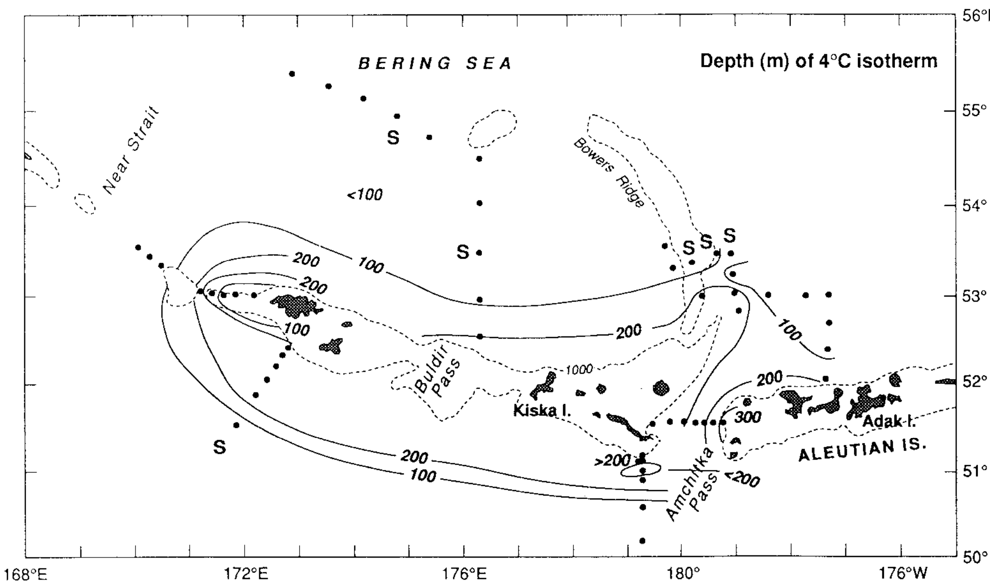

Figure 2. Depth (m) to which the 4.00°C isotherm extends, 13–25 September 1992. S at a station indicates a secondary layer (of 10–40 m thickness) > 4°C below the depth indicated.

Three taut-wire current moorings, deployed in August 1991 in Near Strait, were recovered in September 1992 on the *Miller Freeman* cruise. The moorings were constructed from Kevlar line and had subsurface floats above the upper meters and at intermediate depths. Aanderaa RCM-4 rotor/vane meters were used; each meter also contained temperature, conductivity, and pressure sensors. The data records were checked for errors, and the time series (with a sampling interval of 1 hr) were passed through a 35-hr (cosine-squared, tapered Lanczos) filter, effectively removing tidal signals, to derive daily net vectors and temperature and salinity. Comparisons with CTD data during deployment and recovery suggest that the final temperature and salinity time series are reliable to ~0.1°C and 0.1‰. Moorings B and D had maximum vertical excursions of 10 m. Mooring C, however, had several excursions as great as 80 m. These have little effect on the velocity records; temperature and salinity data during excursions > 20 m, however, were edited from the time series. All but two of the meters had complete records.

3. Water properties

A distinctive characteristic of the Alaskan Stream is the presence of relatively warm subsurface water, at least in its nearshore, high-velocity region (Reed, 1984). Figure 2 shows the depth to which waters warmer than 4°C extends. The sections offshore of Amchitka Pass and Attu Island were generally characterized by the 4°C isotherm reaching depths in excess of 200 m. In Near Strait, only station 41 (Fig. 1)

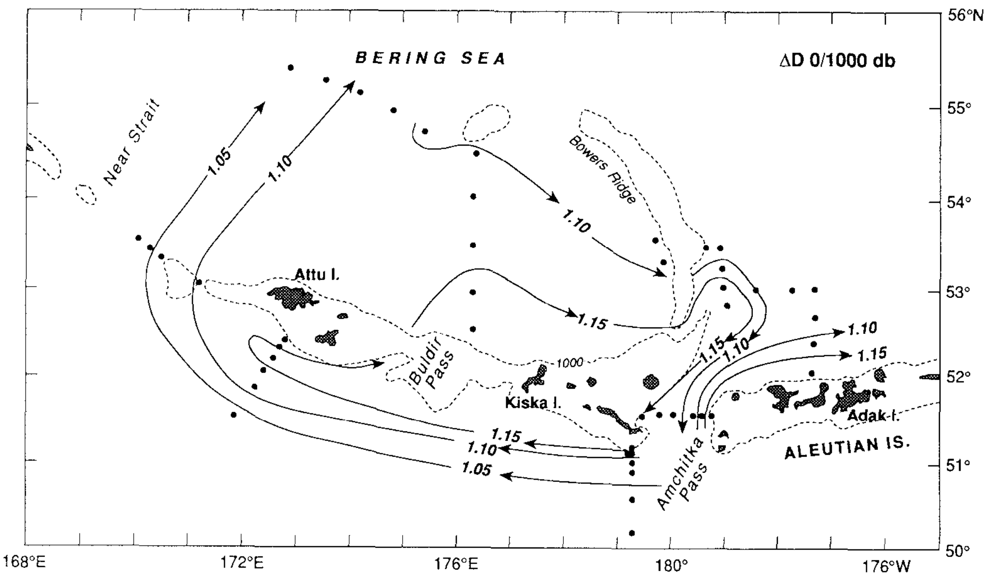

Figure 3. Geopotential topography of the sea surface (in dyn m), referred to 1000 db, 13–25 September 1992.

had 4°C water below 200 m. In the Bering Sea, station 26 (northwest of Kiska Island) had relatively warm subsurface water, as did stations 8, 9, and 58 (east of Bowers Ridge), station 2, and the stations in Amchitka Pass. The distribution in Figure 2 thus indicates typical Alaskan Stream waters south of the Aleutians with extensions into some areas of the Bering Sea.

The Alaskan Stream also typically has low surface salinity, frequently $<32.6‰$. During this cruise, however, only the stations offshore of Amchitka Pass and one site in the pass (station 12) had surface waters $<32.6‰$. It is unclear why this low-salinity feature did not extend westward, unless perhaps eastward winds caused an offshore deflection of the near-surface waters.

4. Geostrophic flow

Figure 3 shows the geopotential anomaly of the sea surface, referred to 1000 decibars (db). It must be stressed that significant baroclinic structure exists below 1000 db in this region (Reed, 1984; Warren and Owens, 1988), but this surface does show the proper direction and relative intensity of flow. Furthermore, it is about the deepest common level that can be used in the passes to show continuity of flow over the entire area.

A relatively intense westward flow was present off Amchitka Pass; it continued westward off Attu Island and northward through Near Strait into the Bering Sea, weakening along its path. An interesting feature is the reversal in direction of the

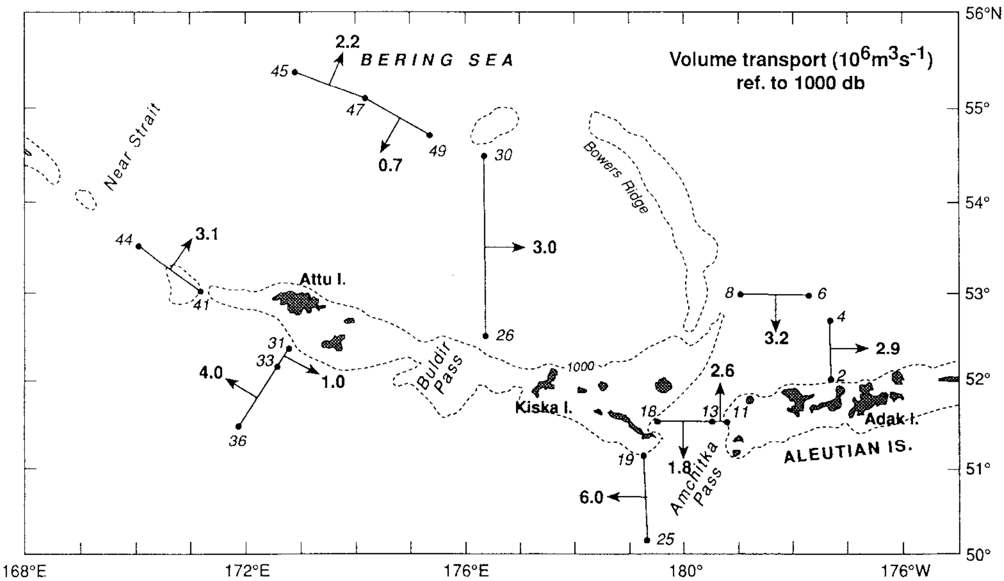

Figure 4. Volume transport (10^6 m^3 s^{-1}), referred to 1000 db, 13–21 September 1992.

inshore waters off Attu Island, with the suggestion of movement through Buldir Pass (sill depth 640 m; Favorite, 1967). This flow then seemed to continue eastward through a break in Bowers Ridge near 52.5N before moving northward along the eastern side of the ridge and then southward and through the western side of Amchitka Pass. (The flow between station 8 and station 9, in a depth of 600 m, was northward.) Finally, there was northward flow on the eastern side of Amchitka Pass and eastward flow near Adak Island. The maximum surface geostrophic speed, referred to 1000 db, was 48 cm s^{-1} between stations 21 and 22. The circulation pattern during this cruise, especially the continuous westward flow south of the Aleutians with an extension into the Bering Sea, was quite different from that in August 1991 (Stabeno and Reed, 1992).

Geostrophic volume transport referred to 1000 db is shown in Figure 4. The results are generally consistent and reasonable. The section south of Attu Island probably did not cross the offshore boundary of the flow. Since we did not operate in Russian waters, the northward flow in Near Strait is likely also deficient, and the existence of Stalemate Bank (near 53N, 171E), with depths < 100 m, may also affect the results. The eastward flow (3.0×10^6 m^3 s^{-1}) northwest of Kiska Island is larger than the combination of inflow through Buldir Pass (1.0×10^6 m^3 s^{-1}) and flow between stations 47 and 49 (0.7×10^6 m^3 s^{-1}). The southward flow between stations 6 and 8 (3.2×10^6 m^3 s^{-1}) is essentially the same as its presumed source (the flow between stations 26 and 30) but is larger than the southward outflow (1.8×10^6 m^3 s^{-1}) through Amchitka Pass. The northward flow through Amchitka Pass and the eastward flow near Adak Island are in good agreement.

Table 1. Comparison of upper-ocean volume transports, referred to 1000 db and 1500 db, during 13–20 September 1992.

Stations	(1) Volume transport, referred to 1000 db (10^6 m^3 s^{-1})	(2) Volume transport, referred to 1500 db (10^6 m^3 s^{-1})	Ratio (1)/(2)
2–4	2.9	3.4	0.85
6–8	3.2	4.5	0.71
19–25	6.0	9.6	0.62
26–30	3.0	4.4	0.68
33–36	4.0	6.6	0.61
41–44	3.1	4.5*	0.69

*referred to 1400 db

It is well known, however, that baroclinic structure extends below 1000 db, and even 1500 db, in this region, especially in the Alaskan Stream (Reed, 1984; Warren and Owens, 1988). Table 1 compares computed transport referred to 1000 db and to 1500 db where this is possible. The ratios of transport referred to 1000 db to that referred to 1500 db for stations 2–4, 6–8, and 26–30 are 0.85, 0.71, and 0.68, respectively. (The high value at stations 2–4 may result from its source region, the eastern side of Amchitka Pass, just barely exceeding 1000 m.) The ratios of 1000-db transport to 1500-db transport for the two Alaskan Stream sections are just 0.61 and 0.62, however, which is in agreement with other evidence for deep baroclinic structure in the Stream. Finally, Alaskan Stream transport (referred to 1500 db) on the section just west of Amchitka Pass was weaker in September 1992 (9.6×10^6 m^3 s^{-1}) than in August 1991 (11.1×10^6 m^3 s^{-1}; Stabeno and Reed, 1992).

5. Drifter trajectories

The trajectories of the seven satellite-tracked drifters were strongly influenced by storms after the last date shown (16 October 1992) in Figure 5. Even some of the data used were likely influenced by wind drift and tidal flow and do not solely reflect geostrophic flow.

Drifters 29 and 70 followed the Alaskan Stream flow in Near Strait, although displaced somewhat to the west of the 1.05 dyn m isoline in Figure 3. Drifter 29 also moved across the northern part of the 1.05 and 1.10 dyn m isolines, but this was two–three weeks after the CTD survey. Buoys 11 and 36 moved through Buldir Pass following the flow suggested by the data in Figure 3, with Buoy 11 continuing toward Bowers Ridge. Buoy 36, however, was affected by a small-scale feature just north of the 1000-m isobath. Drifter 35 initially moved westward in the Alaskan Stream; near 173E though it moved south of the Stream, presumably in response to a storm in late September indicated by weather maps, and eventually became influenced by the eastward part of the Stream off Attu Island. Thus it did not continue westward into

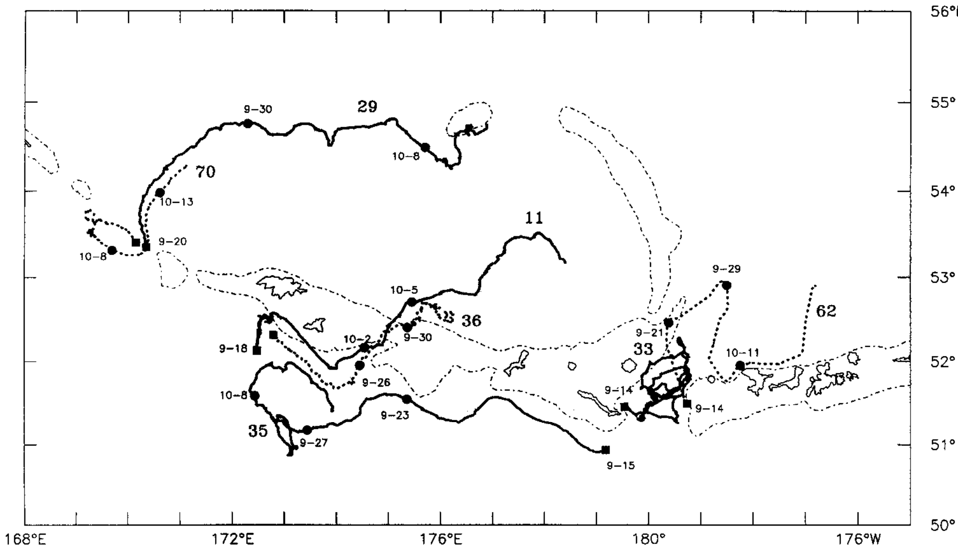

Figure 5. Trajectories of satellite-tracked drifting buoys, 14 September–16 October 1992. The buoy numbers are shown, and selected dates are given.

Near Strait. Drifter 33 was strongly affected by tidal flow in Amchitka Pass and became trapped in a counterclockwise circulation. Drifter 62 initially moved northward, across the southward flow shown in Figure 3, but then did follow the southward flow east of Bowers Ridge and the eastward flow north of the islands.

6. Current time series

Three current moorings in Near Strait (designated B, C, and D; see Fig. 1) were recovered during 19–20 September 1992. They contained velocity, temperature, and salinity time series of 13.1 months duration. We are not aware of any previous Eulerian current measurements in this area. A summary of information on the velocity time series is contained in Table 2.

The bathymetry in the vicinity of the moorings is quite relevant to the flow; the region is complex though, and the different maps are not in good agreement. Our shipboard soundings indicated fairly regular bottom near mooring B. The site at mooring C is a very narrow, steep canyon; the distance between the two 1000-m contours, at its narrowest, is only ~5 km. The site is much more open toward deep water to the north than to the south. Stalemate Bank (near 53N, 171E) is a major shoal; much of the area shown by the 1000-m contour (Fig. 1) is actually less than 100 m. The location of mooring D was on a moderate slope on the northwest side of Stalemate Bank.

Time series plots of current vectors, and temperature at the upper meters, at the three sites are shown in Figures 6, 7, and 8. With the exception of the deepest meters

Table 2. Information on the current moorings, 14 August 1991–17 September 1992. $\overline{KE}$ is the kinetic energy of the mean flow per unit mass, and KE′ is the eddy kinetic energy per unit mass. The standard errors in the net flow (vector mean over the record length), considering the variance, integral time scale, and record length, are at the 95% significance level.

Mooring	Location (N, E)/water depth(m)	Meter depth(m)	Record length (days)	Net flow ($cm\ s^{-1}$, ± std. error, °t)	$\overline{KE}$ ($cm^2\ s^{-2}$)	KE′ ($cm^2\ s^{-2}$)	KE′/$\overline{KE}$
B	53–02,	130	400	6.6 ± 3.2, 020	22	113	5.1
	171–37/	250	400	5.9 ± 2.2, 013	17	61	3.6
	708	400	400	5.8 ± 1.4, 345	17	27	1.6
		550	160	10.4 ± 1.5, 337	54	13	0.2
C	53–04,	130	400	2.1 ± 3.1, 112	2	116	58.0
	171–15/	280	400	1.5 ± 2.8, 067	1	94	94.0
	1494	480	400	2.7 ± 2.4, 009	4	53	13.2
		730	400	6.4 ± 3.8, 007	21	66	3.1
		980	400	7.6 ± 6.1, 358	29	122	4.2
D	53–20,	125	400	7.9 ± 3.7, 025	31	124	4.0
	170–30/	275	400	7.1 ± 2.9, 028	25	91	3.6
	1040	500	400	6.6 ± 2.2, 009	19	59	3.1
		750	166	4.3 ± 1.0, 342	9	13	1.4

at B and D, there was considerable variation in current direction; there was also appreciable variability in magnitude in all records. At each site, flow was well correlated in the vertical in the alongstream direction (correlation coefficients >0.7; $>99\%$ significance level), with the major exception being between the bottom and upper two meters at C (correlation coefficients 0.5–0.6).

Mooring B (Fig. 6) generally had the weakest flow, although not the smallest record-length net flow, which was northward (Table 2). At B flow was mainly northward from October 1991 through April 1992, when it became very weak and variable in direction. The temperature at 130 m was >4°C from mid-October 1991 until mid-January 1992, which suggests the presence of Alaskan Stream water then.

Mooring C (Fig. 7) had both relatively strong northward and southward flow. Although much of the time flow at C was stronger than at B, the net flow at C was statistically insignificant at the upper two meters and was strongest at the bottom (Table 2). (Obviously, the directions for these two meters are not meaningful.) During the first 8 mo, the flow at 980 m was northward and was >15 cm s^{-1} much of the time. It was also clearly greater than anywhere above it. During the last 5 mo (with generally southward flow), this tendency was less apparent. Water warmer than 4°C at 130 m was present during almost the same time as at B, but warm water was also present at the end of the record in agreement with Figure 2.

Several tests were conducted on the bottom two meters at C because of the surprisingly strong flow at depth. There were no problems with the bearings, which

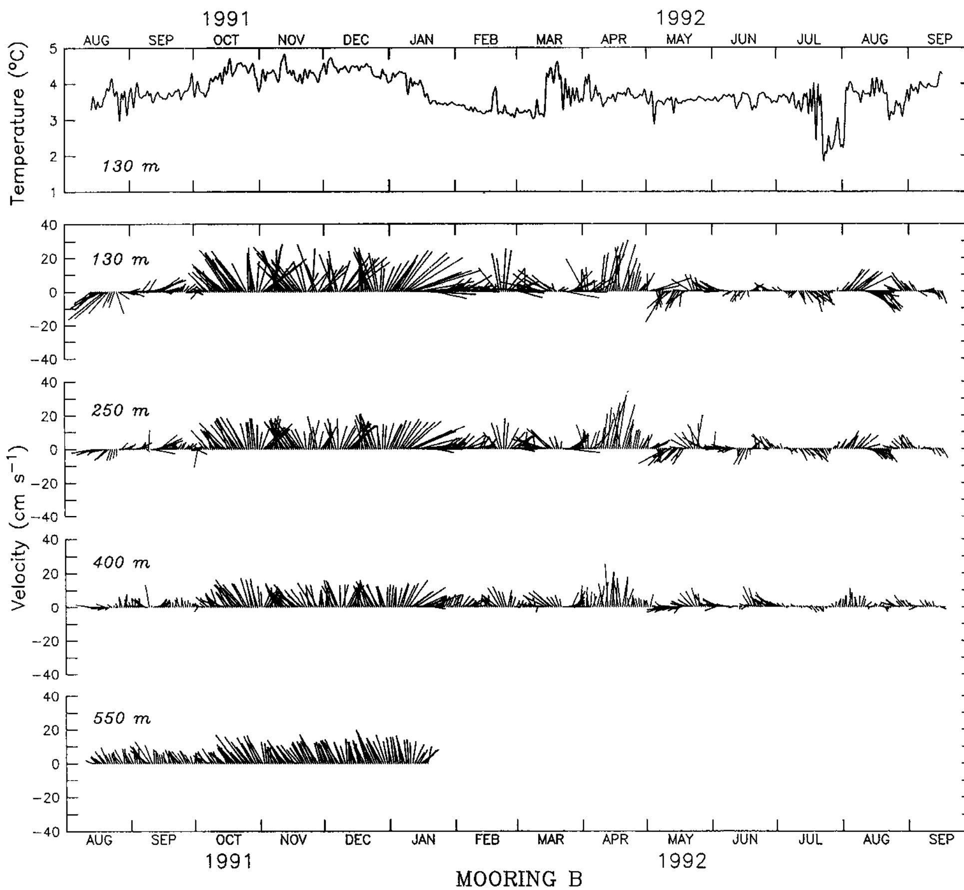

Figure 6. Daily net current vectors and temperature at 130 m (after use of a 35-hr filter) at mooring B, 14 August 1991–17 September 1992.

can cause overspeeding (Reed *et al.,* 1991), and we are convinced that the meters performed properly. The fact that the deep northward flow was relatively stronger than the southward flow may have resulted from the constricted isobaths to the south, as noted above. Velocity spectra showed statistically significant peaks at the period of the lunar fortnightly tide for the bottom two records at C and the bottom record at B but not elsewhere. We suspect that the relatively strong net flows in these three records result from interaction or rectification of the relatively strong tidal current ($\sim$20 cm s^{-1}) by local bathymetry (Magnell *et al.,* 1980). Schumacher and Reed (1992) found a similar bottom-intensified feature in Pribilof Canyon in the eastern Bering Sea.

The data at mooring D (Fig. 8; Table 2) are more suggestive of typical baroclinic flow (decreasing toward the bottom) than at the other two sites. The flow was weak and variable through December 1991, but after then was generally northward until

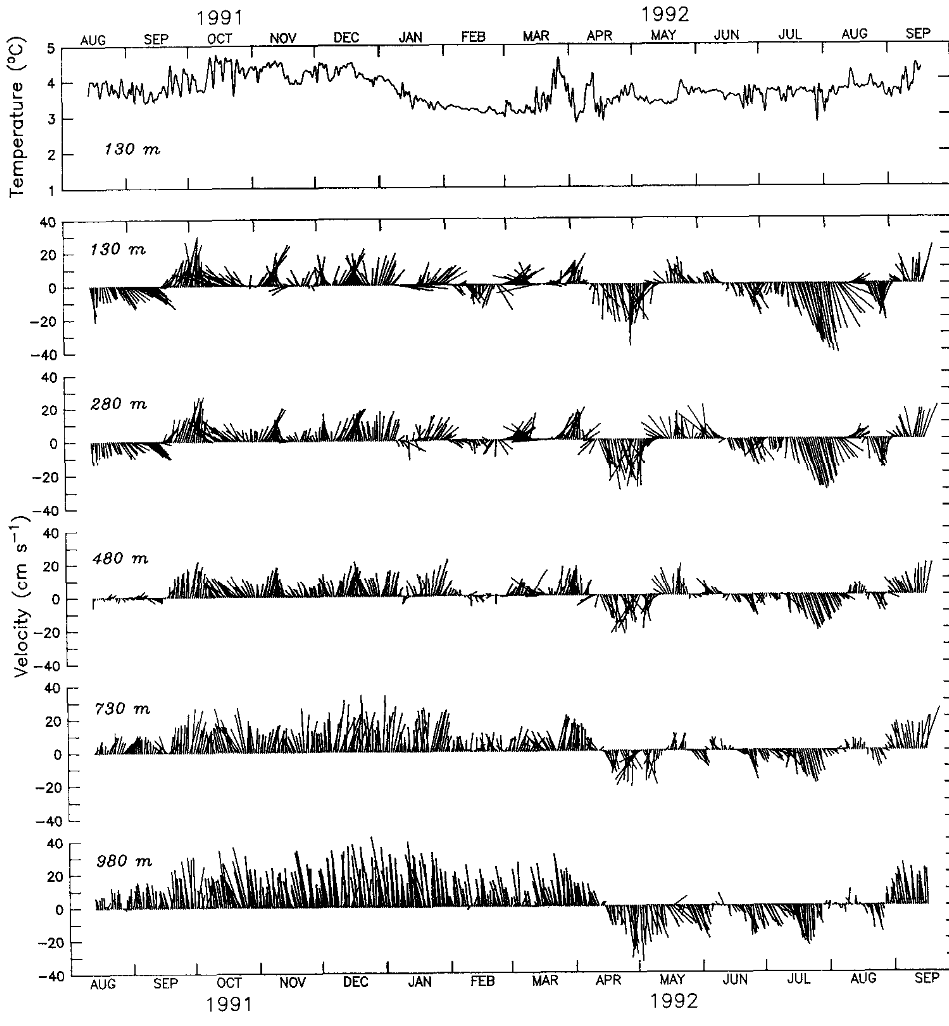

Figure 7. Daily net current vectors and temperature at 130 m (after use of a 35-hr filter) at mooring C, 14 August 1991–17 September 1992.

the end of the record. During the last three months northward flow was often >20 cm s^{-1}. During October–December 1991, temperature at 125 m was >4°C but generally was not at other times. This is curious because flow at D then was quite weak and is not suggestive of Alaskan Stream inflow. (It may be, however, that some of the warm water at C intruded around Stalemate Bank to D.) During our September 1992 survey, the offshore (relatively cold) region of the Alaskan Stream was at the site, and temperatures at the mooring were <4°C.

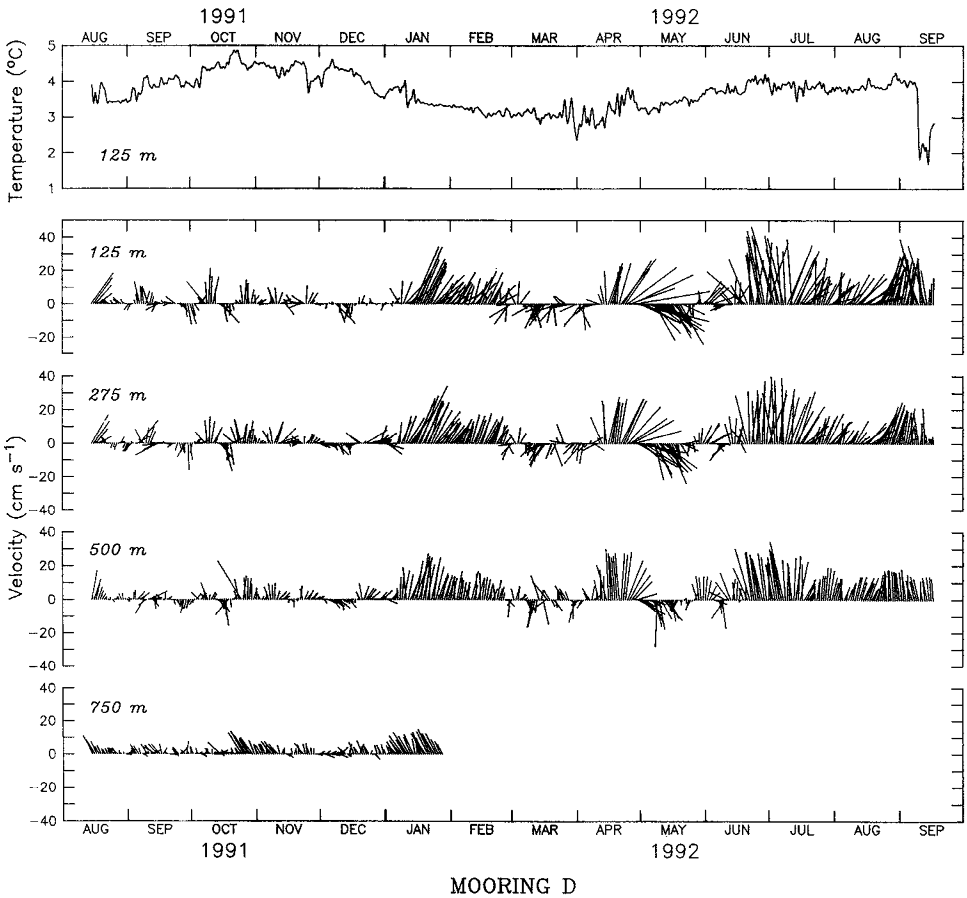

Figure 8. Daily net current vectors and temperature at 125 m (after use of a 35-hr filter) at mooring D, 14 August 1991–17 September 1992.

In summary, northward flow, and relatively warm water (> 4°C) at 130 m, at B and C was present from mid-October 1991 until mid-January 1992, which suggests that Alaskan Stream water was at these sites. (It is not clear from the temperature records when Stream inflow ceased at B and C though because winter cooling affected temperatures at 130 m.) At D, northward flow started in January 1992, without the occurrence of relatively warm water as noted above. Thus the Alaskan Stream seems to have first appeared on the eastern side of Near Strait (east of Stalemate Bank at B and C) in October 1991. In January 1992, the Stream inflow seems to have moved laterally westward to site D. Another interpretation is possible, however. It may be that the Stream was split prior to January 1992, with the offshore part moving westward, as during the circulation anomaly (Stabeno and Reed, 1992), rather than into Near Strait. The subsequent disappearance of Stream waters at B in spring 1992 might be related to the eastward movement of the inner, warm waters off Attu Island as in Figure 3.

The record-length ratios of eddy to mean kinetic energy ($KE'/\overline{KE}$; Table 2) are >1 at all levels and sites except for the short record at 550 m at B. There are segments of the records with fairly steady flow, however, such as September 1991–February 1992 at 730 and 980 m at C and June–September 1992 (at all levels) at D. This latter segment seems to be Alaskan Stream flow and has similar low values of $KE'/\overline{KE}$ to those measured far upstream (Reed and Stabeno, 1989; Reed *et al.*, 1991). The Stream, however, is not present at any of the sites throughout the record.

7. Conclusions

An anomalous circulation existed in this region during much of 1991. That is, no pure Alaskan Stream water flowed through Near Strait; instead, the Stream moved to the south off Attu Island and then turned east (Stabeno and Reed, 1992). An unusual Stream path was first evident from a drifter trajectory in December 1990, but the anomaly is thought to have started earlier. Verkhunov and Tkachenko (1992) reported results from two cruises in the western Bering Sea off Russia that showed a weak Kamchatka Current in fall 1990, compared to spring 1990. We suspect this condition resulted from weak inflow to the Bering Sea through Near Strait that likely started in summer 1990 and lasted more than a year. The anomaly was thought to result from an inertial effect on the Stream rather than from wind stress (Stabeno and Reed, 1992).

Our data in September 1992 indicate an Alaskan Stream inflow through Near Strait of $\sim 5 \times 10^6$ m^3 s^{-1}. In addition, $\sim 1 \times 10^6$ and $\sim 3 \times 10^6$ m^3 s^{-1} flowed northward through Buldir and Amchitka passes, respectively. Thus the net inflow to the Bering Sea was $\sim 7 \times 10^6$ m^3 s^{-1}, since $\sim 2 \times 10^6$ m^3 s^{-1} flowed southward on the western side of Amchitka Pass. The Near Strait inflow during our cruise was smaller than the estimate (10×10^6 m^3 s^{-1}) derived by Favorite (1974), but the Stream transport off Amchitka Pass was rather weak also.

The data from our current moorings suggest that the circulation anomaly ended, and Alaskan Stream inflow through Near Strait started, in October 1991. The inflow initially occurred on the eastern side of the Strait. During January 1992 Stream flow appeared in the central strait (west of Stalemate Bank) and was especially steady and strong from June 1992 until the end of the record. The flow through Near Strait seems not to be bounded and may migrate laterally. This behavior results in relatively high eddy to mean kinetic energy ratios unlike in upstream regions of the Alaskan Stream (Reed and Stabeno, 1989).

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