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A Recent Full-Depth Survey of the Alaskan Stream

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We examine results from a cruise in May 1997. CTD casts to near the bottom were made south of the Aleutian Islands, across Amchitka Pass, and north of the islands. We computed a westward geostrophic speed of 123 cm s^{-1} at 173.5°W in the Alaskan Stream. The computed volume transport there, referred to the bottom, was 25 × 10^{6} m^{3}s^{-1}. On other similar sections, transports were 8–15 × 10^{6} m^{3}s^{-1}. Various complex variations in geopotential height along the Stream apparently altered the cross-stream gradients, and hence the transports. Rotational tendencies were also present. Northward inflow through Amchitka Pass was quite strong (6 × 10^{6} m^{3}s^{-1}). Data north of the islands supported the existence of a zero-velocity reference level of variable depth.

Keywords:
· Alaskan Stream,
· geostrophic flow,
· Defant's method,
· volume transport,
· deep water properties.

1. Introduction

The swift, narrow Alaskan Stream (Favorite, 1967) flows westward just south of the Alaska Peninsula and Aleutian Islands. It is the northern boundary of the cyclonic subarctic gyre. It has become apparent over the last two decades that substantial mass transport exists below the upper kilometer in the Alaskan Stream south of the Aleutian Islands (Favorite *et al*., 1976; Reed, 1984; Warren and Owens, 1988). Hence some sampling to near the ocean bottom is needed to derive total transport, its continuity, and its variability. Specifically, sampling by Reed (1984) to 3000 m, west of 170°W, indicated appreciably larger transports than those referred to 1500 m. Similar results were obtained by Warren and Owens (1988) and Ohtani *et al*. (1997). These previous studies cited suggest transports referred to 1500 m of roughly 12 × 10^{6} m^{3}s^{-1} and transports referred to 3000 m or the bottom in the range 20–30 × 10^{6} m^{3}s^{-1}. Finally, it does not appear that there is any significant seasonal change in Alaskan Stream transport (Favorite *et al*., 1976; Reed *et al*., 1980; Cummins, 1989). That is, baroclinic transport does not spin up in winter in concert with wind-stress curl.

The results presented here are from an attempt to derive total transports along the Stream during a single cruise, 18–30 May 1997, aboard R/V *Wecoma* (operated by Oregon State University). Five full-depth hydrocast sections were taken across the Alaskan Stream west of ~158°W. Sections were also made across passes near 172°W and 180°, and additional sampling was carried out north of the islands (see Fig. 1).

CTD (conductivity/temperature/depth) casts were made with a Seabird 911 plus system, with dual temperature and salinity sensors, to a maximum depth of 6800 m. The CTD was usually lowered to about 25 m above bottom with the aid of an altimeter. Salinity samples were drawn and analyzed on a laboratory salinometer; a correction to the CTD data of +0.002 (±0.001) was derived. A total of 70 casts were taken (Fig. 1).

2. Geostrophic Flow

Figure 2 shows the geopotential topography of the sea surface, referred to 1000 decibars (db). Westward flow (the Alaskan Stream) is apparent on all CTD sections south of the Alaska Peninsula and the Aleutian Islands. In Amchitka Pass (near 180°; depths 1000–1300 m, with a few isolated seamounts), a strong northward flow was present on the eastern side, and a weaker southward branch occurred on the western side. Along the eastern side of Bowers Ridge, there was a weak southward flow. To the east along the north side of the Aleutians, eastward flow occurred as a result of the northward inflow through Amchitka Pass. The gradient of geopotential anomaly across the Alaskan Stream was similar on the two easternmost sections; near 170°W, the gradient was smaller than to the east. At 173.5°W, there was a marked increase in the gradient (and westward flow); at 177.7°W, the gradient was similar to that on the two easternmost sections.

The 0/3000-db dynamic topography is shown in Fig. 3. Its pattern is very similar to the 0/1000-db topography (Fig. 2), but its range south of the Aleutians is slightly less than on Fig. 2 because all of the data are in depths offshore of 3000 m. Figure 3 also shows an eastward flow, whose origin is near Bowers Ridge, that contributes to the eastward flow north of the islands.

Table 1 shows the maximum computed geostrophic speed, referred to the deepest common level (except for the two north-south sections north of the islands, see below),

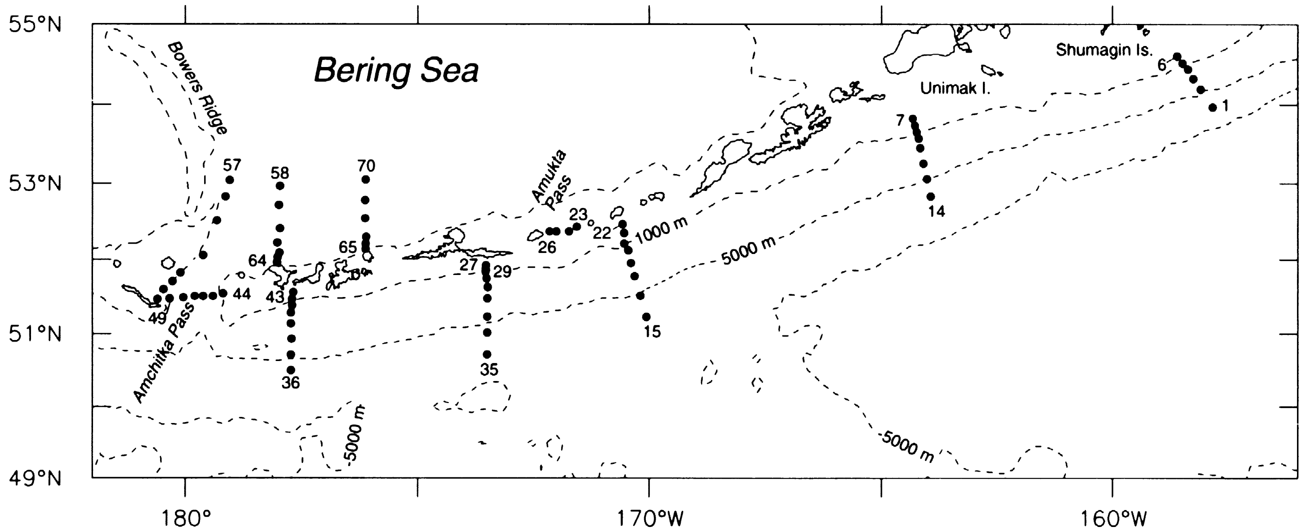

Fig. 1. Location of CTD casts, 18–30 May 1997.

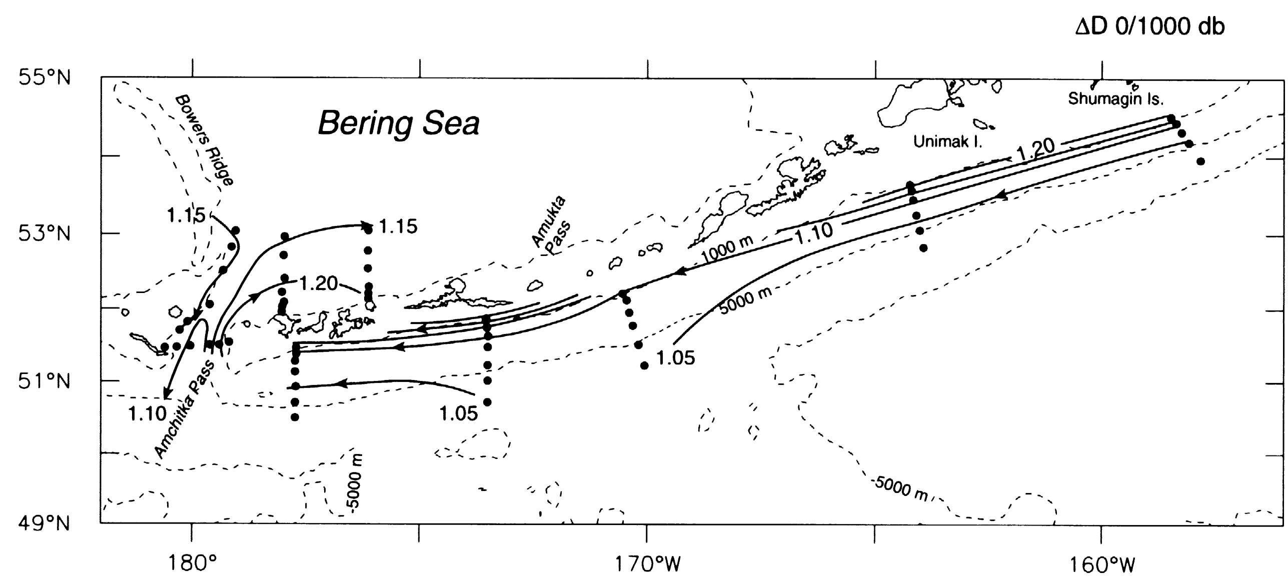

Fig. 2. Geopotential topography (in dyn m) of the sea surface, referred to 1000 db, 18–30 May 1997.

across each CTD section, identified by the end-point stations as shown in Fig. 1. The three easternmost sections had maximum computed speeds, all at the sea surface, between 52 and 66 cm s^{-1} to the southwest. The section at 177.7°W (stations 36–43; Fig. 1) had a peak westward speed, at 150 db, of only 45 cm s^{-1} (Table 1). All of these peak speeds were on the northern side of the Alaskan Stream. The maximum speed in Amchitka Pass was 77 cm s^{-1} northward, between the easternmost two stations. North of the islands, the maximum computed speed was 34 cm s^{-1} eastward. The most striking feature found was the geostrophic speed between stations 29 and 30 at 173.5°W. The speed at 150 db, referred to 1500 db, was 123 cm s^{-1}; the surface speed was 116 cm s^{-1}. In August 1995 at 173.5°W, Reed and Stabeno (1997) found a maximum speed of 112 cm s^{-1} at 100 db, with a surface speed of 70 cm s^{-1}. Both the August 1995 and May 1997 sections had downward sloping (toward the north) density surfaces at 1500 db, which was the deepest common depth and the reference surface used. Since the reference surface was clearly not level, the actual speeds were greater than those computed. Reed and Stabeno (1997) estimated the true maximum speed at ~125 cm s^{-1}; we estimate the maximum speed in the present data set at ~135 cm s^{-1}. These speeds are higher than any previously reported for the

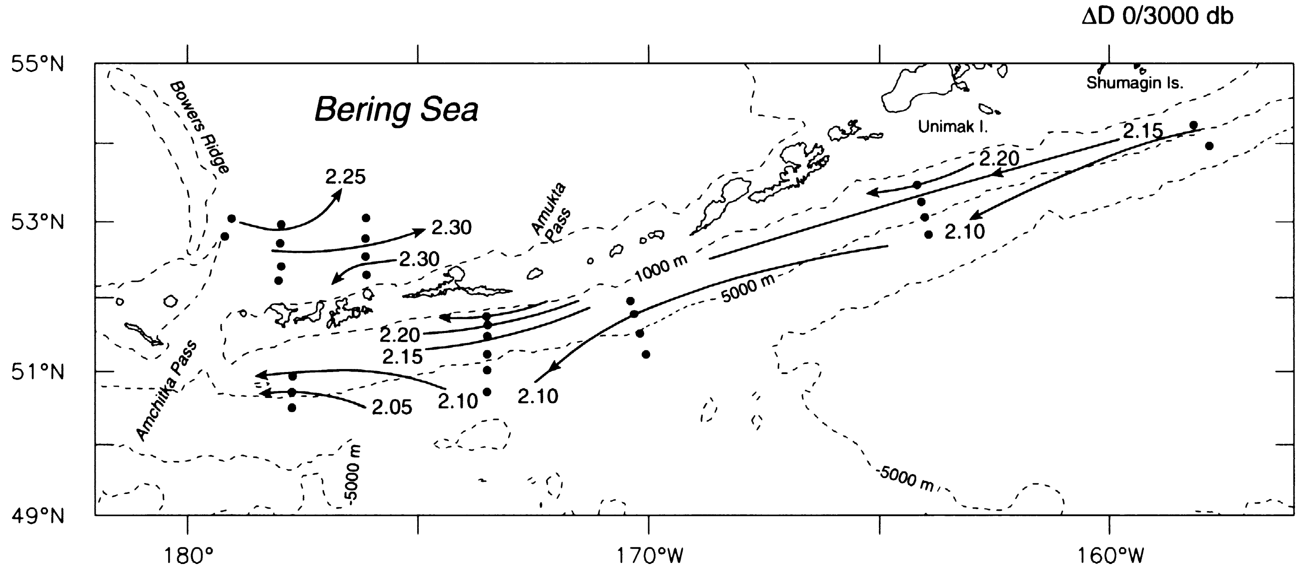

Fig. 3. Geopotential topography (in dyn m) of the sea surface, referred to 3000 db, 18–30 May 1997.

Table 1. Summary of geostrophic flow results near the Aleutian Islands, 18–30 May 1997.

Stations	Volume transport (10^6 m^3s^{-1})				Max. geo. speed
	Above bottom	Above 3000 db	Above 1500 db	Above 1000 db	(cm s^{-1})
1–6	12	12	8	5	66
8–13	11	10	8	6	65
16–20	8	7	3	2	52
23–26	—	—	—	0*	17
29–34	25	23	19	11	123
36–43	15	12	10	6	45
44–49	—	—	—	4	77
57–58	4	4	1	1	—
58–64	8**	8**	6	5	28
58–70	6	6	2	1	—
65–70	4**	4**	2	2	34

*Referred to 300 db.
**Variable reference level (method of Defant).

Alaskan Stream near the central Aleutians (Favorite *et al.*, 1976; Reed, 1984; Ohtani *et al.*, 1997). Also, had our station spacing on the inshore (northern) side of the Stream been greater than the 8–10 km used, peak geostrophic speeds would have been less.

Vertical sections of geostrophic speed at 173.5°W and at ~170°W are shown in Fig. 4. In Fig. 4(a), between stations 29 and 30 (at 173.5°W), speeds exceeded 120 cm s^{-1} between ~80 and 210 db. Speeds were ~20 cm s^{-1} at 1000 db there as well as between stations 30 and 31. In Fig. 4(b) (at ~170°W), between stations 19 and 20, speeds near the surface were relatively weak, and zero-velocity was at 800 db.

3. Volume Transport

The computed volume transports for the various sections on the May 1997 cruise are shown in Fig. 5. Except on the two north-south sections north of the islands, all of the values were derived by using the deepest common levels (near-bottom) as reference surfaces. A summary of the geostrophic transport, identified by the end-point stations used, is given in Table 1.

South of the Aleutian Islands, Alaskan Stream transports on the sections near 158°W and 164°W (Fig. 5) were essentially the same. There was a decrease to only 8×10^6 m^3s^{-1} at ~170°W, however. At 173.5°W, there was a striking increase to 25×10^6 m^3s^{-1}; finally, at 177.7°W there was a

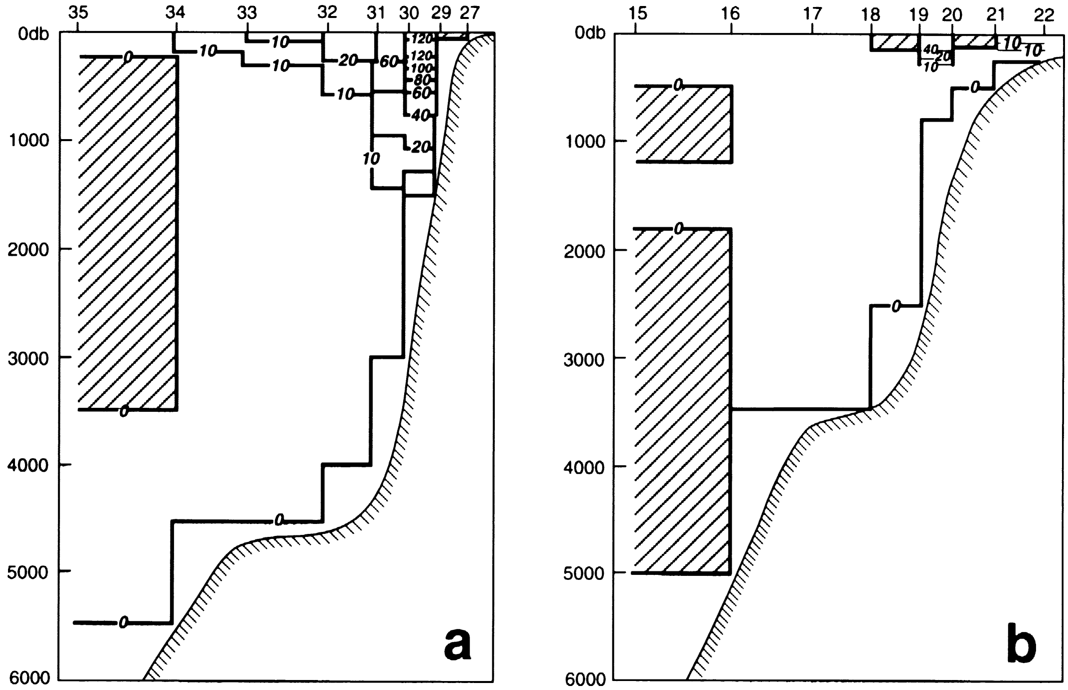

Fig. 4. Vertical sections of geostrophic speed (cm s^{-1}), referred to near bottom along (a) 173.5°W, 24–25 May 1997, and (b) ~170°W, 22–23 May 1997. Hatched areas indicate eastward flow.

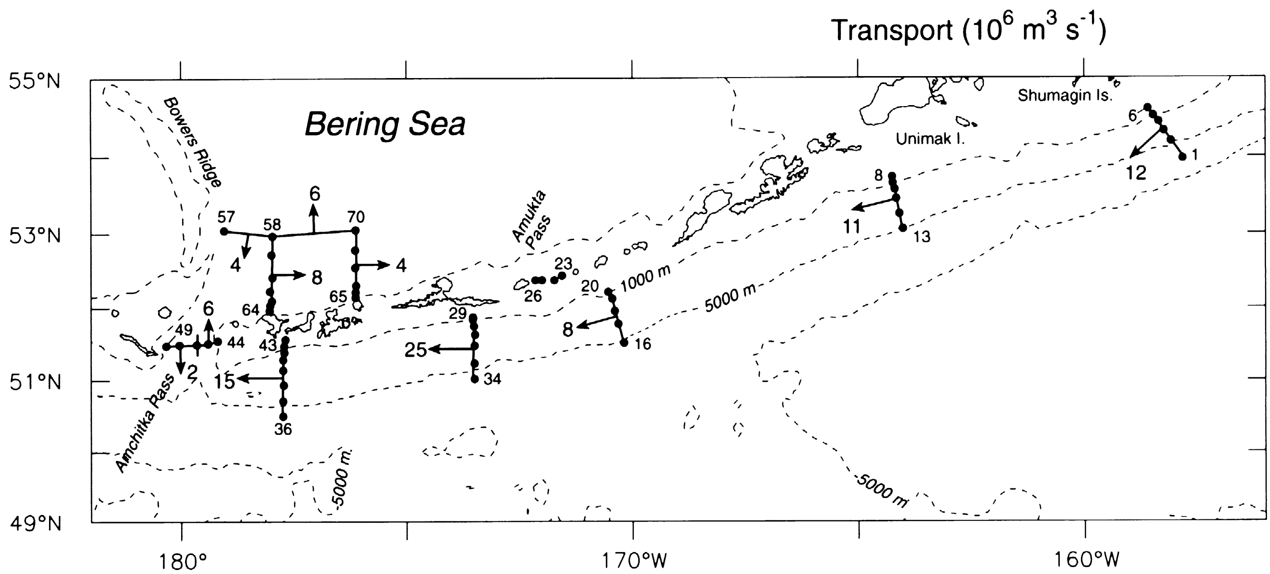

Fig. 5. Computed volume transport (10^6 m^{3}s^{-1}), referred to near bottom, except stations 58–64 and 65–70 where variable reference surfaces were used (see text), 18–30 May 1997.

decrease to 15 × 10^6 m^{3}s^{-1}. Various aspects of the marked spatial changes in Alaskan Stream transport will be discussed in detail below. The two easternmost sections here (at ~158 and ~164°W) have relatively small transports, much like from casts taken to 3000 m in summer 1981 (Reed, 1984). The value of 25 × 10^6 m^{3}s^{-1} at 173.5°W is between the results of Reed (1984; ~20 × 10^6 m^{3}s^{-1}) and Warren and Owens (1988; 28 × 10^6 m^{3}s^{-1}). The time series at 180° by Ohtani *et al.* (1997) gave 26 ± 4 × 10^6 m^{3}s^{-1}. The unusual results from our data are the small values at ~170°W (8 × 10^6 m^{3}s^{-1}) and at ~177.7°W (15 × 10^6 m^{3}s^{-1}).

The northward inflow through Amchitka Pass was 6 ×

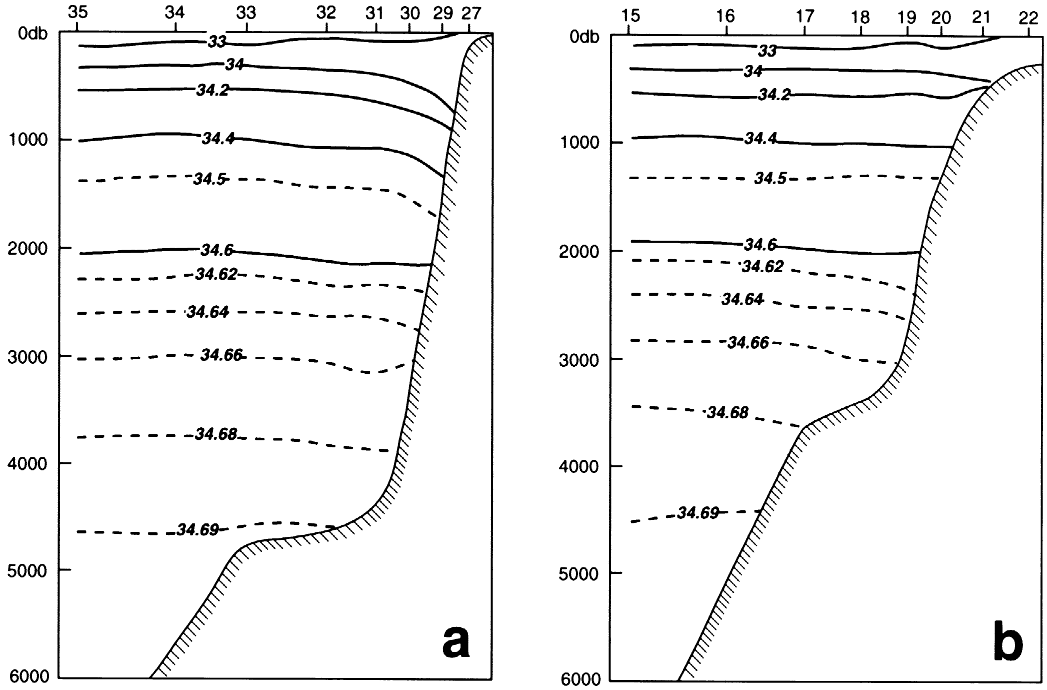

Fig. 6. Vertical sections of salinity along (a) 173.5°W, 24–25 May 1997, and (b) ~170°W, 22–23 May 1997.

10^6 m^3s^{-1}; this is the largest yet observed across this narrow section of the pass (Reed and Stabeno, in press). Part of this flow (2×10^6 m^3s^{-1}) retroflected back to the south, however, for a net flow of 4×10^6 m^3s^{-1} (Fig. 5). This flow, combined with the 4×10^6 m^3s^{-1} between stations 57 and 58, is in agreement with the computed eastward flow (8×10^6 m^3s^{-1}) across 178°W. The Amchitka Pass flow (4×10^6 m^3s^{-1}) continued eastward across 176.1°W, although the northward flow (6×10^6 m^3s^{-1}) between stations 58 and 70 was larger than needed to achieve a balance. Transports across 178°W and 176.1°W in the Bering Sea were computed according to the method used by Reed (1995) and Reed and Stabeno (in press). This method selects reference levels between stations in vertical zones of nearly constant horizontal differences of geopotential anomaly and is often termed the method of Defant (see McLellan, 1965). We stress that use of the deepest common levels just north of the Aleutians often yields poor mass conservation along the flow and sometimes transports in the wrong direction (Reed, 1995). On these two sections, the vertical zones sloped from above 1000 m near the Aleutians to >3000 m (near the bottom) offshore. Use of the deepest levels everywhere results in 1×10^6 m^3s^{-1} less eastward transport than in Fig. 5 at 178°W; at 176.1°W, a *westward* transport of 2×10^6 m^3s^{-1} was obtained. It should be stressed, however, that there was no evidence for intermediate levels of no motion south of the Aleutian Islands, and the deepest common levels were used.

4. Water Properties

Figure 6 shows vertical sections of salinity along 173.5°W and along ~170°W. At 173.5°W (Fig. 6(a)) there were strong isohaline slopes across the flow, trending down to the north (right side) from near the surface to ~4000 db, in agreement with the strong westward flow in the Alaskan Stream (see Fig. 4). Figure 6(b), however, shows weak slopes above 2000 db with moderate slopes below. The isohaline surfaces, such as 34.68, were deeper at 173.5°W than at ~170°W, indicating less dense water with higher geopotential at 173.5°W in agreement with Figs. 2 and 3.

Figure 7 presents the horizontal distribution of temperature at 2750 db. As expected, the warmer water at this deep level was in the inshore part of the Stream, except on the section at 177.7°W. Note the existence of two zones of relatively cold water offshore: at 177.7°W and, especially, near 170°W. The warmest water south of the Aleutians was at 173.5°W. North of the islands, the deep water was even warmer than in the Alaskan Stream as a result of much of the deep inflow occurring from the Alaskan Stream at a relatively shallow level (near 2000 m) through Near Strait (Favorite *et al.*, 1976; also Mishima and Nishizawa, 1955, and Ohtani, 1970).

5. Mechanisms

The most striking feature in this data set is the great disparity in Alaskan Stream transport (Fig. 5), especially among the three westernmost sections. Although Reid and

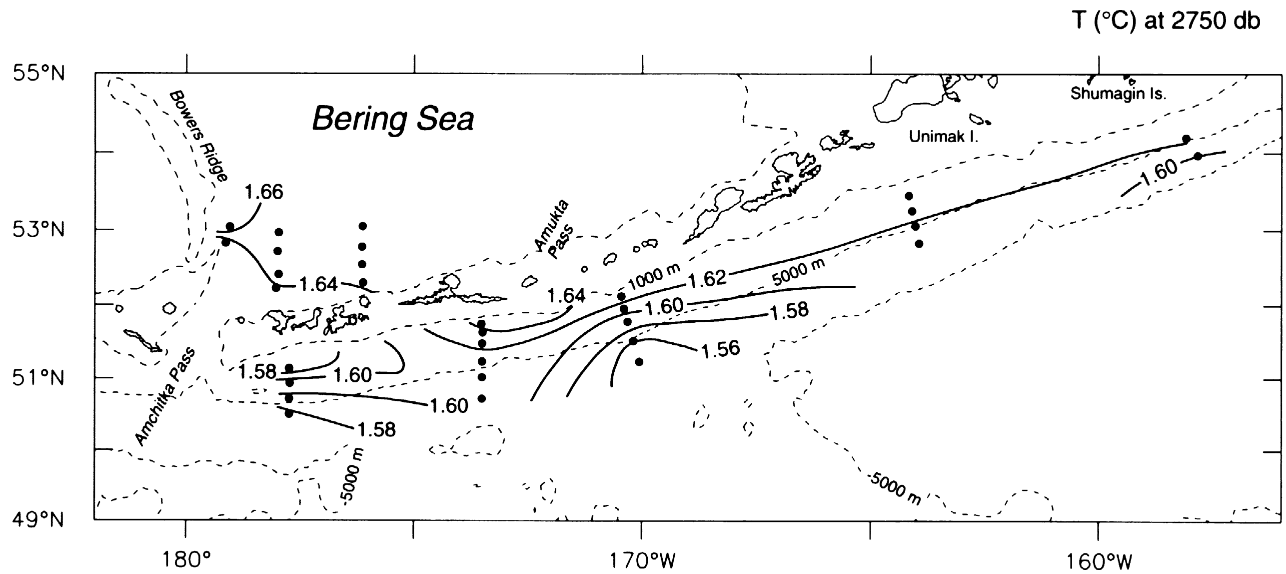

Fig. 7. Temperature distribution (°C) at 2750 db, 18–30 May 1997.

Arthur (1975) showed better developed deep patterns of geopotential anomaly (2000/3000 db, for example) in the western part of the subarctic gyre, and Reed (1984) found greater Alaskan Stream transport toward the west, there is no such consistent pattern in our data. In fact, Table 1 shows that the Stream transports computed above the bottom are only 3–6 × 10^6 m^3s^{-1} greater than the transports computed above 1500 db. These latter transports vary between 3 and 19 × 10^6 m^3s^{-1}, which is greater than the variability shown in Fig. 5. Finally, nearly all of the variability is to the west of 170°W, and the extreme differences can also be seen in the geostrophic speed (Fig. 4) and salinity (Fig. 6) sections.

One could examine transports across the offshore boundary of the Stream between adjacent sections. They were computed above the bottom, and are as follows: stations 1–13, 6 × 10^6 m^3s^{-1} southward; stations 13–16, 10 × 10^6 m^3s^{-1} northward; stations 16–34, 8 × 10^6 m^3s^{-1} southward; and stations 34–36, 10 × 10^6 m^3s^{-1} northward. (See Fig. 5 for locations and comparisons with Stream transports.) These values mainly result from the convoluted offshore boundary of the Stream, as approximated by the 2.10 dyn m isolines in Fig. 3 and the deep offshore isotherms (1.58 and 1.60°C) in Fig. 7. The widely-spaced stations used, however, may not be where the maxima or minima of geopotential actually occurred. Only if there is consistent evidence for an organized inflow or outflow across the southern Stream boundary, as in summer 1959 (Favorite, 1967) or summer 1981 (Reed, 1984), can such calculations across vast distances yield meaningful results. Finally, there is no evidence for significant flow across the inshore Stream boundary, in water depths less than ~300 m, either.

As noted above, most of the variability in Alaskan Stream transport occurred above 1500 db (Table 1). Hence upper-ocean processes must be important. We thus examined satellite altimetry data during 15–25 May 1997 [TOPEX/Poseidon and ERS-2, prepared by R. Leben, University of Colorado, available at http://www-ccar.colorado.edu]. These presentations show anomalies from mean sea surface height between 160°W and 180°. For three of our sections in this region, near 164, 170, and (to a lesser extent) at 177.7°W, there was below normal height near the Aleutians and near-normal height offshore. This would have produced relatively weak westward Stream transport, as observed, at these three locations. At 173.5°W, however, the height anomalies indicate a narrow east-west zone of above normal heights, and thus relatively strong transport, with a strong rotational tendency implied. One feature that was completely missed by our sections was an intense (with a relief of 40 cm) anticyclonic eddy centered near 167°W. The complex, variable structure, with eddy-like features along the Stream, appears to account for our variable transports. Such structure can make efforts to compute transport across the seaward boundary quite dubious.

6. Conclusions

Five full-depth CTD sections were made across the Alaskan Stream in May 1997. Computed peak geostrophic speeds in the Stream varied from 45 to 123 cm s^{-1}. We estimated that the actual maximum speed was ~135 cm s^{-1}, the highest speed reported near the central Aleutian Islands. The computed volume transports varied from 8 to 25 × 10^6 m^3s^{-1}. A scenario that may have produced the transport imbalance was presented. It is interesting that our value of 25 × 10^6 m^3s^{-1} at 173.5°W was similar to the mean of seven deep sections at 180° (taken each June during 1992–1996), reported by Ohtani *et al.* (1997).

The northward inflow of Stream Water on the eastern side of Amchitka Pass was strong, with a peak speed of 77 cm s^{-1} and a transport of 6×10^6 m^3s^{-1}. North of the islands, an eastward flow occurred. A reasonable transport balance was obtained by use of a variable zero-velocity surface, as discussed by Reed (1995).

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