GEOPHYSICAL RESEARCH LETTERS, VOL. 36, L14608, doi:10.1029/2009GL039095, 2009

Freshwater transport from the Pacific to the Bering Sea through Amukta Pass

Carol Ladd[1] and Phyllis J. Stabeno[1]

Received 8 May 2009; revised 12 June 2009; accepted 22 June 2009; published 24 July 2009.

[1] Flow through the Aleutian Passes connects the North Pacific to the Bering Sea and ultimately the Arctic. Moorings spanning the width of Amukta Pass, deployed 2001–2008, allow quantitative assessment of volume and freshwater transports. Volume transport through Amukta Pass averages 4.7 Sv, with maximum transport in January, minimum in September, and a secondary maximum in July. Average freshwater transport through Amukta Pass is $\sim$5800 km^3 yr^{-1} with a seasonal cycle similar to that of volume transport. Combining this estimate with first-order estimates of freshwater transports in the other eastern passes in the Aleutian chain suggests that total freshwater transport is more than five times the cross-shelf flux of freshwater needed to supply transport through Bering Strait into the Arctic. Ongoing measurements in the Aleutian Passes are critical to understanding the influence of these waters on the Bering Sea and the Arctic Ocean. **Citation:** Ladd, C., and P. J. Stabeno (2009), Freshwater transport from the Pacific to the Bering Sea through Amukta Pass, *Geophys. Res. Lett.*, *36*, L14608, doi:10.1029/2009GL039095.

1. Introduction

[2] The extensive ($\sim$1800 km long) Aleutian Island chain separates the Bering Sea from the North Pacific. Exchange between the Pacific and the Bering Sea occurs through 39 passes of which only five have cross-sectional areas greater than 10×10^6 m^2 (Amukta, Amchitka, Buldir, Near, and Kamchatka) [*Favorite*, 1967]. Kamchatka Strait, at the western end of the archipelago, exhibits southward mean flow, while the remaining 38 passes primarily exhibit northward flow. Two currents feed the northward flow through the passes, the Alaska Coastal Current and the Alaskan Stream (Figure 1). The Alaska Coastal Current extends westward to $\sim$170°W feeding the shallow (<100 m deep) passes east of Samalga Pass [*Ladd et al.*, 2005] and supplying water to the eastern Bering Sea (EBS) shelf [*Stabeno et al.*, 2002]. The Alaskan Stream flows westward along the shelf-break south of the Aleutian Islands and feeds the flow through the passes west of Samalga Pass [*Favorite*, 1967], supplying the Aleutian North Slope Current (ANSC) [*Reed and Stabeno*, 1999; *Stabeno et al.*, 2009], an eastward current north of the Aleutians. The Bering Slope Current (BSC) [*Johnson et al.*, 2004; *Kinder et al.*, 1975] flowing northwestward along the EBS shelf break, is a continuation of the ANSC. The BSC is the source of cross-shelf exchange that influences water properties on the EBS shelf. Cross-shelf exchange and inflow from the Pacific via the eastern Aleutian Passes (primarily Unimak) provide the source for fluxes through Bering Strait to the Arctic Ocean.

[3] Freshwater input around the boundaries of the Gulf of Alaska influences salinities far from the source regions. *Favorite* [1967] noted a pronounced surface salinity minimum south of the Aleutian Islands caused by advection of dilute coastal water in the Alaskan Stream. Mean salinity distributions illustrate the continuation of this salinity minimum into the Bering Sea [*Favorite et al.*, 1976]. Fluxes of low salinity water through the Aleutian Passes influence water properties in the EBS and provide a source of freshwater, via cross-shelf exchange, to the EBS shelf and ultimately to Bering Strait. Thus, it is important to quantify the transport of volume and freshwater through the passes and to examine variability in these transports. Due to the relative wealth of data in Amukta Pass, a careful analysis of volume and freshwater fluxes in that pass includes the influence of seasonality and stratification. Estimates for the remainder of the eastern archipelago are also discussed.

2. Methods

2.1. Moorings

[4] Moorings have been deployed in Amukta Pass at four sites from May 2001 through September 2008 (with some gaps; see Figure 2). The first two years of data, along with details of the deployments, were discussed by *Stabeno et al.* [2005]. The moorings each include a 75 kHz ADCP to measure velocities throughout the water column and a SeaBird MicroCat at 6 m above bottom to measure temperature and salinity. The moorings are numbered from east to west (easternmost mooring is AMP1; westernmost is AMP4) (Figure 1). Amukta Pass is $\sim$68 km wide [*Ladd et al.*, 2005] and the four moorings were spaced $\sim$15 km apart across the pass. The radius of deformation has been estimated at 10–20 km [*Reed and Stabeno*, 1997] suggesting that the mooring spacing is marginally sufficient for resolving the horizontal structure of flow through the pass.

[5] To remove tidal variability, the records were low-pass filtered with a Lanczos filter with a half-power point at 35 hours, then subsampled at 6-hour intervals. Transport estimates were calculated from the northward component of velocity. The northward velocity in each ADCP bin was multiplied by cross-sectional area and then summed vertically and horizontally (across the four moorings) to obtain transport through the pass. Seasonal climatologies and standard deviations were estimated from the data by averaging together data from all Januaries, all Februaries, etc. Further details of the mooring deployments, data processing, and transport calculations are given by *Stabeno et al.* [2005].

[1]Pacific Marine Environmental Laboratory, NOAA, Seattle, Washington, USA.

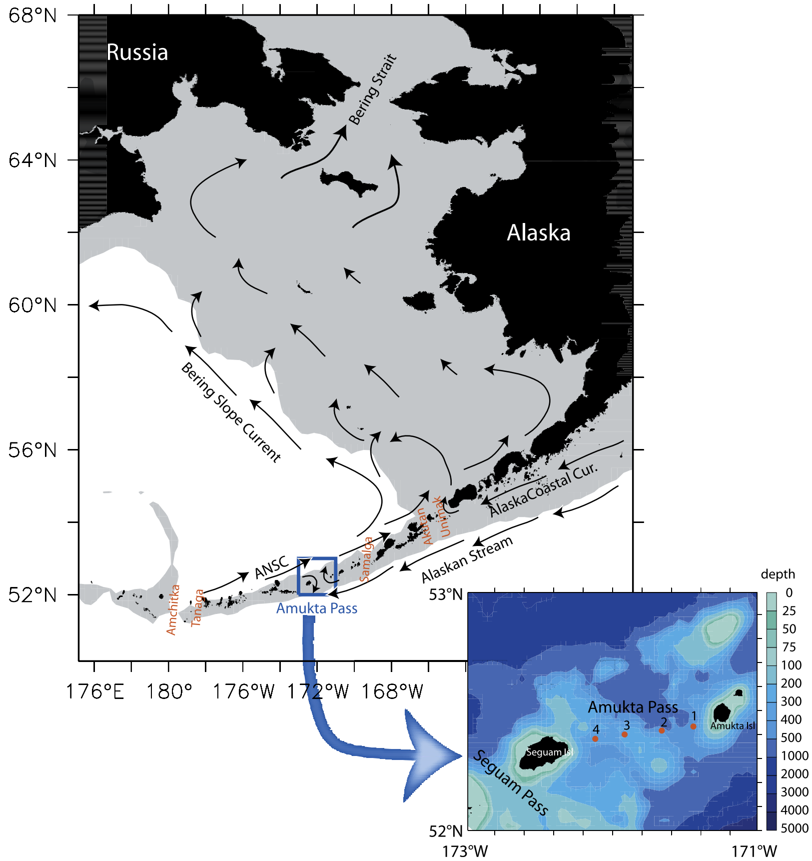

Figure 1. Schematic of circulation in the eastern Bering Sea. Shading indicates depths shallower than 200 m. Inset shows bathymetry of Amukta Pass along with locations of the four moorings (red dots).

2.2. Conductivity, Temperature, Depth (CTD) Transects

[6] A total of 28 CTD transects across Amukta Pass have been sampled between 1992 and 2008, nine of which were discussed by *Reed and Stabeno* [1997]. The depth averaged salinity (33.4) averaged over the 28 casts at the AMP1 location is 0.43 fresher than the annual average bottom salinity from the mooring (Figure 3). All months were sampled at least once except November, December, and January, allowing an incomplete characterization of the annual cycle. Monthly climatologies of salinity were calculated by averaging together all casts taken in a particular month. November, December, and January salinities were estimated via linear interpolation from October and February data.

2.3. Freshwater Flux

[7] The freshwater flux anomaly (hereafter "freshwater flux" or "FW_{flux}") is calculated as

$$FW_{flux} = \int \int_{dzdx} v(x,z) \cdot \frac{(S_{ref} - S(x,z))}{S_{ref}} dx\, dz$$

where $v(x, z)$ is the northward velocity, $S(x, z)$ is salinity, and S_{ref} = 34.8 is the reference salinity following *Aagaard and Carmack* [1989] and *Woodgate and Aagaard* [2005]. While the ADCPs provide measurement of $v(x, z)$ throughout the water column, S is only measured near bottom.

[8] Five methods of using CTD data to estimate $S(x, z)$ were tested: (1) S = 33.4, the depth and time averaged salinity at the AMP1 location (AMP1 accounts for 80% of the volume transport). (2) Time averaged S_{0-200} = 33.2 (salinity averaged over 0–200 m depth) and $S_{200-bot}$ = 33.6 (salinity averaged over 200 m − bottom) were estimated at the AMP1 location. Time averaged volume transports were also estimated for the two layers. (3) Time averaged S_{0-200} and $S_{200-bot}$, v_{0-200}, and $v_{200-bot}$ were estimated for all four locations. (4) Monthly climatology of S_{0-200}, $S_{200-bot}$, v_{0-200}, and $v_{200-bot}$ were estimated at all four locations. (5) $S(x, z)$ was estimated from moored bottom salinity adjusted by −0.43 (as suggested by CTD data; Figure 3). These methods resulted in a tight range of FW_{flux} estimates (5842–6047 km^3 yr^{-1}) indicating that seasonal or spatial (vertical and horizontal) variations in salinity are relatively unimportant to the estimate. Variability in FW_{flux} is primarily determined by variability in volume transport. Time series of FW_{flux} reported below were calculated using method (5).

3. Results

3.1. Volume Transport

[9] *Stabeno et al.* [2005] estimated an average (May 2001–May 2003) northward transport of ~4 Sv (1 Sv = 10^6 m^3 s^{-1}). They found that transport variability on monthly timescales was related to the position and strength of the Alaskan Stream. When the Alaskan Stream weakened

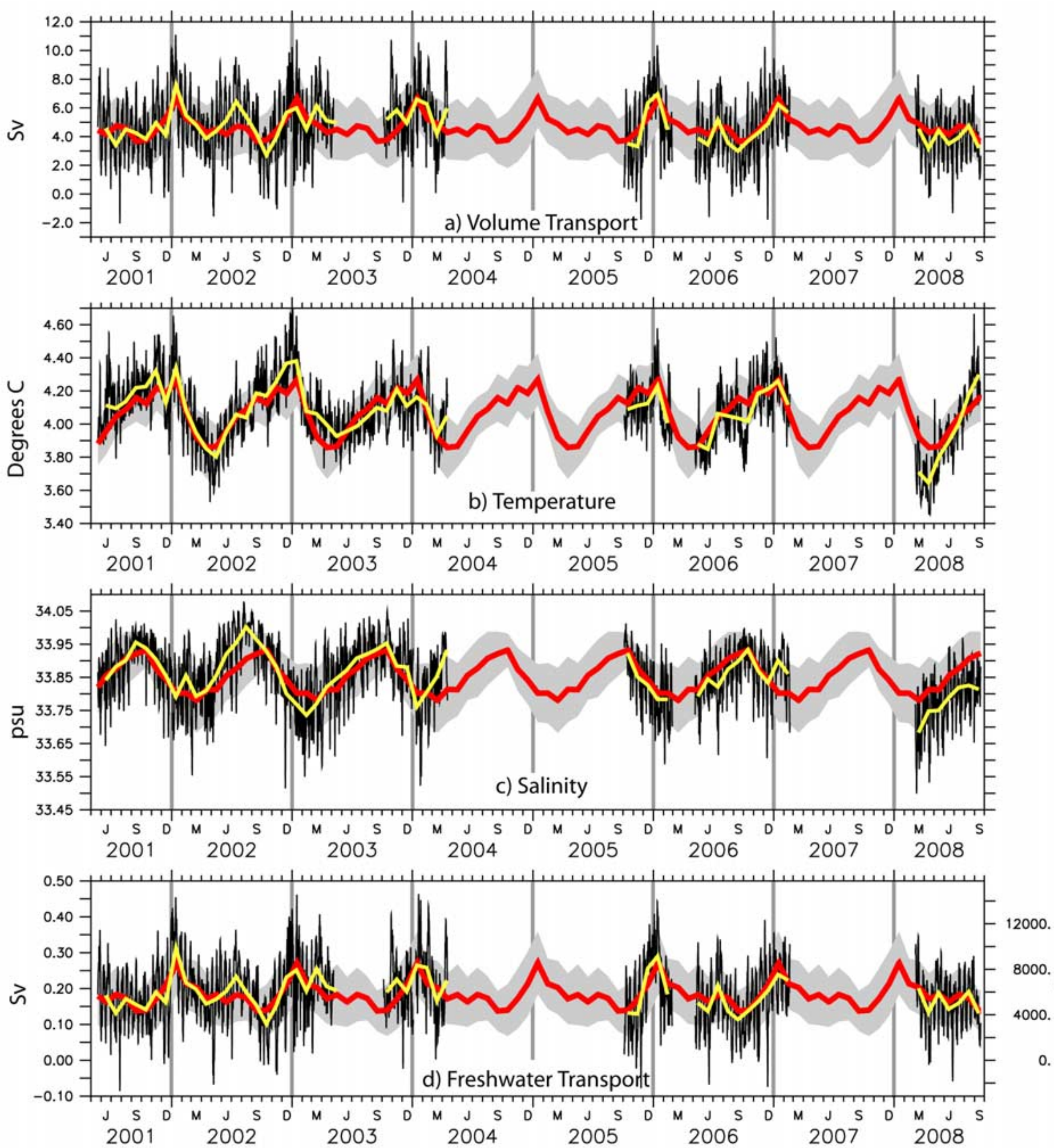

Figure 2. Low-pass filtered time series of (a) volume transport (Sv), (b) AMP1 near bottom temperature (°C), (c) AMP 1 near bottom salinity and (d) freshwater flux (Sv: left axis and $km^3\ yr^{-1}$: right axis) (black). Monthly climatologies (red), monthly averages (yellow), and one standard deviation envelope (gray shading) are also shown. Vertical gray lines denote beginning of each year.

or meandered offshore, transports through Amukta Pass were weaker. Here, we update the analysis of volume transports with data through September 2008. The additional data also allow examination of the seasonal cycle and variability.

[10] Annual average transport is 4.7 Sv (1.9 Sv standard deviation), of which 2.7 Sv (1.3 Sv) is in the top 200 m (Figure 2). Transport is maximum in January, 6.7 Sv (2.0 Sv), and minimum in September, 3.7 Sv (1.5 Sv), with a secondary maximum in July, 4.7 Sv (1.4 Sv). This semiannual pattern is similar to that observed in the ANSC [*Stabeno et al.*, 2009]. Climatological zonal winds are negative (westward) in January and February when volume transport through Amukta Pass is strongest. Zonal winds are maximum (eastward) in August–November when Amukta transport is weakest. A secondary minimum (eastward) in zonal winds occurs in June [*Kistler et al.*, 2001]. The source of inflow into Amukta Pass is the Alaskan Stream (Figure 1). When the zonal wind is positive (eastward), it drives a southward Ekman flux pushing the Alaskan Stream away from the Aleutian Islands, resulting in reduced flow into Amukta Pass. When the zonal wind is negative (westward), the Ekman flux pushes the Alaskan Stream toward the

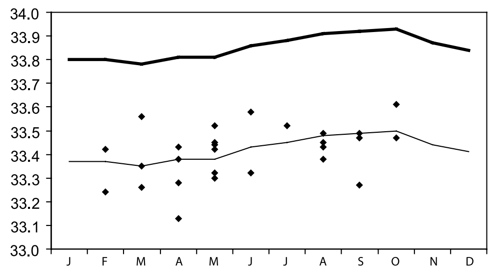

Figure 3. AMP1 moored bottom salinity climatology (bold) and same climatology adjusted by subtracting 0.43 (thin line). Depth averaged salinity from CTD data at the AMP1 location (diamonds).

islands, resulting in enhanced flow through Amukta Pass. This mechanism explains the seasonality of volume transport in Amukta Pass and has been invoked to explain interannual variability in the ANSC [*Bond and Adams*, 2002].

[11] Most of the northward transport through Amukta Pass occurs on the eastern side of the pass. Mean transports calculated from the three eastern moorings (AMP3, 2, and 1) are all northward (0.8, 0.5, and 3.8 Sv, respectively), while the mean transport from the westernmost mooring (AMP4) is southward (−0.4 Sv). Water properties from CTD casts in the western part of the pass are typically significantly saltier, suggesting that this water is generally not a recirculation from the eastern part of the pass. Thus, ~5.1 Sv of northward transport on the eastern side of the pass feeds the ANSC. This transport accounts for the majority of ANSC transport, estimated at ~6 Sv [*Stabeno et al.*, 2009].

[12] Because transport at AMP1 accounts for ~80% of the total transport in Amukta Pass, we show the temperature and salinity from AMP1 only (Figures 2b and 2c). Climatological bottom temperature at AMP1 is maximum in January (4.3°C) and minimum in April (3.9°C); while salinity is maximum in October (33.93) and minimum in March (33.78). From limited CTD data, the seasonal cycle in salinities shallower than 200 m ranges from 32.9 in April to 33.4 in October with no data for November through January.

[13] The seasonal cycle in these water properties is likely due to several factors, including stratification and mixing within the pass and large-scale upwelling/downwelling and its influence on the water properties of the Alaskan Stream. Surface warming and weak winds during the summer enhance stratification, inhibiting mixing as water flows over the abrupt topography of the pass. Thus, colder temperatures and higher salinities at depth are observed during the summer. In the winter, strong winds and surface cooling reduce stratification, enhancing mixing.

[14] The Gulf of Alaska is dominated by strong coastal downwelling during the winter which could lead to fresher salinities and warmer temperatures at depth in the boundary currents. The seasonal cycle of freshwater discharge around the Gulf of Alaska (maximum at the head of the Gulf in October and minimum in February/March [i.e., *Royer*, 2005; *Weingartner et al.*, 2005]) influences the Alaska Coastal Current which flows along the shelf and through the eastern Aleutian Passes (east of 170°W [*Ladd et al.*, 2005]). The influence of freshwater discharge on the Alaskan Stream and the passes west of 170°W is likely minimal. Variability in the Alaskan Stream source waters (properties and transport) may influence the properties observed in the Aleutian Passes on a variety of timescales. However, the scarcity of data collected from the Alaskan Stream makes it difficult to characterize this influence.

3.2. Freshwater Flux

[15] The seasonal cycle in freshwater flux through Amukta Pass (Figure 2d) reflects the seasonal cycle in volume transport. Maximum freshwater flux of 8600 (2800 standard deviation) km^3 yr^{-1} occurs in January and minimum, 4300 (1800) km^3 yr^{-1}, in September. Annually averaged freshwater flux is 5800 (2400) km^3 yr^{-1} (6300 km^3 yr^{-1} for the northward component only). Most of this flux occurs on the eastern side of the pass, with AMP1 accounting for 75% of the northward component (81% of total). Roughly two thirds of the northward freshwater flux (4000 km^3 yr^{-1}) occurs in the upper 200 m of the water column. This layer provides the primary source for on-shelf freshwater fluxes to the EBS shelf.

3.3. Interannual Variability

[16] CTD data suggests that salinities in waters shallower than 200 m have increased in the 2000s as compared to the 1990s by ~0.2. Because observations were not taken during the same time of year in the two periods, this conclusion is tenuous. On the other hand, moored deep salinity was fresher than climatology by ~0.1 during March–September 2008 (Figure 2c). Increased shallow salinity combined with decreased deep salinity implies a recent reduction in stratification.

[17] Volume transport through Amukta Pass also decreased in 2008 (Figure 2a): March–September 2008 transport was ~0.5 Sv smaller than climatology. Increased salinity combined with decreased northward volume transport would result in decreased freshwater flux into the EBS. A volume transport decrease of 0.5 Sv alone would result in ~11% reduction, while an increase of 0.2 in average salinity alone would result in ~14% reduction in freshwater flux. Combining the influence of a 0.5 Sv volume transport decrease with a 0.2 salinity increase results in a decrease of more than 20% in the freshwater flux estimate (from 5800 to 4600 km^3 yr^{-1}). Note that our calculation of freshwater flux (Figure 2d) uses adjusted moored bottom salinity and does not take into account possible changes in stratification.

3.4. Other Passes

[18] Unfortunately, we do not have sufficient data to examine the seasonal cycle or interannual variability of transport or salinity in any other Aleutian Passes. Freshwater flux is estimated for the major eastern and central Aleutian Passes (Table 1) from volume transport estimates from the literature [*Mordy et al.*, 2005; *Reed*, 1990; *Stabeno et al.*, 2005, 2002] and average salinity estimates primarily from data discussed by *Ladd et al.* [2005]. These data are from very limited time periods so the freshwater fluxes are first-order estimates.

[19] The combined input of freshwater for all of the other eastern passes roughly approximates the input through Amukta Pass alone, resulting in a net flux of freshwater to the EBS from the North Pacific of ~11,000 km^3 yr^{-1}. Other

Table 1. Volume and Freshwater Transports Through the Eastern Aleutian Passes

Pass	Volume Transport (Sv)	Average Salinity	Freshwater Flux (km^3 yr^{-1})
Unimak	0.4 [*Stabeno et al.*, 2002]	31.7	1100
Akutan	0.1 [*Stabeno et al.*, 2005]	32.4	200
Samalga	0.4 [*Mordy et al.*, 2005]	32.9	700
Amukta	4.7 (this study)	33.4	5800
Seguam	0.4 [*Stabeno et al.*, 2005]	33.4	500
Tanaga	0.4[a]	33.4	500
Amchitka	2.5 [*Reed*, 1990]	33.9	2000
Total	8.9		10,800

[a]Transport in Tanaga Pass was not measured and is assumed similar to Seguam Pass since the passes are of similar size.

than Amukta Pass, the largest contribution of freshwater to the EBS comes through Amchitka Pass, the deepest of the central and eastern passes (Table 1).

4. Discussion

[20] Estimates of volume and freshwater transport from the North Pacific to the EBS are calculated from almost seven years of mooring deployments in Amukta Pass. Volume transport through Amukta Pass (4.7 Sv net; 5.1 Sv northward) is higher than that estimated for any other eastern/central Aleutian Pass (Table 1) and is higher than previously estimated from more limited data [*Stabeno et al.*, 2005]. Transport through Amukta Pass is roughly comparable to transport estimated for the ANSC/BSC system (~6 Sv [*Stabeno et al.*, 2009]). As Amukta Pass is only ~400 m deep, deeper flow in the ANSC/BSC system must come from elsewhere; probably Amchitka Pass (estimated northward transport of 2–3 Sv [*Reed*, 1990]). This suggests that the ANSC is weak west of Amukta Pass, a conclusion also suggested by drifter data [*Reed and Stabeno*, 1999; *Stabeno and Reed*, 1994].

[21] Flow through the eastern Aleutian Passes supplies the BSC, which in turn supplies water to the EBS shelf. Mass balances suggest that cross-shelf exchange must supply ~0.5 Sv to the shelf from the BSC [*Aagaard et al.*, 2006]. As the source of the shallow part of the BSC, flow through Amukta Pass is the ultimate source of that cross-shelf exchange.

[22] The freshwater flux through Bering Strait has been estimated at 2500 km^3 yr^{-1} ± 300 km^3 yr^{-1} [*Woodgate and Aagaard*, 2005] with significant interannual variability [*Woodgate et al.*, 2006]. From 2001 to 2004, annual mean freshwater flux through Bering Strait increased over 60% with increases in volume transport responsible for ~80% of the increased freshwater flux [*Woodgate et al.*, 2006]. Unfortunately, data in Amukta Pass do not include full calendar years so a comparison of annual means between Amukta and Bering Strait is not possible. However, we see no indication of a trend from 2001 to 2004 in volume or freshwater transport in Amukta Pass.

[23] *Aagaard et al.* [2006] estimate a freshwater budget for the EBS shelf that includes supply of freshwater from cross-shelf transport (~900 km^3 yr^{-1}) and from flow through Unimak Pass (~1100 km^3 yr^{-1}). Our estimate of the supply of freshwater through the eastern/central Aleutian Passes (~11,000 km^3 yr^{-1}) is more than five times that needed to supply the EBS shelf. Freshwater flux through Amukta Pass accounts for roughly half (~5800 km^3 yr^{-1}) of the total flux through the eastern passes. Based on changes in observed volume transport and salinity in Amukta Pass in early 2008, it is estimated that interannual variability may result in fluctuations of freshwater flux of ~20%. Thus, while the observed trend in Bering Strait fluxes between 2001 and 2004 [*Woodgate et al.*, 2006] does not appear to be driven by an increased flux through Amukta Pass, variability in the freshwater flux through Bering Strait may be sensitive to changes in the freshwater flux through the Aleutian Passes in addition to the dynamics of cross-shelf exchange.

[24] Analysis of CTD and mooring data indicates a possible recent decrease in stratification in Amukta Pass. In addition to influencing the supply of freshwater to the EBS, changes in stratification may influence mixing in the passes. Decreased stratification could result in increased vertical flux of nutrients, resulting in higher nutrient input to the euphotic zone of the EBS. Ongoing measurements in the Aleutian Passes are critical to understanding the variability of transports and their influence on the EBS and its ecosystem.

[25] **Acknowledgments.** Many ships have collected data in the Aleutian Passes over the years, but particularly the NOAA Ship *Miller Freeman*. We thank the officers and crew of these ships. Thanks also to D. Kachel and P. Proctor for data processing. Two anonymous reviews resulted in an improved manuscript. Funding for the moorings was provided by Alaska Ocean Observing System and NOAA. Contribution EcoFOCI-N704 to NOAA's Fisheries-Oceanography Coordinated Investigations and 3275 to PMEL.

References

Aagaard, K., and E. C. Carmack (1989), The role of sea ice and other fresh water in the Arctic circulation, *J. Geophys. Res.*, *94*, 14,485–14,498, doi:10.1029/JC094iC10p14485.
Aagaard, K., T. J. Weingartner, S. L. Danielson, R. A. Woodgate, G. C. Johnson, and T. E. Whitledge (2006), Some controls on flow and salinity in Bering Strait, *Geophys. Res. Lett.*, *33*, L19602, doi:10.1029/2006GL026612.
Bond, N. A., and J. M. Adams (2002), Atmospheric forcing of the southeast Bering Sea Shelf during 1995–99 in the context of a 40-year historical record, *Deep Sea Res., Part II*, *49*, 5869–5887, doi:10.1016/S0967-0645(02)00323-5.
Favorite, F. (1967), The Alaskan Stream, *Int. North Pac. Fish. Comm. Bull.*, *21*, 1–20.
Favorite, F., A. J. Dodimead, and K. Nasu (1976), Oceanography of the subarctic Pacific region, *Int. North. Pac. Fish. Comm. Bull.*, *33*, 1–187.
Johnson, G. C., P. J. Stabeno, and S. C. Riser (2004), The Bering Slope Current system revisited, *J. Phys. Oceanogr.*, *34*, 384–398, doi:10.1175/1520-0485(2004)034<0384:TBSCSR>2.0.CO;2.
Kinder, T. H., L. K. Coachman, and J. A. Galt (1975), The Bering Slope Current System, *J. Phys. Oceanogr.*, *5*, 231–244, doi:10.1175/1520-0485(1975)005<0231:TBSCS>2.0.CO;2.
Kistler, R., et al. (2001), The NCEP–NCAR 50-year reanalysis: Monthly means CD-ROM and documentation, *Bull. Am. Meteorol. Soc.*, *82*, 247–268, doi:10.1175/1520-0477(2001)082<0247:TNNYRM>2.3.CO;2.
Ladd, C., G. L. Hunt Jr., C. W. Mordy, S. A. Salo, and P. J. Stabeno (2005), Marine environment of the eastern and central Aleutian Islands, *Fish. Oceanogr.*, *14*, 22–38, doi:10.1111/j.1365-2419.2005.00373.x.
Mordy, C. W., P. J. Stabeno, C. Ladd, S. Zeeman, D. P. Wisegarver, and G. L. Hunt Jr. (2005), Nutrients and primary production along the eastern Aleutian Island Archipelago, *Fish. Oceanogr.*, *14*, 55–76, doi:10.1111/j.1365-2419.2005.00364.x.
Reed, R. K. (1990), A year-long observation of water exchange between the North Pacific and the Bering Sea, *Limnol. Oceanogr.*, *35*, 1604–1609.
Reed, R. K., and P. J. Stabeno (1997), Long-term measurements of flow near the Aleutian Islands, *J. Mar. Res.*, *55*, 565–575, doi:10.1357/0022240973224328.
Reed, R. K., and P. J. Stabeno (1999), The Aleutian North Slope Current, in *Dynamics of the Bering Sea*, edited by T. R. Loughlin and K. Ohtani, pp. 177–191, Univ. of Alaska Sea Grant, Fairbanks.

Royer, T. C. (2005), Hydrographic responses at a coastal site in the northern Gulf of Alaska to seasonal and interannual forcing, *Deep Sea Res., Part II*, *52*, 267–288, doi:10.1016/j.dsr2.2004.09.022.

Stabeno, P. J., and R. K. Reed (1994), Circulation in the Bering Sea basin observed by satellite-tracked drifters: 1986–1993, *J. Phys. Oceanogr.*, *24*, 848–854, doi:10.1175/1520-0485(1994)024<0848:CITBSB>2.0.CO;2.

Stabeno, P. J., R. K. Reed, and J. M. Napp (2002), Transport through Unimak Pass, Alaska, *Deep Sea Res., Part II*, *49*, 5919–5930, doi:10.1016/S0967-0645(02)00326-0.

Stabeno, P. J., D. G. Kachel, N. B. Kachel, and M. E. Sullivan (2005), Observations from moorings in the Aleutian Passes: Temperature, salinity and transport, *Fish. Oceanogr.*, *14*, 39–54, doi:10.1111/j.1365-2419.2005.00362.x.

Stabeno, P. J., C. Ladd, and R. K. Reed (2009), Observations of the Aleutian North Slope Current, Bering Sea, 1996–2001, *J. Geophys. Res.*, *114*, C05015, doi:10.1029/2007JC004705.

Weingartner, T. J., S. L. Danielson, and T. C. Royer (2005), Freshwater variability and predictability in the Alaska Coastal Current, *Deep Sea Res., Part II*, *52*, 169–191, doi:10.1016/j.dsr2.2004.09.030.

Woodgate, R. A., and K. Aagaard (2005), Revising the Bering Strait freshwater flux into the Arctic Ocean, *Geophys. Res. Lett.*, *32*, L02602, doi:10.1029/2004GL021747.

Woodgate, R. A., K. Aagaard, and T. J. Weingartner (2006), Interannual changes in the Bering Strait fluxes of volume, heat and freshwater between 1991 and 2004, *Geophys. Res. Lett.*, *33*, L15609, doi:10.1029/2006GL026931.

C. Ladd and P. J. Stabeno, Pacific Marine Environmental Laboratory, NOAA, 7600 Sand Point Way NE, Seattle, WA 98115-6349, USA. (carol.ladd@noaa.gov)