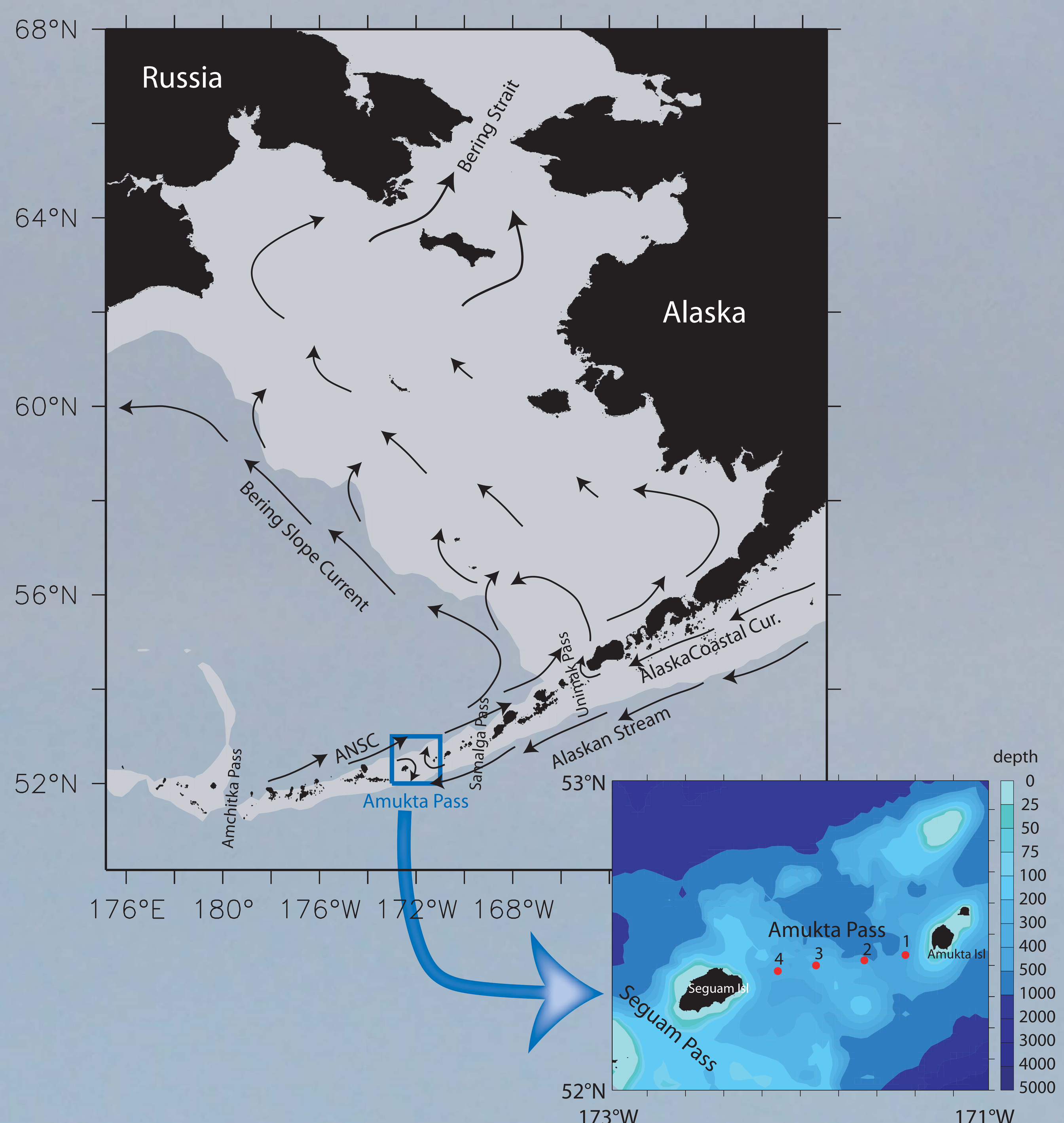

Volume and Freshwater Transports from the North Pacific to the Bering Sea

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The southeastern Bering Sea circulation is dominated by the eastward Aleutian North Slope Current (ANSC) north of the Aleutians and the northwestward Bering Slope Current (BSC) flowing along the eastern Bering Sea shelf break. Cross-shelf exchange from the BSC supplies freshwater to the eastern Bering Sea shelf and ultimately to Bering Strait and the Arctic. Because the Aleutian passes (primarily Amukta Pass) supply the ANSC and the BSC, it is important to quantify the transport of mass and freshwater through the passes and to examine variability in these transports.

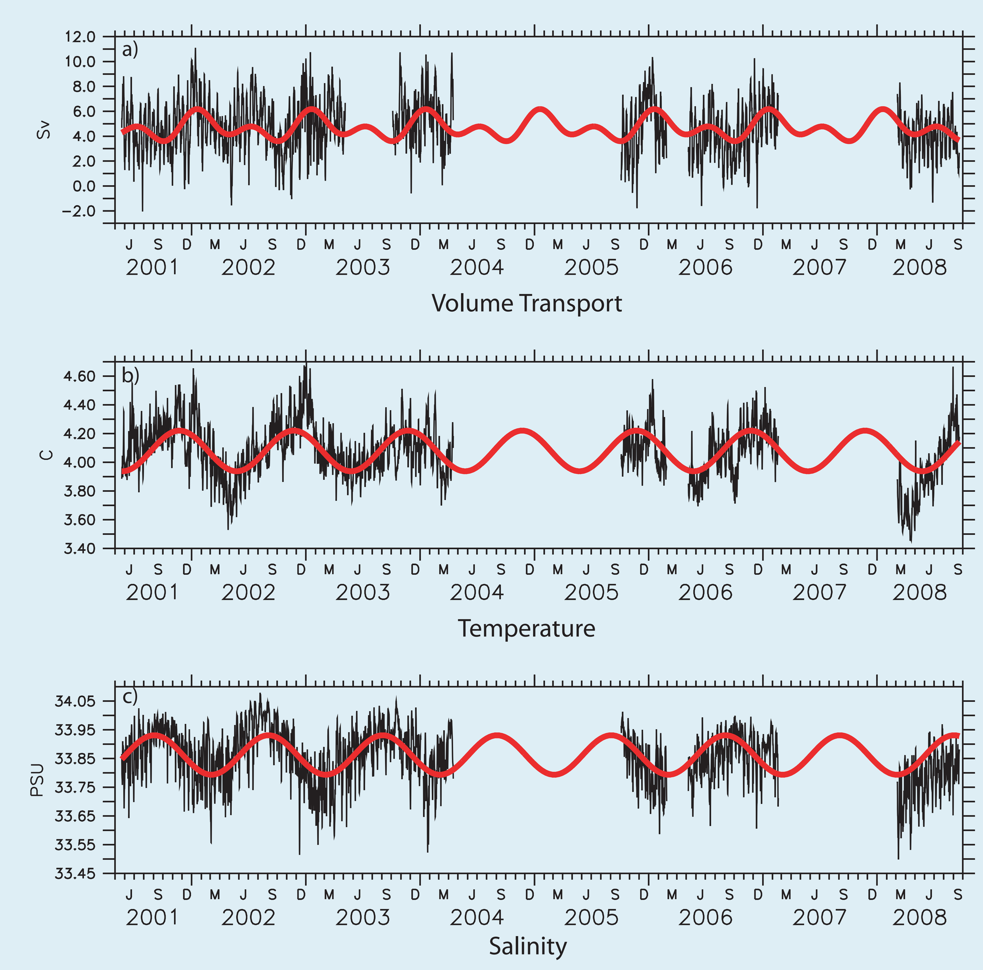
Four moorings, spanning the width of Amukta Pass, have been deployed since 2001. Data from these moorings allow quantitative assessment of the transports through this important pass. In addition, transports through some of the other passes can also be evaluated, although with more limited datasets and higher uncertainty. Variability in transports through the passes is related to the direction of the zonal winds, with westward winds resulting in higher northward transport. Freshwater transport through Amukta Pass alone is large enough to account for the cross-shelf supply of freshwater needed to supply the estimated transport through Bering Strait into the Arctic. Recent data show a decrease in mass transport and a freshening of bottom water in Amukta Pass in 2008. Ongoing measurements in the Aleutian Passes are critical to understanding the influence of these waters on the Bering Sea and the Arctic.

Ecosystems & Fisheries-Oceanography Coordinated Investigations

INTRODUCTION

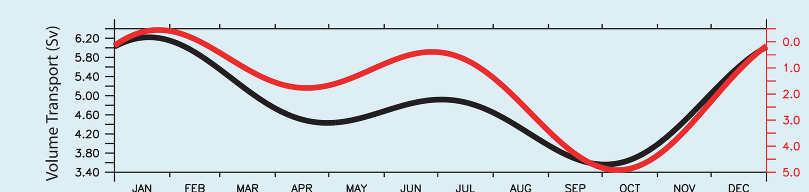
The freshwater flux through Bering Strait has been estimated at 2500 $km^3\ yr^{-1}$ [Woodgate and Aagaard, 2005] relative to a reference salinity of 34.8. Aagaard, et al. [2006] estimate a freshwater budget for the Bering Sea shelf that includes freshwater inflow through Unimak Pass of ~1200 $km^3\ yr^{-1}$, cross-shelf supply of freshwater to the shelf of ~900 $km^3\ yr^{-1}$, precipitation – evaporation of ~80 $km^3\ yr^{-1}$, and runoff of ~320 $km^3\ yr^{-1}$ [Aagaard, et al., 2006; see their Fig. 2]. These numbers sum to balance the flux through Bering Strait.

Because the Aleutian passes supply freshwater to the ANSC and ultimately the BSC, it is important to quantify the transport of volume and freshwater through the passes and to examine variability in these transports. The focus here is on quantifying the volume and freshwater transports through the central Aleutian Passes. Due to the relative wealth of data in Amukta Pass, a careful analysis of volume and freshwater fluxes in that pass will include the influence of seasonality and stratification. Estimates for the remainder of the eastern archipelago are also discussed.

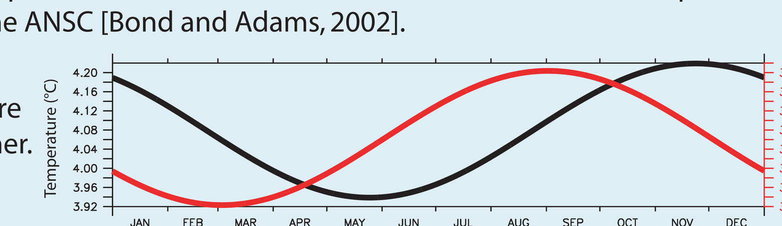


Time series of (a) volume transport (Sv), (b) near bottom temperature (°C), and (c) near bottom salinity in Amukta Pass. Volume transport is calculated from all four moorings (shown as red dots in figure above). Temperature and salinity time series are from AMP1, the easternmost mooring. Annual and semiannual (in the case of transport) harmonics are plotted in red.

Note the anomalies in the 2008 data: volume transport and salinity were anomalously low throughout 2008 while temperature was low early in the year.

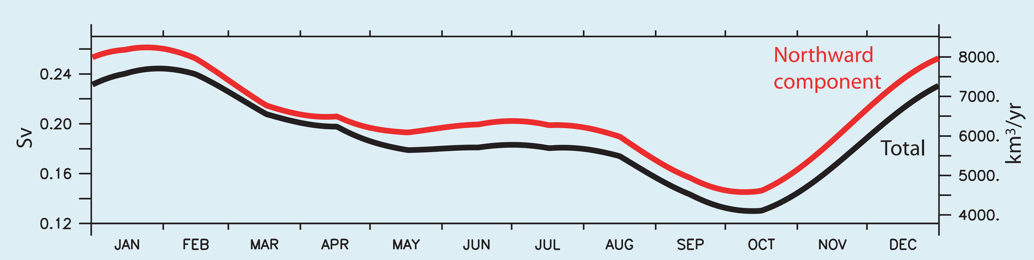


Annual and semiannual harmonics were fit to the volume transport time series. Average transport is 4.7 Sv, of which 2.7 Sv (~57%) is in the top 200m. The amplitudes of both the annual and the semiannual harmonics are ~0.8 Sv. Transport is maximum in January (6.2 Sv) and minimum in October (3.6 Sv) with a secondary maximum in June/July (5.4 Sv). This pattern is similar to that observed in the ANSC [Stabeno, et al., 2009] and is in phase with the seasonal cycle of the zonal winds from the NCEP Reanalysis [Kistler, et al., 2001]. The source of inflow into Amukta Pass is the Alaskan Stream. When the zonal wind is eastward, it drives an Ekman flux towards the south, pushing the Alaskan Stream away from the Aleutian Islands. This results in reduced flow into Amukta Pass. When the zonal wind is westward, the Ekman flux pushes the Alaskan Stream toward the islands, resulting in enhanced flow through Amukta Pass. This mechanism explains the seasonality of volume transport in Amukta Pass and it has also been invoked to explain interannual variability in the ANSC [Bond and Adams, 2002].



Seasonal cycles of temperature and salinity are out of phase with each other. Bottom temperature is maximum in November (4.2°C at AMP1) and minimum in May (3.9°C at AMP1); while salinity is maximum in August (33.93) and minimum in March (33.79). From limited CTD data, shallow salinities are fresher in April and August and saltier in June and October. The seasonal cycle in these water properties is due to a combination of factors, including stratification and mixing within the pass, large-scale upwelling/downwelling and its influence on the salinity and temperature of the deep Alaskan Stream, and the seasonal cycle of freshwater discharge around the Gulf of Alaska. Surface warming and weak winds during the summer enhance stratification, resulting in less mixing to depth as the waters flow over the abrupt topography of the pass. Thus, colder temperatures and higher salinities at depth are observed during the summer. In the winter, the winds are stronger and surface cooling acts to reduce stratification, resulting in enhanced mixing to depth. In addition, zonal winds contribute to stronger downwelling during winter than during summer. This effect results in colder temperatures and higher salinities at depth in the Alaskan Stream during the summer.

FRESHWATER TRANSPORT



The freshwater flux anomaly for Amukta

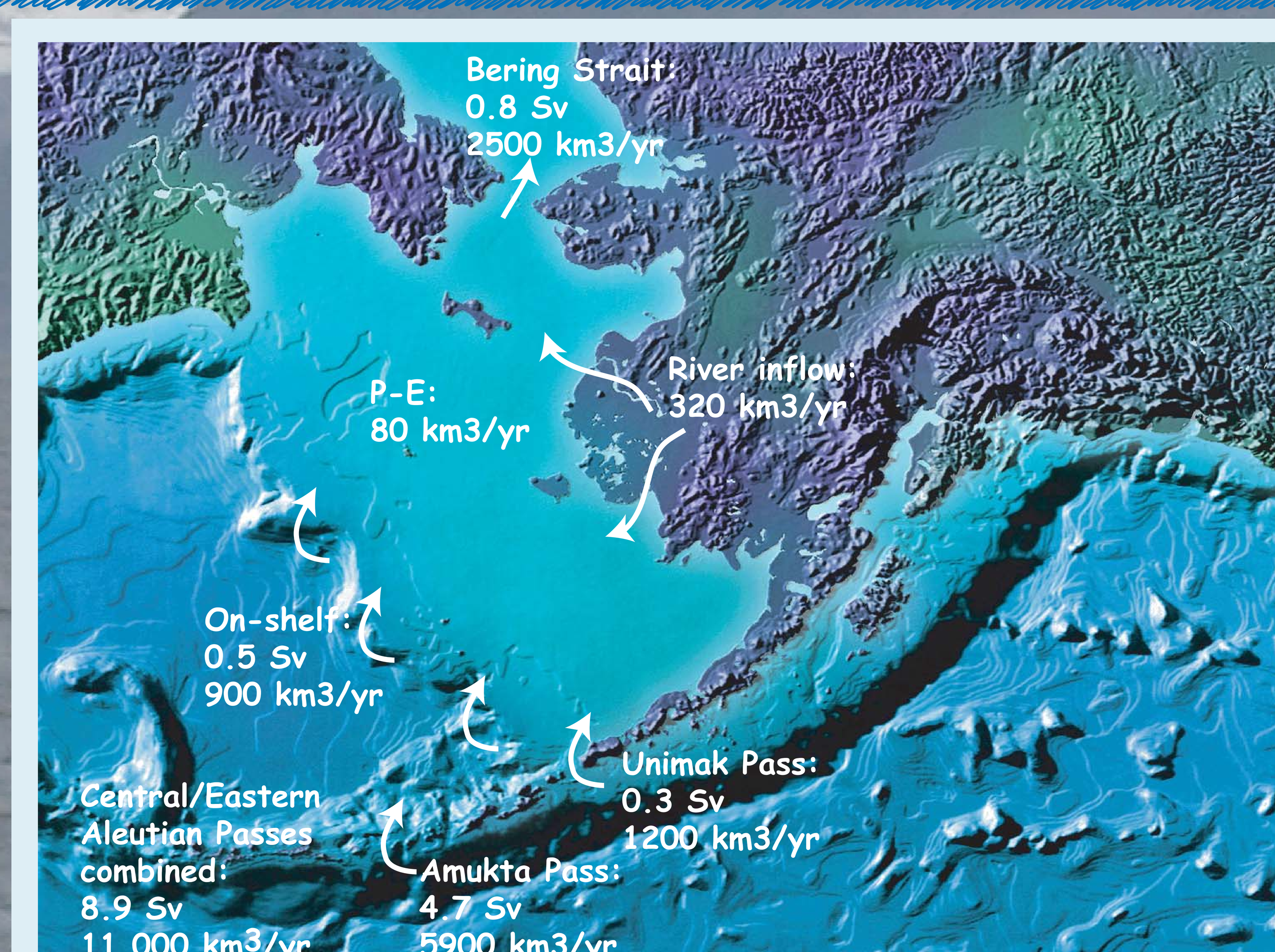
$$FW_{flux} = \iint_{x,z} u(x,z)\cdot\frac{(S_{ref}-S(x,z))}{S_{ref}}\,dx\,dz$$

where $u(x,z)$ is the velocity normal to the section, $S(x,z)$ is salinity, and $S_{ref} = 34.8$ is the reference salinity following Aagaard and Carmack [1989] and Woodgate and Aagaard [2005].

Maximum freshwater transport occurs in January with the minimum occurring in October. Most of the transport occurs on the eastern side of the pass, with AMP1 freshwater transport accounting for 74% of the northward component. Roughly two thirds of the northward freshwater transport occurs in the upper 200m of the water column. This shallow layer provides the source water for on-shelf freshwater transport to the Bering Sea shelf.

Unfortunately, we do not have sufficient data to examine the seasonal cycle of transport or salinity in any other Aleutian passes. Freshwater transport is estimated for the major eastern and central Aleutian passes from volume transport estimates from the literature [Mordy, et al., 2005; Reed, 1990; Stabeno, et al., 2005; Stabeno, et al., 2002] and average salinity estimates [Ladd, et al., 2005].

Pass	Volume Transport (Sv)	Average Salinity	Freshwater Transport ($km^3\ yr^{-1}$)
Unimak	0.4	31.7	1200
Akutan	0.1	32.4	200
Samalga	0.4	32.9	700
Amukta	4.7	33.4	5900
Seguam	0.4	33.4	500
Tanaga	0.4	33.4	500
Amchitka	2.5	33.9	2000
Total	8.9		11,000



CONCLUSIONS

The BSC supplies water to the eastern Bering Sea 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. This cross-shelf exchange also provides a source of freshwater to the shelf and ultimately to flow through Bering Strait. The freshwater flux through Bering Strait has been estimated at 2500 $km^3\ yr^{-1}$ [Woodgate and Aagaard, 2005] relative to a reference salinity of 34.8. Aagaard, et al. [2006] estimate a freshwater budget for the Bering Sea shelf that includes cross-shelf supply of freshwater to the shelf of ~900 $km^3\ yr^{-1}$. We estimate the supply of freshwater through the eastern/central Aleutian passes of ~11,000 $km^3\ yr^{-1}$, more than ten times the amount needed to supply the eastern Bering Sea shelf. Freshwater transports through Amukta Pass account for roughly half (~5900 $km^3\ yr^{-1}$) of the total flux through the passes. Interannual variability may result in fluctuations on the order of 25%. Because the supply of freshwater from the North Pacific is so much higher than the cross-shelf exchange required to balance the freshwater budget, the flux through Bering Strait is probably not sensitive to changes in freshwater flux through the Aleutian Passes. Instead, it is probably more sensitive to the dynamics of cross-shelf exchange (eddies, upwelling/downwelling winds, strength of BSC).

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