

Introduction:

Salinity primarily controls density on the Gulf of Alaska (GOA) shelf and slope. Density variations are a result of winds and freshwater discharge, both of which vary seasonally and interannually [1]. However, the remote setting and rugged orography hinder accurate assessments of precipitation and discharge rates. Under the GLOBEC-LTOP program we are investigating the seasonal variations in freshwater transport and content on the shelf and the mechanisms responsible for this variability. We are also exploring means by which the GOA shelf may be used as a regional precipitation/discharge gauge.

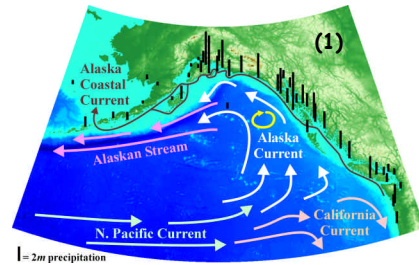


Figure 2. Mean monthly coastal freshwater discharge (blue) and upwelling index (red) for the GoA. The high coastal precipitation rates force a massive, but seasonally varying coastal freshwater discharge that is low in NO_3 because of the high elevations and the rocky, glacial setting of the drainage basins. Discharge is maximal in fall and minimal in winter when the precipitation is stored as snow, but not in phase with the along-shore wind stress, which is maximal in winter and minimal in summer.

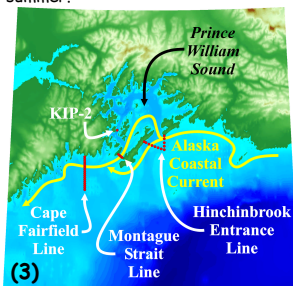
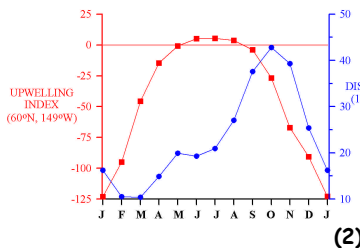
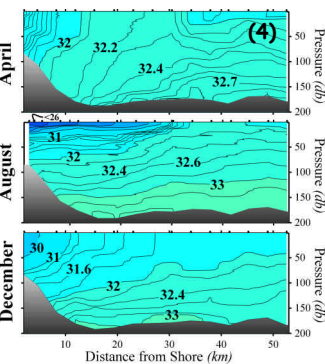


Figure 3. Data from 76 sections (1980 - 2001) across the Cape Fairfield transect are used to construct the annual cycle of baroclinic transport, freshwater transport, and freshwater content for the Alaska Coastal Current. The section cuts across the ACC west of Prince William Sound. The ACC flows through and is fed by outflow from Prince William Sound (PWS). Data from PWS stations in Montague Strait (MS), Knight Island Passage (KIP), and Hinchinbrook Entrance (HE) are discussed later. All stations are occupied during GLOBEC-LTOP cruises.

Figure 4. Cross-sections of salinity (a proxy for density), from April, August, and December 2000 through the ACC offshore of C. Fairfield. The ACC structure varies seasonally in response to winds and discharge. By the end of winter (April), stratification is weak and the ACC is bounded offshore by a steeply inclined, relatively weak **bottom-advected** [2] front. Stratification is strong but horizontal salinity gradients are weak in summer (August) when the frontal structure is of the **surface-advected** type. Stratification weakens through fall (December) but horizontal salinity gradients are strong when the frontal structure is of the **intermediate-plume** type. Although the ACC varies throughout the year, it is generally within 40 km of the coast. On average ~55% of the baroclinic, geostrophic transport (0-150 dbars) across the northern GoA shelf occurs within the ACC.



References:
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 [2] Yankovsky, A. E. and D. C. Chapman, A simple theory for the fate of buoyant coastal discharges, *J. Phys. Oceanogr.*, 27, 1386-1401, 1997.
 [3] Johnson, W. R., T. C. Royer and J. L. Lutck, On the seasonal variability of the Alaska Coastal Current, *J. Geophys. Res.*, 93:12423-12437, 1988
 [4] Stabeno, P. J., R. K. Reed and J. D. Schumacher, The Alaska Coastal Current: continuity of transport and forcing, *J. Geophys. Res.*, 100, 2477-2485, 1995
 [5] Strub, P.T. and C. James, Altimeter-Derived Surface Circulation in the Large-Scale NE Pacific Gyres: Part 2. 1997-1998 El Niño Anomalies, (submitted *Prog. Oceanogr.*)

Fresh Water Variability in the Alaska Coastal Current



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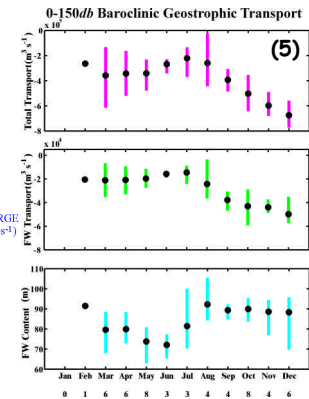
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Sponsored by NSF/NOAA NEP GLOBEC LTOP



Figure 5. The annual cycle of: **alongshore baroclinic transport** (top), **alongshore FW transport** (middle), and **FW content** (bottom). Baroclinic and freshwater transport are maximal in fall and minimal in summer and are in-phase. The freshwater transport is ~10% of the total transport. The freshwater content is maximal in September and minimal in April. However, most of the freshwater transport (90%) and content (60%) occurs within the upper 75 m of the water column and most (80%) of the transport is confined to within 30 km of the coast.

Negative transports denote westward flow. The numbers below the month on the x-axis indicate the sample size (# of transects for a particular month) and the vertical bars portray the observed monthly range.



Methods:

Fresh Water Fraction, $S'(z) = \frac{(S_r - S(z))}{S_r}$ ($S_r = 33.8$ psu)

S_r is the isohaline at the base of the GoA halocline and the foot of the shelfbreak front in the northern GoA

Fresh Water Content (m) = $\int \int S'(z) dz dy$ ($0 < y \leq 40$ km; -150 m $\leq z \leq 0$ m)

Fresh Water Transport ($m^3 s^{-1}$) = $\int \int U_{bc}(z) S'(z) dz dy$
 ($U_{bc}(z)$ is the geostrophic velocity at depth z relative to 150 dbars)

Net Ekman FW Transport ($m^3 s^{-1}$) = $M_E \frac{(S_B - S_E)}{S_r} \times 1000$ km shelf

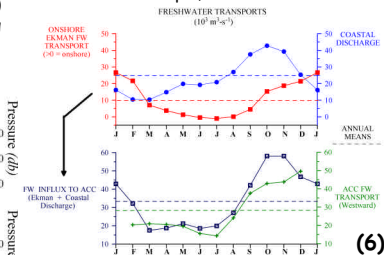
S_E = average monthly salinity of the surface Ekman (assumed constant and 30 m deep)

S_B = average monthly salinity from 31-200m

S_E and S_B are based on shelf stations offshore of the ACC

M_E , the Ekman mass transport, based on the mean monthly GoA upwelling indices between 51N, 131W and 60N, 149W.

Figure 6. The annual cycle of coastal freshwater discharge and the onshore Ekman transport of FW (upper panel). On annual average ~2/3 of the freshwater contribution to the ACC is from coastal discharge while ~1/3 is from the Ekman transport. Although the coastal discharge is the major source of freshwater to the ACC from March through November, the onshore Ekman transport of FW is substantial and the primary source of freshwater for the ACC in winter. Further, the annual cycle formed by summing both components compares favorably (30% at worst) with the magnitude and phasing of the alongshore transport of freshwater (bottom panel). We have ignored other processes that might prove to be important to the ACC freshwater balance. For example, we have not included the FW contribution from the British Columbia coast.



Pro-rating the GoA discharge estimates to this region suggests a mean annual discharge of ~13,000 $m^3 s^{-1}$. We cannot evaluate the barotropic component of the ACC, although current meter data suggest a mean value of ~3 $cm s^{-1}$ [3, 4]. When applied to the ACC the barotropic component increases the mean annual freshwater transport by about ~15,000 $m^3 s^{-1}$, which is of the magnitude of the BC freshwater contribution. We have also ignored horizontal diffusion and/or the role of baroclinic instability in the offshore dispersal of freshwater. Preliminary results from idealized models of the ACC suggest that this efflux is small because the freshwater is effectively trapped within the ACC throughout most of the year by the cyclonic windstress.

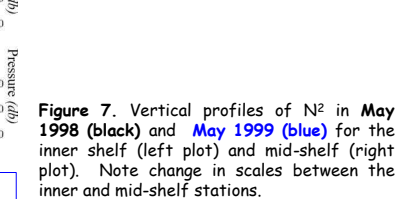


Figure 7. Vertical profiles of N^2 in May 1998 (black) and May 1999 (blue) for the inner shelf (left plot) and mid-shelf (right plot). Note change in scales between the inner and mid-shelf stations.

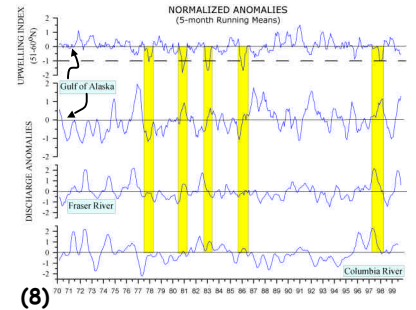
TABLE 1. Comparison of Salinity, Baroclinic, and Fresh Water Transport For March, April, May, 1998 and 1999 along the Cape Fairfield Line.

	Mean Salinity	Mean Total BC Transport ($\times 10^7 m^3 s^{-1}$)	Mean FW BC Transport ($\times 10^7 m^3 s^{-1}$)
1998	31.88	4.1	2.6
1999	32.20	2.2	1.1

CF1:CF12, 0-150db, Sr = 33.8 psu

Table 1 compares the mean baroclinic transport, freshwater transport, and salinity between March and May 1998 (El Niño) and 1999 (La Niña). The ACC was substantially fresher and had a large transport in 1998 compared to 1999. These differences were also reflected in differences in the magnitude and timing of stratification on the inner shelf in the spring of these years (Figure 7), which might have been significant to the initiation of the spring bloom.

Figure 8. Five-month running means of the normalized monthly anomalies of the a) upwelling index (between 60N, 149 W and 51N, 131W), b) GoA coastal discharge, c) Fraser River (BC) discharge, and d) Columbia River discharge from 1970 - 1999. The dashed line indicates upwelling anomalies exceeding 1 standard deviation. Yellow highlights indicate years of anomalously strong downwelling.



In fall 1997 and early winter 1998 there was anomalously strong downwelling AND high discharge into the Gulf of Alaska and along the western N. American coast. The anomalies were approximately in-phase and therefore worked in concert to strengthen and freshen the ACC. In fall 1998 and early winter 1999, there was anomalously weak downwelling AND low discharge into the Gulf of Alaska and along the western N. American coast. Again, the anomalies were approximately in-phase and therefore worked in concert to weaken and salinize the ACC. In aggregate these results are consistent with the results reported in Table 1. Our observations further imply that freshwater from as far south as the Columbia River could have been advected into the northern Gulf of Alaska by way of the ACC. Further support for this suggestion are altimeter observations that indicate an abnormally strong northward flow over the Pacific NW coast in late 1997/early 1998 and the intensification of the cyclonic circulation in the Gulf of Alaska [5]. Figure 8 also implies that 1998 was unusual compared to the other anomalously strong downwelling years (yellow bars). Anomalously strong downwelling AND high discharge at all coastal locations only occurred in 1998 suggesting that indeed this was a very unusual El Niño year.

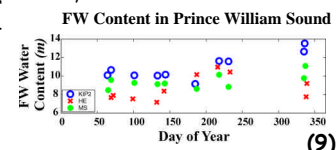


Figure 9 shows the freshwater content at several locations in the Sound (Fig. 2) through a composite year. KIP2 (representative of outflow from the northern sound) contains up to 5 m more freshwater than the inflow stations (HE), while the outflow stations (MS) have intermediate values. We will refine this picture using historical and future data collected under the GLOBEC LTOP, with the goal of developing a climate monitoring scheme for freshwater forcing in this region.

Conclusions:

- 1) The massive coastal freshwater discharge into the ACC is the primary source of freshwater for this coastal current. However, onshore Ekman transport, especially during winter, contributes substantially to the freshwater standing stock and transport of the ACC.
- 2) The significant freshening observed in 1998 (El Niño) compared to 1999 (La Niña) was a consequence of anomalously high runoff into the Gulf of Alaska and along the west coast of North America coupled to anomalously strong, basin-wide cyclonic wind stress. When compared to other El Niños, the 1998 event was atypical due to the broad geographical extent of this coupling.
- 3) Vertical stratification occurred earlier and stronger in spring 1998 compared to spring 1999 because of the freshening. However, the freshening appears to have resulted in substantially lower NO_3 concentrations in spring 1998 vs. 1999 (see poster by Childers et al.).

