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Seasonal variability of near-surface hydrography and frontal features in the northern Gulf of Alaska and Prince William Sound

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[1] The meridional structure and seasonal cycles of near-surface hydrography and frontal features in the northern Gulf of Alaska and Prince William Sound are described from high-resolution measurements of near-surface temperature and salinity acquired by a vessel-mounted thermosalinograph. Near-surface temperature exhibits a well-defined seasonal cycle with little variation between basin and shelf waters. Near-surface salinity exhibits a well-defined seasonal cycle that is confined largely to the shelf waters reflecting the influence of coastal freshwater inputs. Prominent near-surface fronts at the shelf break, at the entrance to Prince William Sound, and in northern Prince William Sound intensify and weaken following the seasonal cycles of freshwater discharges into the northern Gulf of Alaska. These respective fronts are maintained by freshwater from the Alaska Coastal Current, the Copper River, and the snowfields and glaciers of northern Prince William Sound. **Citation:** Okkonen, S. R., D. L. Cutchin, and T. C. Royer (2005), Seasonal variability of near-surface hydrography and frontal features in the northern Gulf of Alaska and Prince William Sound, *Geophys. Res. Lett.*, *32*, L11611, doi:10.1029/2005GL023195.

1. Introduction

[2] The northern Gulf of Alaska (GOA) and its adjoining embayments are the physical setting for one of the most commercially important ecosystems in the world ocean. The largest of these embayments is Prince William Sound (PWS), a semi-enclosed, subpolar body of water (Figure 1). PWS has an estuarine character due principally to the large freshwater input to the sound and to the few narrow passages that limit exchange with the northern GOA [*Schmidt*, 1977; *Muench and Heggie*, 1978; *Royer et al.*, 1990]. The seasonal freshwater input to the region promotes the maintenance of fronts and stratification of the water column. It thereby influences circulation, nutrient supply to the euphotic zone, and the productivity of this ecosystem.

[3] PWS is a nursery for many species of fish including pink salmon and Pacific herring which have historically been cornerstones of local coastal economies. The survival of juvenile pink salmon and juvenile herring depend on the availability of zooplankton from spring through fall [*Willette et al.*, 2001; *Norcross et al.*, 2001]. Zooplankton biomass within PWS varies from year to year [*Cooney et al.*, 2001]. Advection of zooplankton from the northern Gulf of Alaska shelf into PWS contributes to this variability [*Kline*, 1999]. Seasonal abundance, biomass, and cross-shelf distribution of major copepod taxa are outlined in the work of *Coyle and Pinchuk* [2003, 2005]. While the fronts partition the basin, shelf, and PWS waters into different hydrographic domains, the influences of these fronts on exchanges of plankton between these domains are not well understood.

[4] Seasonal temperature and salinity signals in the northern GOA and PWS have been described by a number of authors [e.g., *Royer*, 1979, 1982; *Gay and Vaughan*, 2001; *Vaughan et al.*, 2001; *Royer*, 2005]. However the temporal and/or spatial resolution of these observations has been relatively coarse and generally not well suited to describing the seasonal evolution of frontal features. Recently, a vessel-mounted thermosalinograph has acquired high resolution, near-surface temperature and salinity measurements across the northeastern Pacific Ocean allowing the meridional and temporal variability of northern GOA and PWS frontal features to be described.

2. Data and Methods

[5] A Seabird SBE-45 thermosalinograph (TSG) was installed on the tanker vessel (T/V) Polar Alaska in 2002. The T/V Polar Alaska carries Alaska North Slope crude oil from Valdez, Alaska to refineries in California and Washington. Near-surface temperature and salinity measurements were obtained for the period October 2002 until the ship went into dry dock in June 2004. Post-deployment calibration of the temperature and conductivity sensors indicated sensor drifts of +0.00074 °C/year and −0.0024 psu/month. The raw data were adjusted accordingly.

[6] The TSG measures temperature and salinity of seawater taken from the vessel engines' cooling system intake. During northbound transits the T/V Polar Alaska is lightly ballasted with seawater and the intake depth is ~8 m. During the southbound transits the T/V Polar Alaska is heavily laden with Alaska North Slope crude and the intake

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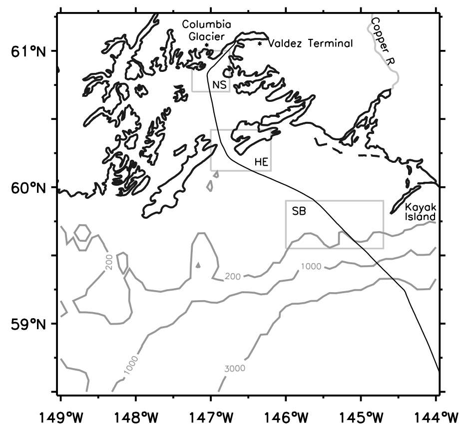

Figure 1. Map of the northern Gulf of Alaska and Prince William Sound region. A representative ship track is shown. Boxes identify the shelf break (SB), Hinchinbrook Entrance (HE), and northern Sound (NS) frontal zones.

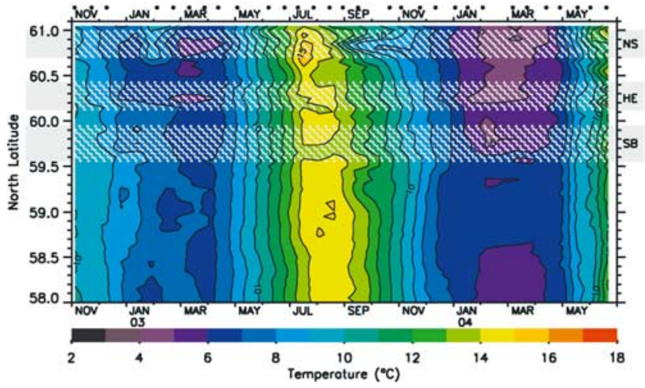

Figure 2. Time-latitude plot of near-surface (~8 m) temperature. The contour interval is 1°C. Dots at the top of the figure indicate dates when the vessel crossed 60°N. The shaded bands identify the SB, HE, and NS frontal regions.

depth is ~13 m. While data acquired from consecutive northbound and southbound transits are generally similar, differences are most pronounced during the summer months when the near-surface layer is most stratified. Temperature and salinity measurements were acquired every 5 minutes from October 2002 to February 2004 and every 30 seconds from March 2004 to June 2004. At a cruising speed of about 30 km h^{-1} (16 knots), these temporal sampling intervals corresponded to spatial sampling intervals of 2.5 km (1.33 n mi) and 0.25 km (0.13 n mi), respectively.

[7] The T/V Polar Alaska completed thirty-four round trips between Valdez and west coast refineries during the period November 2002–June 2004, an average round trip taking about 17 days. Usable data were acquired on twenty-eight of the southbound transits and on thirty of the northbound transits.

[8] TSG data were merged with global positioning system (GPS) navigation data and then bin-averaged every 0.05 degrees of latitude (~5.5 km, meridional distance). Regularly-sampled, time-space arrays of temperature and salinity were generated from linear interpolation (17-day interval) of the time series of bin-averaged temperature and salinity observations. Because of the similarities in horizontal hydrographic structure identified along northbound and southbound transits, only the data from the northbound (8 m sampling depth) transits are presented.

3. Observations

[9] A representative ship track crossing the northern Gulf of Alaska and Prince William Sound is shown in Figure 1. From south to north, outlined boxes SB, HE, and NS identify the shelf break region, Hinchinbrook Entrance region, and northern Sound region, respectively.

[10] The seasonal evolution of the near-surface temperature field is shown in a time-latitude format (Figure 2). A strong seasonal signal with a temperature range of about 4–5°C to >14°C occurs over most of the region although meridional temperature gradients are generally weak throughout the year. The lowest temperatures typically occur during February and March, whereas the highest temperatures typically occur during July and August. Winter 2004 temperatures are about 2–3°C lower than winter 2003 temperatures with larger differences in northern PWS. The SB front (~59.65°N) and HE front (~60.1°N) are revealed by temperatures that are slightly cooler than surrounding temperatures during July and August. The NS front (~60.8°N) exhibits cooler temperatures during September–November.

[11] At polar and subpolar latitudes where ocean temperatures are relatively cool, changes in salinity have a greater influence on seawater density than changes in temperature. Consequently, freshwater inputs significantly influence hydrographic structure and the resulting density-driven flows. The seasonal evolution of the near-surface salinity field (Figure 3) shows that freshwater influence is confined to the shelf. The largest seasonal salinity variation occurs in northern PWS (ΔS > 10 psu). A rapid freshening begins in May with the freshest values occurring in July and August. The freshwater plume within PWS exhibits a southward component of propagation through the summer and early fall. This freshwater pulse rapidly erodes during October

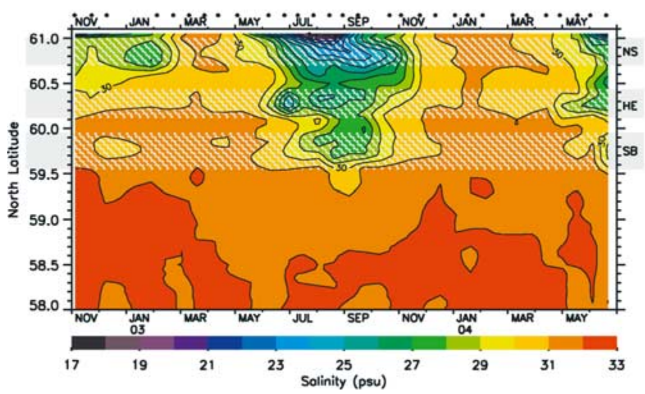

Figure 3. Time-latitude plot of near-surface (~8 m) salinity. The contour interval is 1 psu. Dots at the top of the figure indicate dates when the vessel crossed 60°N. The shaded bands identify the SB, HE, and NS frontal regions.

and November with the most saline values within PWS occurring between January and March 2004. Interannual variability is evident as winter 2003 salinities in northern and central PWS are somewhat ($\leq$1 psu) fresher than those observed in winter 2004. On the south side of HE the lowest salinities occur during June through August when Copper River discharge peaks. The highest salinities occur during the winter months when river discharge is low. At the shelf break, the lowest salinities are observed during mid-July through mid-October, roughly coinciding with the peak in regional, rather than local, fresh water discharge (*Royer*, 1982). Seaward of the continental slope (south of $\sim$ 59.3°N) the seasonal variation in near-surface salinity is relatively small ($\Delta S < 1$ psu).

[12] Satellite imagery, in which suspended sediments are sometimes used as tracers of freshwater in this region [e.g., *Ahlnas et al.*, 1987; *Royer et al.*, 1990], reveals the freshwater sources that maintain these near-surface fronts. Light blue colored sediment plumes, readily apparent in an August 2003 Terra/MODIS false-color image of the northern GOA region (Figure 4), suggest that the principal freshwater sources for the SB front, the HE front, and NS front are, respectively, the Alaska Coastal Current (ACC), the Copper River, and snowfields and glaciers in and near Port Valdez. The August MODIS image is not unique. It is a representative depiction of the suspended sediment (freshwater tracer) distribution evident in many images acquired during spring through fall seasons in different years.

[13] As can be inferred from Figure 3, the strongest salinity gradients (fronts) are generally observed from late spring to early fall. This coincides with the period when freshwater inputs are relatively large [*Royer*, 1982] and winds (and wind mixing) are relatively weak [e.g., *Livingstone and Royer*, 1980; *Stabeno et al.*, 2004]. Nonetheless, a time-latitude plot of the meridional density gradient (Figure 5) indicates that gradients (fronts) between HE and the SB persist through the winter months although the gradients are much weaker than occur during the summer months. It can also be inferred that the HE front inhibits near-surface exchange between the shelf and PWS, although most effectively so during the summer months.

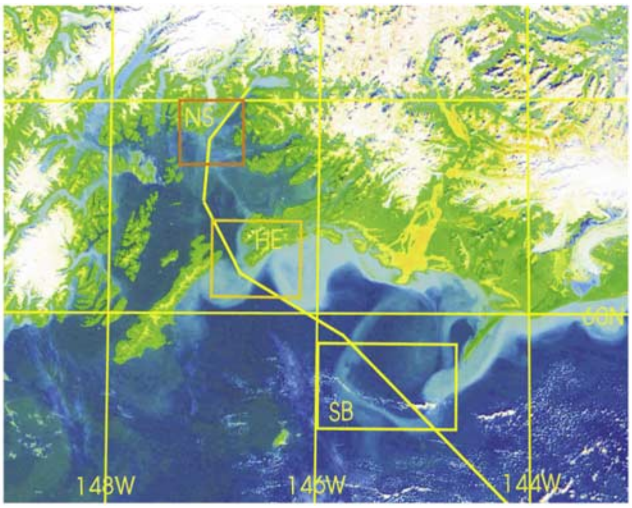

Figure 4. Terra/MODIS false-color image (22 August 2003) of the northern Gulf of Alaska and Prince William Sound region. Suspended sediments appear light blue. Boxes identify the SB, HE, and NS frontal zones.

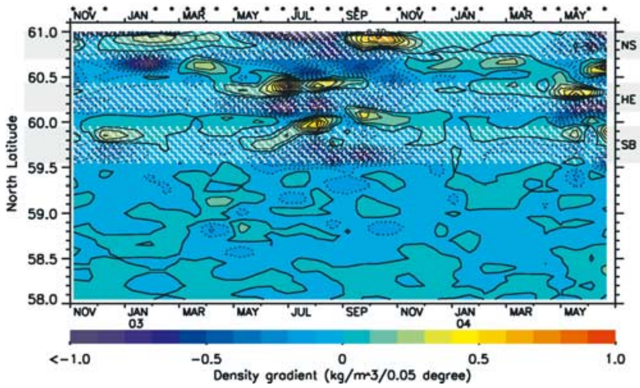

Figure 5. Time-latitude plot of the meridional gradient of near-surface ($\sim$8 m) density. The contour interval is 0.1 kg m^{-3} 0.05 degree^{-1}. Values less than -1 kg m^{-3} 0.05 degree^{-1} have been set to -1 kg m^{-3} 0.05 degree^{-1}. Dots at the top of the figure indicate dates when the vessel crossed 60°N. The shaded bands identify the SB, HE, and NS frontal regions.

4. Summary and Conclusions

[14] Thermosalinograph measurements of temperature and salinity have been used to describe the meridional structure and seasonal evolution of near-surface hydrography and frontal features in the northern Gulf of Alaska and Prince William Sound. A well-defined seasonal cycle in near-surface temperature was shown to extend across basin and shelf waters whereas a well-defined seasonal cycle in near-surface salinity was confined largely to shelf waters. This stresses the importance of the coastal discharge to the freshwater budget of the Northeast Pacific as compared to the regional precipitation over the ocean. Fronts in northern PWS, across Hinchinbrook Entrance, and at the shelf break intensify and weaken in concert with the seasonal cycles of freshwater inputs from the snowfields and glaciers of northern Prince William Sound, the Copper River, and the Alaska Coastal Current, respectively.

[15] A common representation of the trajectory of the ACC in the vicinity of PWS has it turning northward onto the inner shelf after it passes Kayak Island to then flow westward in front of Hinchinbrook Entrance [e.g., *Royer et al.*, 1990, *Weingartner et al.*, 2005]. The TSG data indicate, however, that the near-surface expression of the HE front intensifies one-to-two months earlier than the SB front suggesting that the ACC does not significantly contribute to near-surface flow in front of HE, at least during the summer months. This suggestion is supported by satellite imagery that shows near-surface freshwater flow in front of HE derives principally from Copper River discharge.

[16] **Acknowledgments.** We are grateful for the support of Polar Tankers and the officers and crew of the T/V Polar Alaska for installation and accommodation the thermosalinograph. The MODIS image was obtained from NASA's Visible Earth website. This work was supported by the *Exxon Valdez* Oil Spill Trustee Council, project 02614.

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