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Seasonal transport variations in the straits connecting Prince William Sound to the Gulf of Alaska

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ABSTRACT

Exchange of water between Prince William Sound and the Gulf of Alaska has a significant impact on its circulation and biological productivity. Current meter records from moored instruments in the two major straits connecting Prince William Sound to the Gulf of Alaska are analyzed to characterize the seasonal variations in water exchange. Eight individual deployments, each lasting for about 6 months, were made during the years 2005–2010. Two moorings were placed across each passage to account for horizontal flow variability. Monthly averaged, depth-integrated transport in winter is characterized by a strong barotropic inflow through Hinchinbrook Entrance and outflow through Montague Strait. The transport through each passage can reach 0.2 Sv, which could replenish the volume of Prince William Sound in as little as 3 months. Depth-integrated transport is weaker and more variable in direction in summer than in winter, implying that Prince William sound is not always a simple flow-through system. Monthly transports range between -0.05 and 0.08 Sv in each passage, and the corresponding flushing times exceed 1 year. The flow through both passages is highly baroclinic in the summer, so that the layer transport can be significant. For example, the deep inflow through Hinchinbrook Entrance can reach 0.05 Sv, which would flush the deep regions of Prince William Sound (>400 m) in only 23 days. The transport imbalance between Montague Strait and Hinchinbrook Entrance cannot be accounted for by considering other terms in a volume budget such as local freshwater input, meaning the imbalance is mostly a result of under-resolving the cross-strait flow variability. The magnitude of the monthly mean depth-integrated transport through Montague Strait and Hinchinbrook Entrance depends non-linearly on the shelf winds. Strong downwelling conditions, characteristic of the winter, drive inflow through Hinchinbrook Entrance, which is balanced by outflow through Montague Strait. Weak downwelling or upwelling conditions, characteristic of the summer, allow deep water from below the shelf break to flow in through Hinchinbrook Entrance.

1. Introduction

Prince William Sound (PWS) is a semi-enclosed, subarctic coastal sea in the northern Gulf of Alaska (GoA) (Fig. 1). While inhabited by a relatively small human population, it is a region of considerable economic and environmental value because it has traditionally supported a rich commercial fishery. Since 1977, crude oil has been transported by tankers from the marine terminal of the Trans-Alaska pipeline in Valdez to refineries outside of Alaska. In March 1989, the fully laden Exxon Valdez grounded on Bligh Reef in northeastern PWS, and leaked 11 million gallons of oil. Under the influence of strong northeasterly winds, the oil spread southwestward, eventually exiting PWS through Montague Strait. Therefore, a quantitative understanding of the flow in both major passages connecting PWS to the Gulf of Alaska is important for oil spill response and contingency planning.

Water exchange with the GoA is also significant because it may import scalar quantities which affect the local circulation or biology. Water flowing into PWS from the shelf will have some properties of the relatively fresh Alaska Coastal Current, which then forms a significant part of the PWS freshwater budget (Simmons, 1996). The addition of buoyancy can then impact the circulation within PWS (Bang and Mooers, 2003; Wu, 2011; Halverson et al., this issue). Exchange with the GoA is expected to have impacts on the local primary and secondary productivity (Eslinger et al., 2001). For example, stable carbon and nitrate isotope ratios in net plankton, juvenile herring, and juvenile

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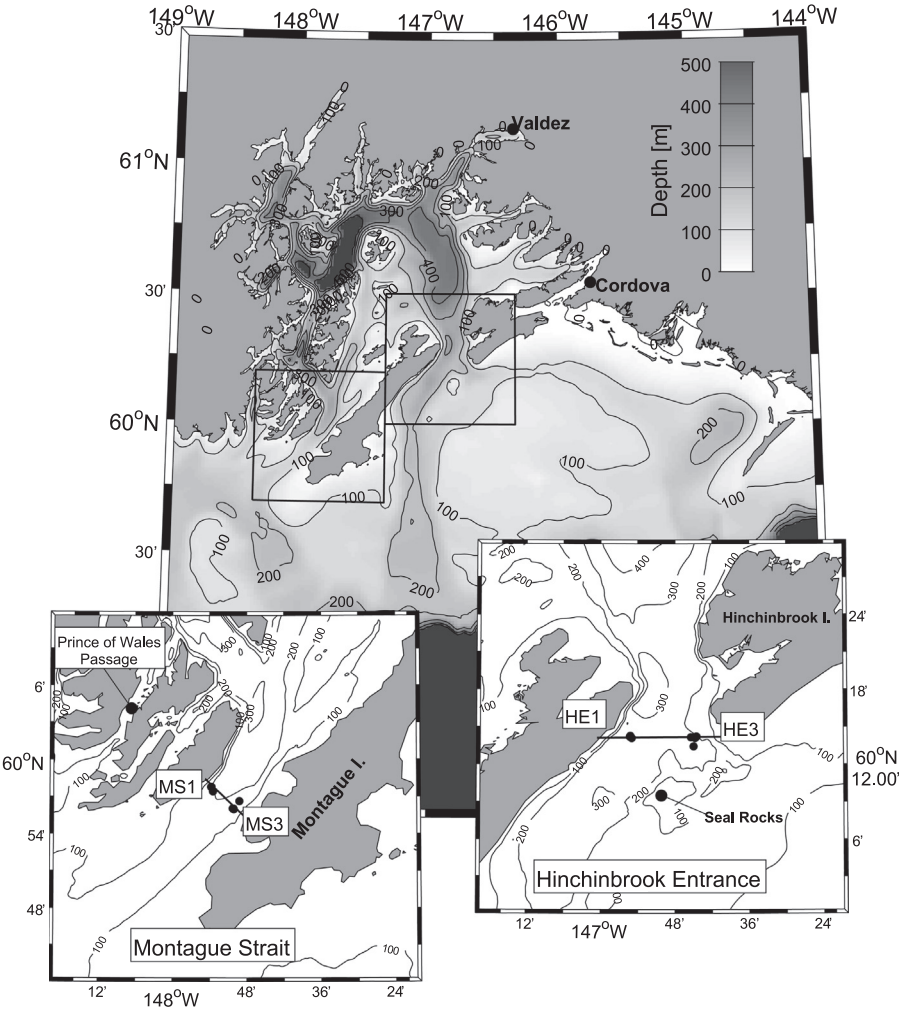

Fig. 1. Prince William Sound and its major connections to the Gulf of Alaska, Montague Strait and Hinchinbrook Entrance (small panels). The contour interval for all charts is 100 m.

walleye pollock sampled in PWS show that these organisms can originate from the GoA (Kline, 1999). Therefore, exchange between these systems can import (or export) organisms, which then has consequences for higher trophic levels.

This paper aims to improve upon past observational estimates of the water exchange between Prince William Sound and the Gulf of Alaska. The analysis is based on a multi-year, moored current meter time series that resolves some cross-strait variability.

1.1. Physical description and regional oceanography

Prince William Sound consists of a central basin flanked by numerous inlets (Fig. 1). It has some fjord-like properties, being deeper than the adjacent shelf, and receiving freshwater in excess of evaporation. The central basin is about 50 km wide, which is large enough to permit a significant lateral circulation. The average depth of PWS is 200 m, the central basin depth reaches 450 m, and the maximum depth is nearly 800 m. It covers an area of nearly 8400 km^2, and contains about 1700 km^3 of water (Table 1). Two major passages connect PWS to the continental shelf: Montague Strait (MS) and Hinchinbrook Entrance (HE). The continental shelf in the vicinity of PWS is 100–150 km wide, and ranges from about 100 to 200 m in depth.

Prince William Sound receives copious amounts of freshwater in the form of precipitation, snowmelt, and glacial meltwater. As much as 8 m of annual rainfall has been measured on Montague Island in southwestern PWS (Royer, 1979). Prince William Sound is surrounded by the Chugach mountains, and the precipitation primarily derives from orographic lifting of moist offshore air. The larger inlets on the western and northern sides of PWS are fjords with tidewater glaciers, and these can contribute a substantial amount of freshwater (e.g. Walters et al., 1988). Freshwater input into PWS is high from June to October, peaking in August, and low during the remaining months (Simmons, 1996).

The large-scale atmospheric pressure system which usually determines the local wind is the Aleutian Low. On the shelf adjacent to PWS, the Aleutian Low drives easterly winds, which in turn promote coastal downwelling. Frequent cyclonic storms in winter can elevate the easterly winds to gale force (Stabeno et al., 2004).

Table 1
Hypsographic summary of Prince William Sound by surface area and by volume.

	Depth (m)					
	> 0	> 100	> 200	> 300	> 400	> 500
Area (km^2)	8400	5550	3420	2200	1210	350
(%)	100	67	41	26	14	4
Volume (km^3)	1660	990	560	280	100	40
(%)	100	60	34	17	6	2