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Pteropods, eddies, carbon flux, and climate variability in the Alaska Gyre

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Abstract

Pteropod abundances in net tows and sediment traps are used to evaluate the link between episodic pteropod carbon flux in the North Pacific Ocean and Haida eddies and climate variability. Large deposition events of *Clio pyramidata* (a subtropical species of pteropod) at 3800 m sediment traps at Ocean Station Papa (OSP, 50°N, 145°W; 1983–2000) lag large El Niño events, represented by the Northern Oscillation Index (NOI), in the North Pacific by 1–2 years during observations from 1983 to 2000. Strong ENSO events may inject *C. pyramidata* source populations into the subarctic from southern regions because of greater northward transport of water along the continental margin and in some cases, because of a northward shifting of the subarctic boundary in deeper waters. Subsequently, conditions in the North Pacific following large negative NOI events may allow *C. pyramidata* to build and sustain high populations in the Alaska Gyre. Several very negative NOI years coincided with strong eddy intensity. Eddies are capable of concentrating high densities of pteropods (*C. pyramidata* and *Limacina helicina*) and so may further intensify climate-driven pteropod-based carbon inputs in the North Pacific. Pteropods contribute organic (tissue) and inorganic ($CaCO_3$ = aragonite) carbon to the deep ocean, yet they are not usually included in mass flux sediment trap studies because it is difficult to distinguish “swimmers” (live at the time of capture) from “sinkers” (dead at the time of capture). At 2.5 $g\,m^{-2}\,yr^{-1}$, $CaCO_3$ flux due to *C. pyramidata* at OSP is comparable to existing pelagic estimates for all open-ocean calcifiers including coccolithophorids, foraminfera, and all pteropods. Particulate inorganic carbon (PIC) from *C. pyramidata* in OSP sediment traps is ~17% of values measured in other studies that do not include pteropods in their totals. Average yearly flux of organic particulates at OSP due to *C. pyramidata* is 1.6 $g\,m^{-2}\,yr^{-1}$ and is about 49% more than the annual particulate organic carbon (POC) flux estimated by Wong et al. (1999) for OSP.

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1. Introduction

Inputs of carbon to the Alaska Gyre are episodically enhanced via sinking of large numbers of pteropods. In this paper we quantify pteropod carbon flux in the Alaska Gyre using sediment traps at Ocean Station Papa (OSP) near the southern margin of the Alaska Gyre at 50°N, 145°W. We also investigate possible mechanisms for pteropod aggregation and distribution throughout the North Pacific. Climate variability due to El Niño Southern Oscillation (ENSO) events and the Pacific Decadal Oscillation in the North Pacific may affect particulate carbon vertical flux in the Alaska Gyre by increasing densities of pteropods, in particular the density of a large subtropical species, *Clio pyramidata*. Two likely mechanisms of pteropod aggregation and retention in the North Pacific are concentration in anticyclonic Haida and Sitka eddies that form along the west coast of North America and increased northward transport of subtropical waters during years influenced by El Niño. Concentration of pteropods in eddies is probably enhanced in major ENSO years, and thus these two mechanisms are almost certainly linked.

Concern about global warming and the effects of increasing atmospheric CO_2 on the environment motivate scientific interest in the long-term fate of anthropogenic CO_2 in the oceans. Dissolved CO_2 concentrations affect the quantity of CO_2 that can be absorbed from the atmosphere by surface waters. Biological processes that regulate concentrations of dissolved CO_2 include production and oxidation of organic matter and the precipitation–dissolution of $CaCO_3$. $CaCO_3$ production and export is an important mechanism by which carbon is transported from the ocean's surface to its abyss and likely affects regulation of marine CO_2 levels (Francois et al., 2002; Inglesias-Roderiguez et al., 2002). Particulate inorganic carbon export from the surface mixed layer is called the "carbonate pump". Its role with respect to air–sea pCO_2 gradients is unclear and often ignored (Wong and Crawford, 2002). Pteropods are one source of carbonate (aragonite) that has largely been omitted from oceanic carbon flux estimates (Inglesias-Roderiguez et al. (2002); but see: Berger (1978), Berner and Honjo (1981), Betzer et al. (1984) for examples where they have been considered). This omission leads to an underestimate of the amount of $CaCO_3$ produced in shallow water sediments and dissolved in deep water. Data from sediment traps show that aragonite may contribute from 12% to >50% of total $CaCO_3$ flux in some areas (Lalli and Gilmer, 1989).

Large anticyclonic Sitka and Haida eddies form in late winter along the eastern margin of the subarctic Pacific and then propagate westward into the Alaska Gyre (Crawford and Whitney, 1999; Crawford et al., 2002). Physical and chemical characteristics of Haida eddies are given in Crawford (2002) and Whitney and Robert (2002). In general, Haida eddies are about 100–200 km in diameter, 300–400 m thick and can persist for several years, traveling as far as 1000 km from their origin and carrying nutrients from the nearshore into the North Pacific (Whitney et al., 2005). Haida eddy seaward penetration into the Alaska Gyre can extend westward of 140°W (Crawford et al., 2000). Following very large El Niño events in the North Pacific, eddy number, size, and southward penetration are greater than average (Crawford, 2002; Crawford et al., 2002). Sitka eddies (Tabata, 1982) form along the Alaskan Panhandle north of 55°N and differ from Haida eddies in their water mass characteristics (Crawford, 2002). They generally reside in the northern extreme of the Gulf and sometimes enter the Alaskan Stream. Some biology of Sitka eddies has been studied (Batten and Crawford, 2005).

Zooplankton communities in Haida eddies are a mixture of shelf- and slope-origin species from the nearshore formation region (Mackas and Galbraith, 2002; Batten and Crawford, 2005) and subarctic oceanic species that colonize the eddy from the sides and below, after the eddy leaves the nearshore region (Mackas et al., 2005). Densities of most nearshore-origin species decrease with eddy age (Mackas and Galbraith, 2002), while offshore-origin species approach ambient Alaska Gyre concentrations. Two marked exceptions to this pattern, however, are the pteropods *Limacina helicina* and *C. pyramidata*. Both species are often more abundant within Haida eddies than in any