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Observations of exchange between eastern Casco Bay and the western Gulf of Maine

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Abstract

Exchange of water between eastern Casco Bay and the adjacent Gulf of Maine shelf is examined to assess the circulation processes that impact the distribution and occurrence of a toxic dinoflagellate, *Alexandrium fundyense*, in eastern Casco Bay. Over the inner shelf adjacent to the bay, tidal variance is weak, and the across-shelf current is highly coherent and in phase with the along-shelf wind stress. Although tidal current variance increases as one advances into the bay, non-tidal currents account for 30–40% of the across-shelf current variance at the bay entrance. Between the shelf and the bay interior is a transition region, where the circulation response to wind forcing changes as the wind adjusts to the changing orientation of the shoreline. Far from shore, the overall large-scale coastline orientation dominates the wind-driven response, but within a few internal Rossby radii, the local coastline clearly dominates the flow patterns and across-shelf wind becomes locally shore-parallel inside the bay. Within the bay interior, the across-shelf wind is highly coherent and in phase with the near-surface subtidal across-shelf current. The Kennebec River north of the study area supplies freshwater to eastern Casco Bay in all seasons. A pool of low-density, relatively fresh water at the entrance to the bay sets up an across-shelf density gradient that is reversed from a typical estuary, and likely contributes to the mean surface on-shelf transport in this region. Surface-drifter trajectories observed over the course of the study suggest that both the across-shelf wind and the across-shelf density gradient are important in driving surface up-bay transport and in the retention of surface-dwelling organisms in eastern Casco Bay.

Keywords: United States; Maine; Gulf of Maine; Casco Bay; Bay/shelf exchange; Estuarine circulation; Near-shore flows

1. Introduction

ECOHAB-GOM (Ecology and Oceanography of Harmful Algal Blooms—Gulf of Maine) is a study designed to understand the dynamics of the toxic dinoflagellate *Alexandrium fundyense* in the Gulf of Maine (GOM). A key objective of the project is to understand better the transport processes linking *A. fundyense* source regions with areas where toxic blooms occur. In this paper, the exchange of water between eastern Casco Bay and the western GOM shelf is examined.

Casco Bay is a large (20×40 km), complex coastal system with depths ranging between 3 and 50 m. The Bay is separated into western and eastern regions by the Harpswell Neck Peninsula (Fig. 1). In

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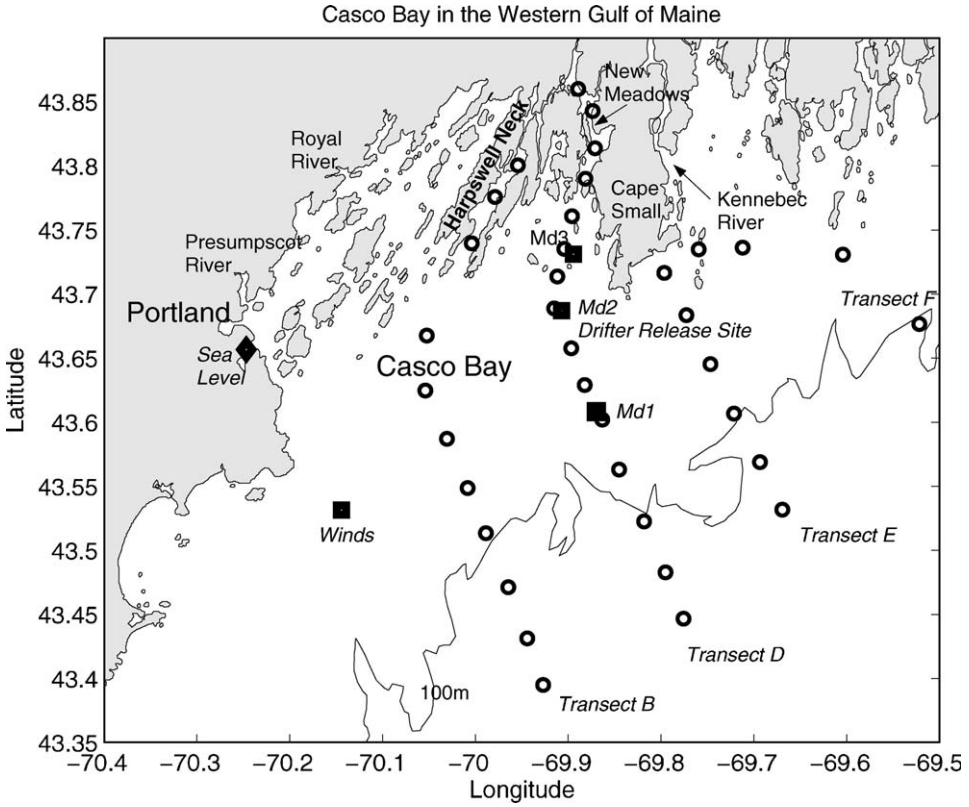

Fig. 1. Map of Casco Bay, showing CTD survey stations and mooring locations.

western Casco Bay, the major tidal constituent is the semi-diurnal lunar tide (M_2) (Parker, 1982). Tidal current amplitudes are as high as $0.60\,m\,s^{-1}$ in the channels connecting the western Bay and the adjacent shelf, and tidal sea-level range is approximately 3 m near Portland. Western Casco Bay receives freshwater directly from the Royal and Presumpscot Rivers, which have a combined annually averaged discharge of order $40\,m^3\,s^{-1}$. What may be the dominant freshwater source to eastern Casco Bay is the Kennebec/Androscoggin river system (referred to as 'the Kennebec'). The Kennebec discharge empties into the GOM northeast of Casco Bay, and is at least an order of magnitude larger than any local source of freshwater to the Bay. The combined annually averaged discharge for the Kennebec and Androscoggin rivers is over $300\,m^3\,s^{-1}$, though instantaneous daily values can exceed $4000\,m^3\,s^{-1}$ during the spring freshet (March–June).

Kistner and Pettigrew (1999) demonstrated that freshened shelf water, largely of Kennebec origin, migrates into eastern Casco Bay. This fresh-water lens sets up a baroclinic pressure gradient field that results in onshore surface flow within the New Meadows River estuary. Surface up-estuary flow was observed by Kistner and Pettigrew during both high- and low-discharge conditions, suggesting the up-estuary density-induced flow occurs under variable freshwater inputs.

Another dominant feature adjacent to Casco Bay is the southwestward-flowing Western Maine Coastal Current (WMCC) (Vermersch et al., 1979; Churchill et al., 2005). A plume of relatively fresh water, containing discharge from the Kennebec and rivers farther to the east, is often embedded within the current. The across-shelf structure of the plume is significantly influenced by along-shelf wind stress in a manner consistent with Ekman dynamics, where upwelling-favorable winds result in widening of the plume as far offshore as 50 km, and downwelling-favorable winds narrow the plume to within 10 km of the coast (Fong et al., 1997; Geyer et al., 2004).

The Casco Bay region often experiences shellfish toxicity during the spring and early summer (April–June), with high abundances of *A. fundyense* occurring in eastern Casco Bay as far inshore as the