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The kinematic and hydrographic structure of the Gulf of Maine Coastal Current

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Abstract

The Gulf of Maine Coastal Current (GMCC), which extends from southern Nova Scotia to Cape Cod Massachusetts, was investigated from 1998 to 2001 by means of extensive hydrographic surveys, current meter moorings, tracked drifters, and satellite-derived thermal imagery. The study focused on two principal branches of the GMCC, the Eastern Maine Coastal Current (EMCC) that extends along the eastern coast of Maine to Penobscot Bay, and the Western Maine Coastal Current (WMCC) that extends westward from Penobscot Bay to Massachusetts Bay. Results confirm that GMCC is primarily a pressure gradient-driven system with both principal branches increasing their transport in the spring and summer due to fresh-water inflows, and flowing southwestward against the mean wind forcing during this period. In the spring and summer the subtidal surface currents in the EMCC range from 0.15 to 0.30 $\mathrm{m\,s^{-1}}$ while subtidal WMCC currents range from 0.05 to 0.15 $\mathrm{m\,s^{-1}}$. The reduction of southwestward transport near Penobscot Bay is accomplished via an offshore veering of a variable portion of the EMCC, some of which recirculates cyclonically within the eastern Gulf of Maine. The degree of summer offshore veering, versus leakage into the WMCC, varied strongly over the three study years, from nearly complete disruption in 1998 to nearly continuous through-flow in 2000. Observations show strong seasonal and interannual variability in both the strength of the GMCC and the degree of connectivity of its principal branches.

Keywords: Gulf of Maine; Coastal current; Seasonal variability; Interannual variability; Cyclonic gyres; Offshore current veering

1. Introduction

The Gulf of Maine (GOM) is a mid-latitude marginal sea that is bounded by the coastlines of New England and Atlantic Canada. Like other northern-hemisphere marginal seas, the general circulation of the GOM is cyclonic (Bigelow, 1927). The principal cyclonic circulation cell is centered in the eastern GOM and has accordingly sometimes been referred to as the Jordan Basin Gyre (e.g., Pettigrew et al., 1998). The schematic summer surface circulation diagram presented by

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Bigelow (1927) remained essentially unaltered until the study of Brooks (1985). Based primarily on hydrographic data, Brooks (1985) modified the schematic surface patterns, showing both the cyclonic flow of the interior regions and an indication of the coastal current system over the shelf regions that set southwestward along the coast of Maine. In addition, Brooks (1985) included an indication of the deep circulation patterns of the slope water, and its derivatives, that enter the Northeast Channel.

The relative isolation of the GOM from the open waters of the North Atlantic, together with significant input of fresh water from the Scotian Shelf (Smith, 1983; Brown and Irish, 1993) and several large river systems including the St. John, the Kennebec-Androscoggin, and the Penobscot, produce a degree of estuarine character to the general circulation and property distributions within the gulf. There is deep inflow of relatively high-salinity slope water through the Northeast Channel and compensating outflow of surface and intermediate waters through both the Northeast Channel and the Great South Channel at either end of Georges Bank. However, like other marginal seas but unlike archetypal estuaries, the GOM is large relative to its internal deformation radius (~10 km) and thus supports a vigorous meso-scale circulation including a complex, variable, and little-studied coastal current system that flows from the gulf coast of Nova Scotia to Massachusetts.

While little is known in detail about the Gulf of Maine Coastal Current (GMCC), it is generally thought to consist of multiple branches with at least partial and/or intermittent flow through from one to another (Lynch et al., 1997; Pettigrew et al., 1998). The GMCC has two principal branches: the Eastern Maine Coastal Current (EMCC), identified with the cold coastal band that extends from the mouth of the Bay of Fundy southwestward along the eastern coast of Maine to the vicinity of Penobscot Bay; and the Western Maine Coastal Current (WMCC), which extends from Penobscot Bay to Cape Cod Massachusetts, and is not easily identified by surface temperature patterns. The scientific consensus is that a major portion of the EMCC turns offshore at a variable location in the vicinity of Penobscot Bay (Brooks and Townsend, 1989; Bisagni et al., 1996; Pettigrew et al., 1998), contributing to the cyclonic circulation around Jordan Basin, and that another portion may continue southwestward contributing the WMCC (Pettigrew et al., 1998). The nature of the connection between the two principal branches of the GMCC, and the issue of whether or not there are times when the EMCC follows exclusively one route or the other, has remained unresolved.

The physical characteristics of the GMCC system have been the subject of intense interest but little direct observation. Most of the observations that have been reported from the shelf regions were part of larger-scale, sparsely sampled surveys that were focused on the overall circulation and water property distributions of the GOM (e.g., Bumpus and Lauzier 1965; Brooks, 1985; Brooks and Townsend, 1989; Pettigrew et al., 1998). Exceptions to this generalization are recent studies of the WMCC by Geyer et al. (2004) and Churchill et al. (2005) that incorporate modern current meter and hydrographic surveys.

Townsend et al. (1987) and Brooks and Townsend (1989) emphasize the importance of the coastal current system and its rich load of inorganic nutrients to the biological productivity of the GOM. Advective transport of the high-nutrient waters of the cold, vertically mixed, EMCC waters toward the southwest and offshore into the Jordan Basin was shown by Pettigrew et al. (1998) to represent significant contributions, especially to the offshore regions that are normally nutrient depleted during the late spring and summer.

The variability and pathways of the EMCC, and its connection to the WMCC, take on added importance given the very high densities of the toxic red tide dinoflagellate, *Alexandrium fundyense*,[1] that have been recently documented in the waters of the EMCC during summer (Townsend et al., 2001). The Ecology and Oceanography of Harmful Algal Blooms (ECOHAB) GOM study showed that the concentrations of the red tide organism were consistently high during the summer months. Satellite data suggest that interannual differences in frontal zone structure associated with the EMCC are linked to the strength of toxic events along the western GOM shore (Luerssen et al., 2005). Thus the trajectories and pathways of the HAB-laden waters of the EMCC, which are centered on the outer eastern shelf away from the

[1]Both *A. tamarense* and *A. fundyense* occur in the Gulf of Maine (Anderson et al., 1994). We consider these to be varieties of the same species (Anderson et al., 1994; Scholin et al., 1995). Thus, for the purpose of this study, the name *A. fundyense* is used to refer to both forms, as this is the dominant variety observed in the study area (Anderson et al., 1994).