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Surface and bottom temperature and salinity climatology along the continental shelf off the Canadian and U.S. East Coasts

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ABSTRACT

A new hydrographic climatology has been created for the continental shelf region, extending from the Labrador shelf to the Mid-Atlantic Bight. The 0.2-degree climatology combines all available observations of surface and bottom temperature and salinity collected between 1950 and 2010 along with the location, depth and date of these measurements. While climatological studies of surface and bottom temperature and salinity have been presented previously for various regions along the Canadian and U.S. shelves, studies also suggest that all these regions are part of one coherent system. This study focuses on the coherent structure of the mean seasonal cycle of surface and bottom temperature and salinity and its variation along the shelf and upper slope. The seasonal cycle of surface temperature is mainly driven by the surface heat flux and exhibits strong dependency on latitude ($r \approx -0.9$). The amplitude of the seasonal cycle of bottom temperature is rather dependent on the depth, while the spatial distribution of bottom temperature is correlated with latitude. The seasonal cycle of surface salinity is influenced by several components, such as sea-ice on the northern shelves and river discharge in the Gulf of St. Lawrence. The bottom salinity exhibits no clear seasonal cycle, but its spatial distribution is highly correlated with bathymetry, thus Slope Water and its intrusion on the shelf can be identified by its relatively high salinity compared to shallow, fresher shelf water. Two different regimes can be identified, especially on the shelf, separated by the Laurentian Channel: advection influences the phasing of the seasonal cycle of surface salinity and bottom temperature to the north, while in the southern region, river runoff and air-sea heat flux forcing are dominant, especially over the shallower bathymetry.

1. Introduction

It would be an euphemism to say that the Canadian and U.S. East Coast are an important area for fisheries. Considering how European fishermen used to cross the Atlantic Ocean to confront the mists of the Grand Banks and the marks that their often tragic epics left in literature (Kipling, 1897; Loti, 1886), the impact of the region in history and science is not to be underestimated. Accordingly, numerous previous studies examined the oceanography of the individual regions along the continental shelf from the Mid-Atlantic Bight to the Labrador Sea. Yet, a relatively limited number of studies have tried to understand the links between these regions, or considered the eastern shelf as one coherent system.

The temperature, salinity, depth and width of the continental shelf all vary considerably along the approximately 5000 km distance between Labrador and Cape Hatteras, posing a significant challenge to examining the climatology in a coherent fashion. The Labrador Shelf is partly or completely covered by sea-ice from December to June (see the red contour in the Fig. 1 for maximum extent of the 15% sea-ice concentration). The maximum extent of ice coverage is reached in February or March, and the ice, pushed southward by both the wind-driven and the buoyancy-driven circulations, is found as far south as 45°N, covering most of the Newfoundland Shelf and the Gulf of St. Lawrence (Ikeda et al., 1996; National Snow and Ice Data Center, 2006). This sea-ice insulates the shelf water from atmospheric forcing and thus alters the variability of temperature and salinity on the Labrador Shelf, and also in the Gulf of St. Lawrence from January to April. This is not the case in the Mid-Atlantic Bight, where waters never reach freezing temperatures. Bathymetry also encourages a more

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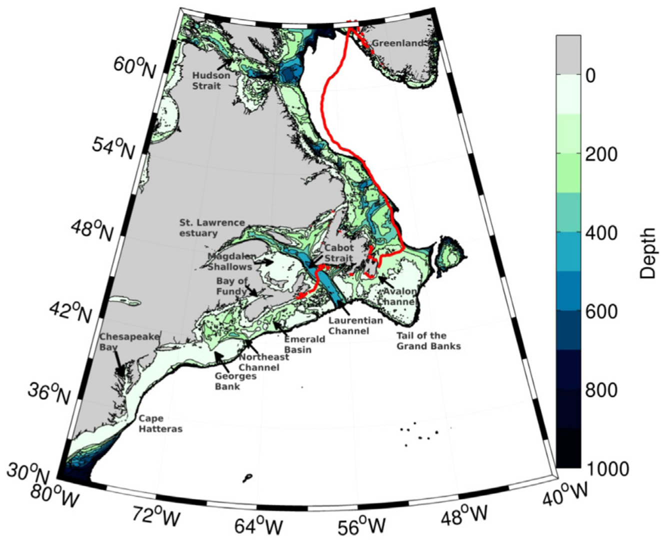

Fig. 1. Bathymetry of the study area. Contours are given every hundred meters from 0 to 1000 m. The red line shows the maximum 15% concentration sea-ice extent. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

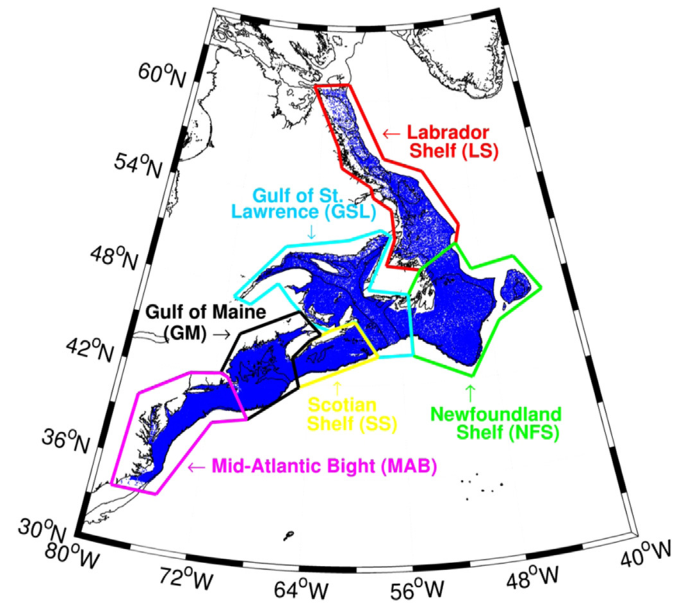

Fig. 2. Description of the six sub-regions. Each data point is represented by a blue dot. Contours represent the 0, 200 and 600 m isobaths. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

regional focus, with the shelf break shoaling from 300 m in the north to 50 m in the south, the 500 m deep Laurentian Channel bisecting the shelf just west of the Grand Banks, and with the shallow, open Grand Banks of Newfoundland contrasting the deep, enclosed basins of the Gulf of Maine.

Despite these regional differences, Chapman and Beardsley (1989) have used oxygen isotope measurements to demonstrate the interconnected nature of the coastal circulation in the western North Atlantic, tracing the origin of the shelf water in the Mid-Atlantic Bight poleward to the southern coast of Greenland. Furthermore, Loder et al. (1998) discuss the circulation, transport, and hydrography of the northeastern North American coastal ocean as a single large-scale physical regime, predominantly influenced by this coastal boundary current system. Features of the shelfbreak front, where cooler fresher shelf water meets warmer saltier Slope Water, exhibit similar large-scale continuity. The examination by Fratantoni and Pickart (2007) of over 700 synoptic hydrographic sections between the west coast of Greenland and the Mid-Atlantic Bight demonstrated a coherent evolution of both the structure of the front and its associated current.

The Baffin Current and the westward branch of the West Greenland Current converge on the northern Labrador Shelf to form the Labrador Current and its associated shelf flow (see Figs. 1 and 2 for the map of study area ; also see the Figure 1 of Fratantoni and Pickart (2007)). While a large portion of this current recirculates into the subpolar gyre upon reaching the Grand Banks of Newfoundland (Fratantoni and McCartney, 2010), the rest follows the shelf equatorward, ultimately reaching the Mid-Atlantic Bight, where it encounters the Gulf Stream near Cape Hatteras (Fratantoni and Pickart, 2007). According to Loder et al. (1998), this circulation is driven by buoyancy. Since the Labrador Current is the western boundary current of the subpolar gyre and the Gulf Stream is the western boundary current of the subtropical gyre, our area of study is confined between two major gyres carrying contrasting water masses and is influenced by both. Snow and ice melts from Greenland and Hudson Strait area represent a significant source of fresh water to the coastal boundary current system on the Labrador Shelf, further combined with the St. Lawrence river runoff, to form the mean flow on the Scotian Shelf (Chapman and Beardsley, 1989; Khatiwala et al., 1999). Further south, freshwater input is predominantly from rivers and estuaries in the northern Gulf of Maine and southern Mid-Atlantic Bight. Fresh shelf water is mixed with saltier Slope Waters through various means, including vertical tidal mixing (Garrett and Loder, 1981), winter convective overturning (Mountain and Jessen, 1987), and as part of cross-shelf exchanges through deep channels such as the Laurentian and Northeast Channels (Galbraith, 2006; Mountain and Manning, 1994), as well as smaller channels cutting into the Scotian Shelf (Drinkwater and Gilbert, 2004).

Previous studies have shown that temperature and salinity at the surface and the bottom of the ocean exhibit coherent variability along the shelf over a range of timescales. Loder et al. (1998) emphasized this coherence on seasonal time scales based on maps and vertical sections of winter and summer temperature and salinity. On interannual timescales, Petrie (2007) reported a coherent structure of bottom temperature and salinity anomalies from the Labrador Shelf to the Gulf of Maine associated with the North-Atlantic Oscillation. Finally, Shearman and Lentz (2010) showed that century-long ocean warming trends observed along the entire northeast U.S. coast are not related to local atmospheric forcing but driven by atmospheric warming of source waters in the Labrador Sea and the Arctic, which are advected into the region.

The remainder of this paper is organized as follows. In Section 2, we describe the construction of the climatology, including data sources, quality control and gridding procedures. In Section 3, the mean seasonal cycles of surface/bottom temperature/salinity are described with focus on their latitudinal coherence and variation along the shelf and upper slope over the study region. More detailed examination of the specific regional patterns is presented in Section 4. The discussion and conclusion are given in Section 5.

2. Data

2.1. Sources

To obtain a coherent dataset over a large region, from Cape Hatteras to the Labrador Shelf, and over the longest possible time span, two different data sets were processed in an identical way and combined. The first one, the temperature and salinity from the