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The impact of Scotian Shelf Water "cross-over" on the plankton dynamics on Georges Bank: A 3-D experiment for the 1999 spring bloom

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Abstract

The 1999 March SeaWiFS images detected an intense phytoplankton bloom on the southern flank of Georges Bank (GB). The bloom covered a large portion of the southern flank between the 60 and 200 m isobaths, and later extended to and connected with an even larger patch near the Northeast Peak (NEP) and Browns Bank. A three-dimensional (3-D) model experiment was conducted to examine the cause of the bloom and the impact of Scotian Shelf Water on the spring phytoplankton bloom dynamics. The finite volume coastal ocean model (FVCOM) provided the hydrodynamic fields for Lagrangian particle trajectory, tracer and biological model experiments. Process-oriented modeling experiments showed that the formation and maintenance of the phytoplankton bloom on the southeastern flank of GB is related to the weak stratification caused by the transport of the colder but fresher Scotian Shelf Water across the Northeast Channel (NEC). With sufficient nutrients from the slope, the bloom could result from in situ growth of phytoplankton near the slope where the stabilizing salinity front is located. The model results suggest that the timing and location of the phytoplankton bloom on the southern flank of GB is sensitive to the spatial distribution of temperature and salinity on the bank, the flow fields across the NEC, and the location of the salinity front near the shelf break.

Keywords: Phytoplankton; Algal bloom; Modelling; Finite volume; Coastal Ocean model; Scotian Shelf Water

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1. Introduction

The springtime phytoplankton bloom in the Gulf of Maine (GOM) and Georges Bank (GB) is a recurrent seasonal event that persists for weeks (Riley, 1941; O'Reilly et al., 1987; Townsend and Thomas, 2001, 2002). It usually occurs in March and April over a large area, and can be easily detected in satellite images (Thomas et al., 2003). Spring phytoplankton blooms are important in modifying the elemental composition of surface waters, providing the food source for higher trophic levels, and potentially having a long-term (months) impact on lower trophic level food web dynamics (Cloern, 1996). On GB, the timing, location and magnitude of blooms appear to be critical for the recruitment success of zooplankton populations. For example, the production rate of copepod *Calanus finmarchicus* could be limited by the lack of food (phytoplankton) on the southern flank of the bank during spring time (Campbell et al., 2001). Therefore, a detailed examination of the spatial-temporal evolution of phytoplankton blooms will improve our understanding of zooplankton population dynamics on GB, which is further related to populations in a higher trophic level, such as cod and haddock.

In a natural system, patchiness of the spring bloom is mainly controlled by (1) spatial variability in the local balance between phytoplankton production and loss and (2) spatial and temporal variations in the transports of water and phytoplankton (Lucas et al., 1999). This dynamics can be summarized by the following equation:

$$\frac{\partial C}{\partial t} = B - \nabla(VC) + \nabla(K\nabla C),$$

where $C(x, y, z, t)$ is the concentration of phytoplankton at position (x, y, z) at time t; $V(u, v, w)$ represents the advective fluid velocities in x, y, z directions; Kx, Ky, Kz are diffusivities in x, y, z directions; $\nabla = (\partial/\partial x, \partial/\partial y, \partial/\partial z)$ is the Laplacian operator; and B is the biological source and sink terms. On the left side of equation is the local rate of change of C. On the right side, the second term is advection and the third term is the diffusion term. B can vary significantly in the horizontal due to variations in water depth as well as differences in turbidity, nutrient concentrations, grazing pressures, turbulent mixing, and so on.

As suggested in 1-D and 2-D modeling studies (Ji et al., 2006), in the absence of advection the spring bloom in the deeper areas of GB could develop only when thermally induced stratification developed, usually after late April. However, observational data suggest that early spring phytoplankton blooms did occur occasionally in the deep flank areas. For instance, a significant bloom was observed on the southern flank of the bank in March 1999 (described in next section), indicating the important role of horizontal transport on the spring bloom dynamics in this area (Ji et al., 2006). Water on the northeast peak (NEP) and the southern flank could be advected from many sources, including the GOM, the southwestern Scotian Shelf, the central bank, and continental slope. Flow from the GOM onto the bank is a major pathway of water onto GB and has been described in various studies (e.g., Butman et al., 1987; Beardsley et al., 1997; Chen et al., 2001), while the flow of Scotian Shelf Water (SSW) across Northeast Channel (NEC) (referred as "cross-over" hereafter) appears to be episodic as suggested by historical data (Bigelow, 1927; Hopkins and Garfield, 1981; Flagg, 1987) and recent satellite-derived sea-surface temperature (SST) and hydrographic data (Bisagni et al., 1996). Using the low-salinity (<32 PSU) signature of SSW, Bisagni and Smith (1998) showed that "cross-over" events could be related to the passage of cyclonic eddies and recur with a 3–5 yr time scale. Water exchange between the central bank and the surrounding area is mainly controlled by wind-driven transport. Both modeling studies (e.g., Lewis et al., 2001) and drifter experiments (Naimie et al., 2001) indicate that the displacements of plankton from the central bank to the NEP and the southern flank could occur in 10 days with strong winds in a off-bank favorable direction. A final potential source is from the slope water in the form of warm-core rings (WCRs) as suggested by (Ryan et al., 1999, 2001). Interactions of WCRs with the surrounding hydrography can enhance phytoplankton biomass within the ring core and along the shelf break of GB. However, this process usually occurs during late spring (May).

Once the water flows onto the NEP and the southern flank, it follows a clockwise circulation along isobaths between about 60 and 100 m with maximum speeds of about 5–8 cm/s (Chen et al., 2001). The occurrence of blooms on the northern flank and NEP (upstream) has a significant influence on the ecosystem dynamics on the southern and southwestern flanks (downstream), since the post-bloom water from upstream is usually nutrient