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Data assimilative hindcast on the Southern Flank of Georges Bank during May 1999: frontal circulation and implications

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Abstract

The circulation of the tidal front along the Southern Flank of the Georges Bank region during May 1999 is examined for the purpose of understanding the transport of larval fish for periods of days to a week. Assimilation of shipboard ADCP data from several Georges Bank cruises into 3-D models is used to produce the hindcast circulation. Adjustments to boundary nodal elevations are estimated to minimize the misfit between model and observations both in frequency and time domains as described in Lynch and Hannah (J. Atmos. Oceanic Technol 18 (2001) 962) and Lynch and Naimie (Cont. Shelf Res. 22 (2002) 2191). An intercomparison of different methods of applying the adjustments is completed using drifter records and dye patch trajectories to provide a measure of skill. The computed flow fields show a skill of 2.4 km day^{-1} when compared to (unassimilated) drifter trajectories. The tracking of a dye-patch recovers an observed near-bottom cross-bank flow component that is not present without assimilation. Using these flow fields we then investigate the importance of the front as a retention mechanism using passive particle simulations. Wind, heat flux, and tides control the circulation across and along the tidal mixing front. Three 3-day time periods, before, during and after a wind event during May 1999 were studied. Model simulations suggest a highly variable cell-like circulation in the frontal region (onshore near the bottom, upwelling shoalward of the front, offshore at mid-depth and downwelling seaward of the front) that controls the exchange and retention of particles. During the periods when the cell-like circulation is active the highest accumulation of particles occurs in the areas surrounding the front.

Keywords: Data assimilation; Georges Bank; Tidal front; Modeling; Hindcast

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1. Introduction and background

In 1999, the final GLOBEC field program focused on a detailed study of cross-frontal exchange processes on Georges Bank. The bank, being landward of the shelf break on the border of US and Canada, defines the seaward extent of the Gulf of Maine (Fig. 1). The general circulation around Georges Bank is associated with the residual anti-cyclonic flow and has been intensively studied (Bumpus, 1976; Backus and Bourne, 1987). The topographic rectification of the strong tidal currents is the primary cause of this residual flow (Loder and Wright, 1985). Increased heat flux causes the development of strong stratification in late spring (April–May) over the deeper areas of the Southern Flank of the Bank where tidal mixing is reduced. On the central region of the Bank the tidal energy is sufficiently strong to overcome stratification and the whole water column is mixed by the tides (Garrett et al., 1978). Between these regions a tidal mixing front is established. The cross-bank horizontal density gradient created by the front increases the vertical shear of the along-bank flow creating a jet flowing in the along-bank direction.

A cross-bank secondary circulation develops in association with the tidal mixing front (e.g., Garrett and Loder (1981)). The main characteristics of this secondary flow are the presence of upwelling in the mixed region (on-bank of the front) and the occurrence of downwelling in the stratified region (off-bank of the front). Associated with the downwelling there is near-surface convergence and near-bottom divergence. The combined effect of this secondary circulation is the appearance of a cell-like circulation pattern. This secondary circulation has a significant effect on the transport and retention of larval fish on Georges Bank (Lough and Manning, 2001). Previous model results have recovered these features in the cross-bank direction (Loder and Wright, 1985; Lynch et al., 1992; Naimie, 1996) with bottom flow on-bank in the tidally mixed region and off-bank flow in the deeper part of the Southern Flank where stratification is present. The apparent cross-isobath flow in the vicinity of the bottom is estimated to be on the order of $1\,cm\,s^{-1}$ and this value is consistent with estimations from observations by Butman and Beardsley (1987). A similar value ($1.6\,cm\,s^{-1}$) was obtained by Houghton (2002) from dye-patch dispersion and observed temperature change as the dye passed through the frontal structure.

To further investigate the complexity of these cross-frontal processes a series of observations and model simulations were conducted at sea (Lynch et al., 2001) and, herein, in hindcast mode. The goal of the model experiments at sea was to provide the observational scientists with detailed flow fields to aide in the design of their field experiments. In the present set of hindcasting experiments, the goal is to develop a better understanding of the oceanic conditions during the cruise experiments using enhanced modeling tools. A companion paper exploring the dynamics of the Georges Bank Northern Flank jet and frontal regions is presented in this volume (Proehl et al., 2004).

Data assimilative models are used to improve the realism of the simulations. Previous studies (Lynch et al., 2001; Lynch and Naimie, 2002) showed the usefulness of data assimilation techniques for the Georges Bank region. In the present study we explore the benefits of these techniques to produce a more accurate description of the processes associated with the tidal mixing front.

2. Review aspects: data assimilation

Data assimilation has been used in the meteorology field for decades, but it is relatively new to oceanography. The idea is that imperfect observations and dynamical models can be blended to make better estimates of oceanic conditions, given knowledge of the underlying processes' variability and the various sources of error. General descriptions of oceanographic applications are provided by Thacker (1992); Bennett (1992); and Wunsch (1996). Data assimilation is a necessary component in the development of prediction systems because of the loss of predictability associated with nonlinear physical dynamics in complex models (Robinson and Lermusiaux , 2001). Disagreements between model results and observations can be the consequence of poor model representation of physics dynamics, deficient selection of the model