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Continental Shelf Research 25 (2005) 875–900
CONTINENTAL SHELF RESEARCH
www.elsevier.com/locate/csr

Modeling turbulent dispersion on the North Flank of Georges Bank using Lagrangian Particle Methods

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Received 22 March 2004; received in revised form 27 September 2004; accepted 29 September 2004

Abstract

Circulation and transport at the North Flank of Georges Bank are studied using a data-assimilative 3-D model of frontal dynamics under stratified, tidally energetic conditions over steep topography. The circulation model was used in real-time during a cross-frontal transport study. Skill is evaluated retrospectively, relative to CTD, ADCP, drifter, and fluorescent dye observations. Hydrographic skill is shown to be retained for periods of weeks, requiring only initialization from routine surveys and proper atmospheric heating subsequently. Transport skill was limited by the wind stress input; real-time forecast winds taken from an operational meteorological model produced cross-isobath Ekman transport which was not observed locally. Retrospective use of observed local wind stress removed this cross-frontal bias.

The contribution of tidal-time motion to the dispersion of a passive tracer is assessed using an ensemble of passive particles. The particle release simulates an at-sea dye injection in the pycnocline, which is followed for four days. Non-advective vertical tracer transport is represented as a random walk process sensitive to the local eddy diffusivity and its gradient, as computed from the turbulence closure. Non-advective horizontal tracer transport is zero for these ensembles. Computations of ensemble variance growth support estimates of (Lagrangian) horizontal dispersion.

Off-bank, ensembles are essentially non-diffusive. As an ensemble engages the mixing front, its vertical diffusivity rises by 3 orders of magnitude, and horizontal spreading occurs in the complex front. The resultant horizontal dispersion is estimated from the ensemble variance growth, in along-bank and cross-bank directions. It is partitioned, roughly, between that contributed by 3-D advection alone, and that initiated by vertical diffusion.

Engagement in the mixing front occurred in the forecast ensemble as a result of Ekman drift produced by an erroneous wind prediction. In the hindcast, observed wind left the ensemble non-diffusive and compact, advecting parallel to the mixing front and experiencing some advective shear dispersion.

Lagrangian dispersion is event-specific and both simulations here represent credible events with dramatically different ecological outcomes. The skill metrics used are less sensitive, indicating that metrics tailored to surface-layer

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doi:10.1016/j.csr.2004.09.022

phenomena would be more appropriate in a data-assimilative context. The hindcast is closer to truth, based on first principles (better information). The level 2.5 closure used is realistic in the ocean interior; the near-surface processes need further refinement, especially as both surface- and bottom-generated turbulence affect these events strongly.

Keywords: Dispersion; Georges Bank; Langrangian Ensemble; Hindcast; Forecast; Mixing; Diffusion

1. Introduction

Georges Bank has been a focus of oceanographic activity for over 50 years. It is a shallow bank, depth <60 m, length scale ~ 150 km, on the eastern North American shelf (Fig. 1). It separates the deeper shelf basins of the Gulf of Maine from the Atlantic Basin, and straddles the territorial waters of the US and Canada. It has been home to an important commercial fishery since European contact; this and other offshore economic activities have attracted mariners and oceanographers to it, such that there is a large accumulated literature. In the 1970s the community produced the landmark multidisciplinary volume by Backus and Bourne (1987). The decadal MARMAP program (MArine Resources Monitoring Assessment and Prediction) reflected sustained US Agency interest in the physical and biological features of the Bank, in a larger US East Coast context (Sherman et al., 1996; O'Reilly and Zetlin, 1998; Berrien and Sibunka, 1999; Meise and O'Reilly, 1996). In turn the US GLOBEC program (Global Ocean Ecosystem Dynamics) initiated its Northwest Atlantic study over the Bank during the 1990s, leading to three refereed volumes (Wiebe and Beardsley, 1996; Wiebe et al., 2001; Beardsley et al., 2003) and an ongoing synthesis effort.

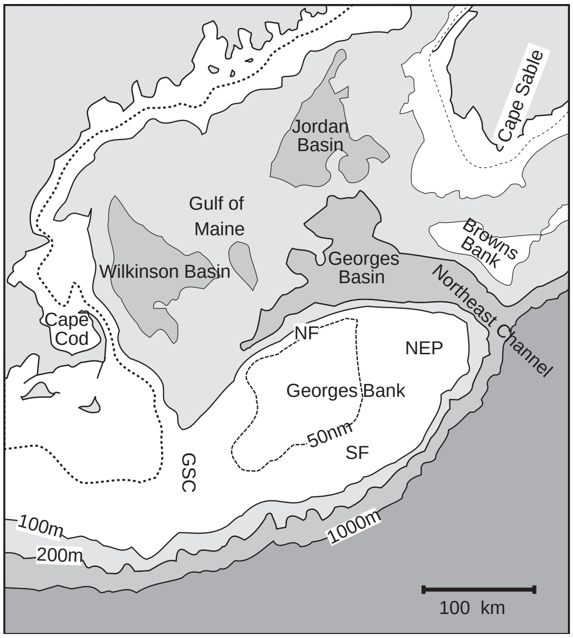

Fig. 1. Georges Bank. The four sectors of the bank indicated are NF (North Flank), NEP (NorthEast Peak), SF (South Flank) and GSC (Great South Channel, sill depth 70 m). The three basins of the Gulf of Maine connect to the Atlantic basin through Northeast Channel (sill depth 230 m). The US/Canada boundary crosses NEP. From Lynch et al. (1998b).

Fundamental to Georges Bank phenomena is the predictable occurrence of a mixing front surrounding the shallow bank top. The attendant frontal circulation patterns reflect variability at many scales, against a backdrop of tidally generated bottom turbulence. The work to date confirms that important biological aspects of the Bank depend critically on physical/biological interactions in this frontal system (Loder et al., 1988; Tremblay et al., 1994; Werner et al., 1996; Lynch et al., 1998a, 2001; Miller et al., 1998; McGillicuddy et al., 1998; Lynch, 1999; Aretxabaleta et al., 2005).

In previous work we have concentrated on the development of a real-time forecasting system which can be deployed at sea, in direct contact with the in situ data and the scientists conducting the sampling. Our basic system is rooted in a standard 3-D physical simulator. Using this we construct limited-area oceanic forecasts, concentrating simulation detail over the Bank itself but bounding the simulation close in. This simulator is fed by local observation of wind, current and hydrography, and by estimated remote influences (the unmeasured meteorological forcing; the