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Structure and timing of recirculation around Georges Bank: an observational and modeling study at the Great South Channel: Part I—ensemble smoother

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Abstract

An ensemble smoother is used to assimilate moored temperature, salinity, and velocity data into a local area primitive equation model. The overall goal of the analysis is to estimate variability of Georges Bank recirculation, i.e., northward flow through the Great South channel in support of the US Global Ocean Ecosystem Dynamics (GLOBEC) Georges Bank experiment. Here, identical twin experiments are carried out to test the ensemble smoother with a finite-element circulation model of the Great South Channel, based on a previous formulation designated QUODDY. The ensemble smoother utilizes a finite number of Monte Carlo model simulations to estimate model error covariance. The prior distribution from which the ensemble members are simulated is implicitly defined by the forward model by adding spatially correlated Gaussian random variables to the initial conditions, and time-dependent boundary elevations. Atmospheric forcing (wind stress) is derived from buoy measurements and is assumed to be known with certainty. The accuracy of the estimator depends on the state space variable being estimated and proximity to the data. In these twin experiments the domain-wide mean error variance of temperature, salinity, and velocity were reduced 96%, 93%, and 89%, respectively. The prediction statistics for the estimate are accurate throughout the domain. Non-linearity of the forward model and subsequent skewness of the posterior probability density function (pdf) are investigated. It is found that the posterior distribution is sufficiently Gaussian to use Gaussian confidence intervals. These results give confidence for using the numerical formulation and ensemble smoother to examine variability in circulation at Great South Channel with available data.

Keywords: Ensemble smoother; Monte Carlo; Non-linear data assimilation; Coastal circulation; Great South Channel; Georges Bank

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Nomenclature

ψ	system state (including time dimension)
ψ^{model}	model state
ψ^{prior}	prior (without the benefit of data) estimate of ocean state
$\psi^{posterior}$	posterior (with benefit of data) estimate of ocean state
ψ^{truth}	true state (in twin experiments)
$f(\psi^{model})$	prior distribution over model space
$f(\psi^{model}\|d)$	posterior distribution over model space
ξ	simulated measurement noise
d	vector of observations
H	measurement operator
P	forecast covariance matrix
P^{prior}	model prior error covariance for all time points
T	discrete time-averaging operator
W	data error covariance

0. Introduction

The U.S. Global Ocean Ecosystem Dynamics (GLOBEC) Phase II experiment on Georges Bank (GB) focused on retention and loss of water and its burden from the bank (Fig. 1a). The timing of recirculation through Great South Channel is hypothesized to play an important role in the recruitment of cod and haddock, two target species, during their planktonic stages (Anonymous, 1992). Nine moorings were deployed at the southwestern corner of Georges Bank, both across the Great South Channel and southern flank of the bank (Fig. 1b), to observe the circulation in and around the Great South Channel. The expectation was to directly estimate the structure and timing of recirculation, defined as northward flow of water through Great South Channel. Unfortunately many of the instruments were lost or damaged during the period of deployment.

The principal goal of this analysis is to examine the possibility of assimilating the remaining data (temperature, salinity, and velocity) into a regional primitive-equation model in order to estimate the time-averaged flow and density structure over a contiguous series of 10 tidal cycles for the duration of the deployment, January–August 1997. The estimated oceanographic fields will then be used to assist with the interpretation of oceanographic variability at the Great South Channel (Schlitz and Smith, 2005).

Georges Bank is a broad, shallow submarine bank of continental shelf off the northeastern United States of America that partially separates the deeper Gulf of Maine from the main body of the Atlantic Ocean (Fig. 1a). At the eastern end of Georges Bank a deep channel, Northeast Channel, allows inflow of Slope Water from the North Atlantic into the Gulf of Maine. Great South Channel at the western end of the bank allows water near the surface in the Gulf of Maine to flow onto the continental shelf, and also provides a pathway for recirculation of water flowing along the southern flank of Georges Bank.

Within Great South Channel and along the southern flank of Georges Bank the most energetic currents occur at the semi-diurnal period (M2). Speeds along the major axis are 70–75 cm s^{-1} within the channel (Manning and Beardsley, 1996). Long-term mean currents tend to flow clockwise around the bank, described as a partially closed gyre, with steady northward flow through Great South Channel in the summer, but highly variable during other seasons (e.g., Butman et al., 1982, 1987; Naimie et al., 1994, 2001; Limeburner and Beardsley, 1996). Detailed measurements of currents in the area of Great South Channel during the transition are sparse.

The dominant forces influencing the sub-tidal circulation on the southern flank of Georges Bank are wind, density gradients, and tidal rectification. Prior studies (e.g., Manning and Beardsley, 1996; Butman et al., 1982; Naimie et al., 1994) conclude that the general alongbank flow into the Middle Atlantic Bight, characteristic of the period when the waters are relatively unstratified, is replaced by partial recirculation through the Great South