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Application of a vanishing, quasi-sigma, vertical coordinate for simulation of high-speed, deep currents over the Sigsbee Escarpment in the Gulf of Mexico

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ABSTRACT

Recent observations over the Sigsbee Escarpment in the Gulf of Mexico have revealed extremely energetic deep currents (near 1 m s^{-1}), which are trapped along the escarpment. Both scientific interest and engineering needs demand dynamical understanding of these extreme events, and can benefit from a numerical model designed to complement observational and theoretical investigations in this region of complicated topography. The primary objective of this study is to develop a modeling methodology capable of simulating these physical processes and apply the model to the Sigsbee Escarpment region. The very steep slope of the Sigsbee Escarpment (0.05–0.1) limits the application of ocean models with traditional terrain-following (sigma) vertical coordinates, which may represent the very complicated topography in the region adequately, can result in large truncation errors during calculation of the horizontal pressure gradient. A new vertical coordinate system, termed a vanishing quasi-sigma coordinate, is implemented in the Navy Coastal Ocean Model for application to the Sigsbee Escarpment region. Vertical coordinate surfaces for this grid have noticeably gentler slopes than a traditional sigma grid, while still following the terrain near the ocean bottom. The new vertical grid is tested with a suite of numerical experiments and compared to a classical sigma-layer model. The numerical error is substantially reduced in the model with the new vertical grid. A one-year, realistic, numerical simulation is performed to simulate strong, deep currents over the Escarpment using a very-high-resolution nested modeling approach. The model results are analyzed to demonstrate that the deep-ocean currents in the simulation replicate the prominent dynamical features of the observed intense currents in the region.

1. Introduction

Observations of currents in the deep Gulf of Mexico have shown that the abyss is far from quiescent. Strong near-bottom currents exceeding 1 m s^{-1} have been measured in water depths of 2000 m over the Sigsbee Escarpment (SE), south of New Orleans (Hamilton and Lugo-Fernandez, 2001; Hamilton et al., 2003). Evidence of extreme deep currents in the region, potentially important for offshore petroleum exploration and extraction activities, has led to intensive observational efforts in the area (discussed in Section 2) and has sparked interest within the oceanographic community (Hamilton, 1990; Hamilton and Lugo-Fernandez, 2001; Oey and Lee, 2002; Hamilton, 2007).

Despite a growing database of deepwater current measurements and analyses of the observations, mechanisms generating the deep strong currents remain unclear. It has been speculated that intensification of currents along a steep slope is a manifestation of topographic Rossby waves (TRWs, Rhines, 1970) propagating along the isobaths such that the shallow water is to the right (Hamilton, 1990). The mechanisms generating these TRWs are unclear. The waves may be excited by interactions of energetic mesoscale circulation features with topography. The energetic circulation features are a product of the Loop Current, a branch of the North Atlantic's western boundary current that dominates the basin-scale circulation in the Gulf of Mexico. The Loop Current enters the Gulf through the Yucatan Strait and leaves the Gulf through the Straits of Florida (Fig. 1a). The Loop Current flows clockwise with near-surface velocities more than 0.8 m s^{-1} making a loop that extends northward. The Loop Current sheds anticyclonic mesoscale eddies (Loop Current eddies) that drift westward with smaller scale cyclones, called frontal eddies, along their periphery (the circulation in the Gulf is analyzed in detail in the literature, e.g., Sturges and Lugo-Fernandez, 2005). It is hypothesized that variations in the position of the front of the Loop Current, Loop Current eddy shedding events, and the propagation of Loop Current eddies and their associated smaller cyclones across the Gulf of Mexico generate the TRWs over the deep continental slope

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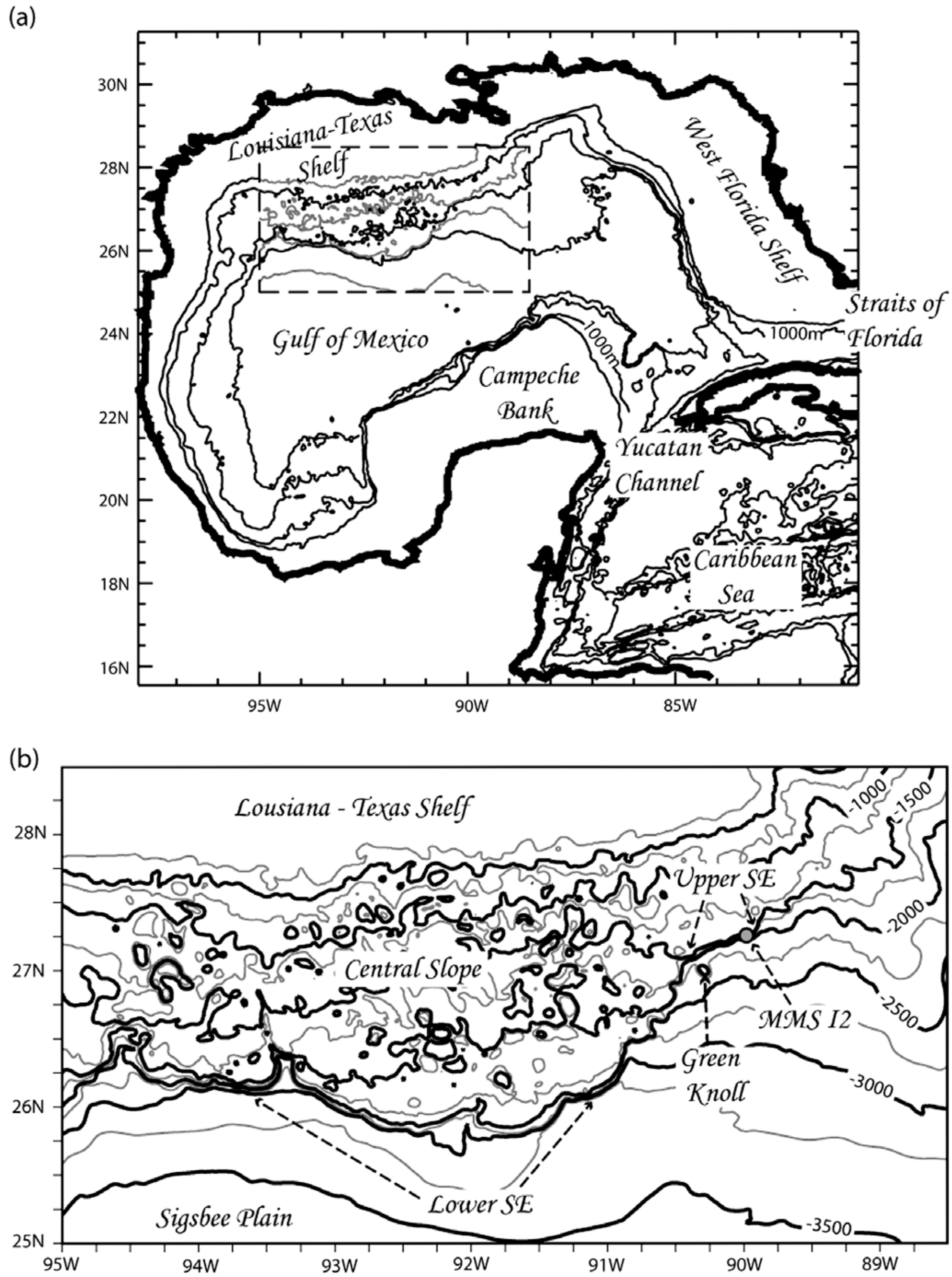

Fig. 1. (a) Bathymetry of the Gulf of Mexico model domain. Bathymetry contours are drawn every 1000 m. The Sigsbee Escarpment high-resolution model domain is indicated with a rectangle, and bathymetry contours in this area are drawn every 500 m. (b) Bathymetry of the Sigsbee Escarpment model domain. Bathymetry contours are drawn every 250 m. The location of the MMS I2 mooring is indicated in the lower panel.

responsible for the deep strong currents observed over the Sigsbee Escarpment (Hamilton and Lugo-Fernandez, 2001; Oey and Lee, 2002).

Although previous studies suggest that strong events over the SE are a manifestation of TRWs, this idea has to be revisited and validated and alternative hypotheses should be considered. For example, recent observations suggest that strong currents along the SE could be related to deep eddies impinging upon the slope (Donohue et al., 2006). Other key questions concerning the deep-water dynamics remain unanswered, and include: Are strong currents in the deep Gulf of Mexico dynamically uncoupled from the upper-ocean currents? What governs the periodicity of the energetic currents? Are wave-like motions over the deeper western part of the SE dynamically related to the upper SE further to the northeast?

A suitable model of the SE could help in addressing all of these questions. Observational studies have shown that the SE strongly influences the local deep dynamics and resulting current patterns (Donohue et al., 2006). Thus, it is envisioned that an appropriate model of the SE should have accurate representation of the bottom topography. The model should have very fine resolution for representing the steep slope because the SE is roughly 10-km wide at the narrowest places, with vertical extents of 500–1000 m. Due to the extremely complex bottom topography in the area and the very steep slope of the SE, developing a model of this region is challenging and has numerical issues that must be addressed.