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ScienceDirect
Ocean Modelling 20 (2008) 313–335
Ocean Modelling
www.elsevier.com/locate/ocemod

Comparison of overflow simulations on different vertical grids using the Finite Element Ocean circulation Model

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Received 20 July 2007; received in revised form 12 October 2007; accepted 15 October 2007
Available online 6 November 2007

Abstract

The Finite Element Ocean circulation Model (FEOM) is applied to study the sensitivity of density driven overflows to the vertical discretization and bottom topography representation using the dynamics of overflow mixing and entrainment (DOME) setup. FEOM allows for hybrid grids combining σ, $z+\sigma$, full cell, partly shaved cell and fully shaved cell grids within the same numerical kernel thus isolating as far as possible effects of mesh geometry from those of model numerics. The sensitivity of diapycnal mixing, entrainment, plume thickness and plume meridional distribution to vertical discretization and partly to the subgrid process parameterization is explored. It is shown that simulations on pure σ grids or the combination of $z+\sigma$ resolve the overflow processes best in terms of downslope plume propagation, plume thickness and dilution, and also have the least resolution dependence. Grids using z-levels generate excessive spurious mixing when resolution is insufficient. Applying partial cells improves the plume representation, but still requires higher horizontal and vertical resolution to converge to the σ grid results. It is demonstrated that increasing lateral viscosity causes the plume thickness to reduce whereas increasing lateral diffusivity has opposite effect. When keeping the Prandtl number constant, the increase in diffusivity and viscosity leads to an increase in mixing and plume thickness on z-level grids and also on σ-grids when lateral dissipation is oriented along geopotential surfaces. Using the along σ- diffusion helped to obtain correct plume thickness and entrainment on σ grids. Increasing the vertical mixing coefficients leads to an increase in diapycnal mixing and in downslope penetration as well.

Keywords: Overflow; Diapycnal mixing; Vertical discretization; Resolution; Subgrid parameterization; Finite element

1. Introduction

Overflows are density driven currents flowing down topography. They are an important ingredient of the deep limb of the thermohaline circulation of the world ocean being a source of the deep water in the world ocean's basins. Accurate representation of entrainment associated with overflows and final density classes

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1463-5003/$ - see front matter
doi:10.1016/j.ocemod.2007.10.005

is of vital importance for ocean general circulation models (OGCM), yet it still is a challenge for the ocean modeling community (Griffies et al., 2000). The model's vertical discretization and bottom representation is one of the most significant factors defining the model ability to simulate overflows.

Despite several recent studies demonstrating the practical utility of z-level ocean models to simulate overflows (Legg et al., 2006; Riemenschneider and Legg, 2007), using them is still accompanied with difficulties. This is mainly due to the step-like representation of the bottom topography in traditional z-level models as shown in previous work (Gerdes, 1993; Beckmann and Döscher, 1997; Winton et al., 1998). When dense water flows down passing discrete "stairs", excessive vertical mixing generally causes artificial dilution and entrainment (Winton et al., 1998). To overcome this difficulty, augmenting z-level models with a bottom boundary layer (BBL) has been tried to better resolve overflows (Beckmann and Döscher, 1997; Campin and Goosse, 1999; Killworth and Edwards, 1999; Song and Chao, 2000). Using the partial step topography (Adcroft et al., 1997; Pacanowski and Gnanadesikan, 1998) can also make improvement to the representation of overflows, however, the spurious mixing resulting from the stepwise topography still remains a problem to be solved (Riemenschneider and Legg, 2007).

Both σ and isopycnal coordinate models can represent flows over topography more accurately and are able to concentrate vertical resolution in regions of overflow dynamics. For this reason they were extensively used in numerical studies of overflows including simulations of the Denmark Strait Overflow (DSO) with σ grid models (Jungclaus et al., 2001; Käse et al., 2003), and the Mediterranean outflow with both σ (Jungclaus and Mellor, 2000) and isopycnal (Papadakis et al., 2003) models. The study of Penduff et al. (2002) suggests that simply smoothing the topography in a z-level model leads to results qualitatively resembling those from a σ grid model. Smoothing topography is indeed a useful practical strategy (also in σ models), but as we show in this work z-level grids still have excessive plume dilution even on a uniform slope.

The DOME project (Dynamics of Overflow Mixing and Entrainment, see www.rsmas.miami.edu/personal/tamay/DOME/dome.html) established an idealized configuration to study the dynamics of overflows and to compare skill of different models in representing it. This model configuration is mainly patterned after the overflow in the Denmark Strait. Overflow plume features and the accompanying diapycnal mixing, entrainment and BBL dynamics have been studied with this configuration using different models and different vertical grids (Ezer and Mellor, 2004; Legg et al., 2006; Tseng and Dietrich, 2006), providing a useful insight into the ability of current OGCM to tackle the overflows.

This study adds to this effort using the Finite Element Ocean circulation Model (FEOM) based on a fully unstructured triangular meshes on the surface and prismatic elements in the volume (Wang et al., 2007). It has grown from the earlier approach by Danilov et al. (2004), but departs strongly from it in employing different numerical kernel and discretization.

In this work, we exploit the ability of FEOM to work with different vertical grids using the same numerical kernel. Our goal is to explore the influence of vertical discretization types and bottom representation on plume characteristics in the DOME setup. The resolution and parameterization of subgrid processes influence the plume characteristics too, and the current study touches these aspects from the perspective of performance of several vertical grids.

The vertical grid types considered by us are σ, the combination of z and σ, which includes several bottom following layers and z-levels above them, the z-level grid and two modification of it, the partly shaved cell and fully shaved cell grids. The latter two allow an improved bottom representation while using z-levels except the very last layer, and is in effect similar to the shaved cell approach of structured models (Adcroft et al., 1997). Studying the influence of grid types on simulated overflow dynamics with hybrid grid models has the advantage of isolating (as far as possible) the effect of grid types from the model physics and numerics. In this respect, the current work follows in the same line as the work by Ezer and Mellor (2004) based on the Princeton Ocean Model (POM). The ability of FEOM to support different grid types within the same numerical kernel is due to its finite-element discretization which considers the grid as a collection of elements and works with contributions from elements, which can be regular, deformed or cut.

The paper is organized as follows. Section 2 briefly describes the FEOM, the vertical discretization it supports, and the numerical setup. Section 3 presents the comparison of the performance of different vertical grids as well as confronts our results to those from other models. The final section concludes the work.