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An OGCM with movable land–sea boundaries

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Abstract

An ocean general circulation model (OGCM) with wetting and drying (WAD) capabilities removes the vertical-wall coastal assumption and allows simultaneous modeling of open-ocean currents and water run-up (and run-down) across movable land–sea boundaries. This paper implements and tests such a WAD scheme for the Princeton Ocean Model (POM) in its most general three-dimensional setting with stratification, bathymetry and forcing. The scheme can be easily exported to other OGCM's.

Keywords: Wetting and drying; Inundations; Ocean general circulation model (OGCM); Princeton Ocean Model (POM); Tides; Tsunamis; Estuarine outflows

1. Introduction

Open-sea models (i.e. OGCM's) are now routinely used to simulate eddies and jets as well as wind, river-buoyancy and tidal-driven flows; some OGCM's also have data assimilation capabilities for hindcast and forecast. Examples are: Chassignet et al. (2003), Dinniman and Klinck (2004), Ko et al. (2003), Marchesiello et al. (2003), Romanou et al. (2004), Sheng and Tang (2003), Smith et al. (2000), and our own model, Oey et al. (2003, 2004, 2005) and Fan et al. (2004). Our model is based on the Princeton Ocean Model (POM; Blumberg and Mellor, 1987) which, as do also virtually all open-sea models, assumes that the coast is a vertical wall, placed say at the 10 m isobath. Coastal boundaries constrain fluid flows and the land–sea interface also locally becomes important as one approaches the coast, where the vertical-wall assumption is clearly incorrect.

Estuarine and near-coast modelers must often deal with a land–sea boundary that is dynamically active: i.e. the land side can wet and the sea side can dry (Leendertse, 1970; Lynch and Gray, 1980; Stelling et al., 1986; Siden and Lynch, 1988; Flather and Hubbert, 1990; Falconer and Chen, 1991; Casulli and Cheng, 1992; Cheng et al., 1993; Hervouet and Van Haren, 1996; Balzano, 1998; Ji et al., 2001; Stelling and Duinmeijer, 2003; Oey, 2005; hereinafter, O2005). The physical reality of a dynamic coastal boundary is dramatically (and tragically) demonstrated during the Indian Ocean *tsunami* of 26 December 2004. Estuarine models that

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do treat *wetting and drying* (WAD) processes are generally detailed for localized (coastal) applications with less attention paid to open-sea simulations of, say, rings and oceanic jets such as the Loop Current or the Gulf Stream.

This paper implements WAD based on near-coast modelers' ideas (above) to the three-dimensional POM with general stratification and forcing. The upshot is a unified model that deals with both open-ocean and WAD physics. The numerical treatments detailed herein directly apply to many popular models that employ terrain-following sigma-coordinate on the *C*-grid, such as HYCOM (http://hycom.rsmas.miami.edu/; HYCOM uses sigma-coordinate on the shelf; in very shallow waters near the coast the coordinate switches back to *z*-coordinate; however, this may be a fixable artifice), NCOM (http://www7320.nrlssc.navy.mil/IASNFS_WWW/), and ROMS (http://marine.rutgers.edu/po/index.php?model=roms). With suitable changes, the techniques also apply to *z*-coordinate models; however, WAD processes in *z*-level are more restricted (Lin and Falconer, 1997). With regard to practical ocean forecast, this work may be useful to those who wish to design systems that are also relevant near the coast.

Section 2 discusses the WAD scheme. Section 3 tests the new code and Section 4 concludes the paper.

2. A wetting and drying scheme

Consider an ocean region R with land boundary ∂R (lands may be islands). The ocean state (sea-level, currents, density, etc.) as a function of space and time is to be simulated. OGCM's treat land boundaries as walls across which normal fluxes = 0; thus water depth $H \neq 0$ (10 m, say) at immediate grids seaward of ∂R. In codes, this zero-flux condition is often conveniently imposed by multiplying variables by a land mask FSM = 1 (0) at water (land) cells. O2005 removes this vertical-wall coastal constraint in POM using a simple WAD scheme. The scheme was tested on two-dimensional depth-averaged flows. I now extend the method to the full set of primitive equations in three dimensions with general baroclinicity and forcing.

2.1. Some definitions

Clear definitions of topography and height are necessary when discussing WAD (Fig. 1). Choose ∂R to be an absolute land boundary (ALB) across which water can never flood and FSM is set to 0. Given R, ∂R is

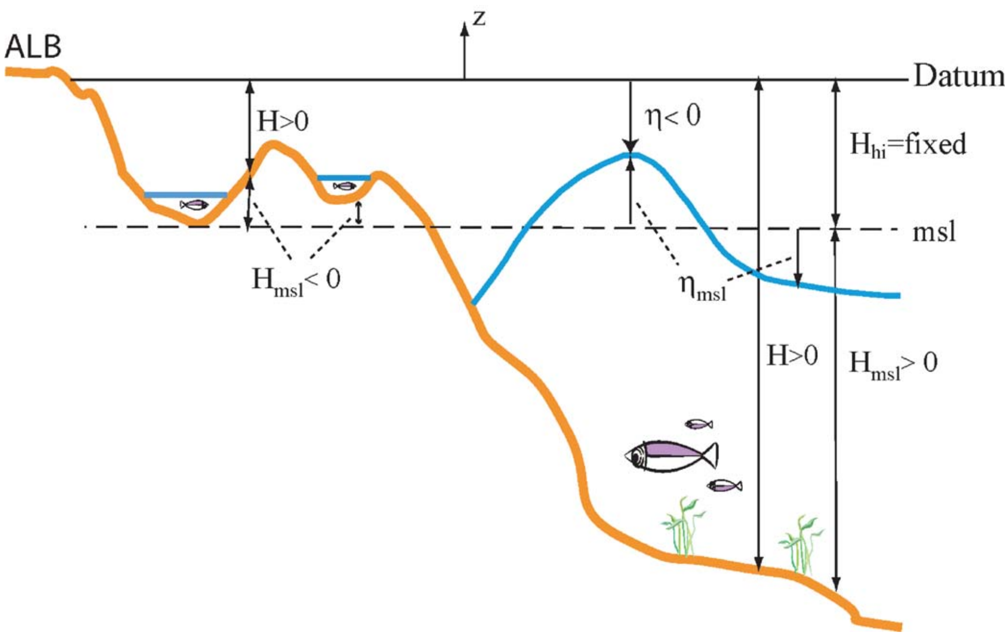

Fig. 1. Definitions of variables used in wetting and drying scheme. Acronyms ALB = absolute land boundary, msl = mean sea level.