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Continental Shelf Research 25 (2005) 935–972

CONTINENTAL SHELF RESEARCH

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A cross-scale model for 3D baroclinic circulation in estuary–plume–shelf systems: II. Application to the Columbia River

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Received 7 May 2004; received in revised form 21 September 2004; accepted 23 September 2004

Abstract

This article is the second of a two-part paper on ELCIRC, an Eulerian-Lagrangian finite difference/finite volume model designed to simulate 3D baroclinic circulation across river-to-ocean scales. In part one (Zhang et al., 2004), we described the formulation of ELCIRC and assessed its baseline numerical skill. Here, we describe the application of ELCIRC within CORIE, a coastal margin observatory for the Columbia River estuary and plume. We first introduce the CORIE modeling system and its multiple modes of simulation, external forcings, observational controls, and automated products. We then focus on the evaluation of highly resolved, year-long ELCIRC simulations, using two variables (water level and salinity) to illustrate simulation quality and sensitivity to modeling choices. We show that, process-wise, simulations capture well important aspects of the response of estuarine and plume circulation to ocean, river, and atmospheric forcings. Quantitatively, water levels are robustly represented, while salinity intrusion and plume dynamics remain challenging. Our analysis highlights the benefits of conducting model evaluations over large time windows (months to years), to avoid significant localized biases. The robustness and computational efficiency of ELCIRC has proved invaluable in identifying and reducing non-algorithmic sources of errors, including parameterization (e.g., turbulence closure and stresses at the air-water interface) and external forcings (e.g., ocean conditions and atmospheric forcings).

Keywords: Mathematical modeling; Ocean, coastal, and estuarine circulation; Eulerian–Lagrangian methods; Finite volumes; Finite differences; Semi-implicit methods

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0278-4343/$ - see front matter © 2005 Published by Elsevier Ltd.
doi:10.1016/j.csr.2004.12.003

1. Introduction

Integrated observatories (Clark and Isern, 2003; Martin, 2003; USCOP, 2004) are expected to dramatically improve the understanding of the ocean across scales and processes, and to provide unprecedented, objective information to address societal priorities regarding ocean preservation and utilization. Meeting these lofty expectations will require improvements in underlying technologies (e.g., models, platforms, sensors, and information technologies), as well as adjustments in their use.

A preview of challenges to come has been provided by selected prototype ocean observatories (Parker, 1997; Glenn et al., 2000; Steere et al., 2000; Rhodes et al., 2001; Baptista, 2002). Developed and maintained since 1996 for the Columbia River estuary and plume, CORIE (CCALMR, 1996–2004; Baptista et al., 1998; Baptista et al., 1999) is one such prototype. CORIE was designed from the onset as a multipurpose, regional infrastructure for research, education, and management. The design includes three integrated components: a real-time observation network, a modeling system, and a web-based information system.

Perhaps surprisingly, of the three CORIE components, the modeling system has posed the most fundamental challenges, calling for new modeling technologies and paradigms. In particular, we found the need to develop a new cross-scale 3D baroclinic circulation code (ELCIRC; Zhang et al., 2004) in order to meet operational requirements of efficiency and quality. Also, automated integrative procedures—including the generation of model forcings, quality controls and modeling products—have become essential to creating, improving, and interpreting simulations. Moreover, multiple simulation modes—including daily forecasts, multi-year hindcasts, and scenario simulations—forced the development of multi-scale, long-term calibration and validation strategies and procedures.

Here, we describe the CORIE modeling system (Section 2) and present selected results (Section 3), with emphasis on water levels and salinities. The description of the modeling system is intended as a reference for derivative papers, which will complement the present work by exploring in further depth specific modeling aspects, and scientific and management applications of CORIE. The results in Section 3 illustrate the extent to which the modeling system is already able to describe complex, multi-scale circulation processes in the Columbia River and help identify directions for further improvement. In Section 4, we discuss implications for derivative research on Columbia River circulation, for further algorithmic development of cross-scale numerical models and for coastal estuarine and plume modeling within the requirements of ocean observatories.

2. The CORIE modeling system

One of the world's classic river-dominated estuaries, the Columbia River, is a highly dynamic system that responds dramatically to changes in ocean tides and water properties, regulated river discharges, and coastal winds. A dominant hydrographic feature on the U.S. west coast, the Columbia River plume exports dissolved and particulate matter hundreds of kilometers along and across the continental shelf (Barnes et al., 1972; Grimes and Kingsford, 1996). In response to seasonal changes of the large-scale coastal circulation patterns, the plume typically develops northward along the coastal shelf in fall and winter, and southwestward offshore of the shelf in spring and summer. However, the direction, thickness, and width of the plume—and, in particular, the near-field plume—can change in hours to days in response to local winds (CCALMR, 1996–2004; Hickey et al., 1998; Garcia-Berdeal et al., 2002).

Compressed and often stratified, the Columbia River estuary is subject to extreme variations in salinity intrusion and stratification regime (Hamilton, 1990; Jay and Smith, 1990; Chawla et al., in prep.). Two main channels (one dredged for navigation) cut the otherwise shallow estuary (Fig. 1). A shallow coastal region north of the Columbia River mouth combines with Coriolis to establish an underlying tendency for the near-plume to move north. This northward tendency is countered by the exit angle of the navigation