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A process-oriented numerical study of currents, eddies and meanders in the Leeuwin Current System

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Abstract

While observations provide insight for the basic nature of features in the Leeuwin Current System (LCS), process-oriented studies are useful for systematically investigating the characteristics and dynamical forcing mechanisms for the currents and eddies in the LCS. This process-oriented numerical study investigates the roles of wind forcing, thermohaline gradients and bottom topography on currents and eddy generation in the LCS with a terrain-following primitive equation model, in this case the Princeton Ocean Model (POM), on a beta-plane off the western and southwestern coast of Australia.

Results show that the LCS is an anomalous Eastern Boundary Current that generates a surface poleward current predominantly over the shelf break, an equatorward surface current with upwelling next to the coast in localized regions, an equatorward undercurrent, and highly energetic mesoscale features such as meanders and eddies. Thermohaline gradient effects are shown to be the primary mechanism in the generation of a poleward (equatorward) current (undercurrent), eddies and meanders in the LCS. Inshore of the poleward surface flow, next to the coast, wind forcing plays an important role in generating an equatorward coastal current and upwelling. The major role of the wind is to slow the poleward surface flow, enhance eddy spin up and create localized upwelling regions, such as in the north near Shark Bay and just north of Cape Leeuwin. Bottom topography is shown to be an important mechanism for intensifying and trapping currents near the coast, weakening subsurface currents and intensifying eddies off capes. The surface poleward current is predominantly steered by the shelf break, frequently leaving the coast as it follows the 200-m depth contour southward to Cape Leeuwin and eastward into the Great Australian Bight. Overall, the results of this process-oriented study compare well with available observations in the LCS.
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Keywords: Leeuwin Current; Eddies; Meanders; Princeton Ocean Model; Numerical modeling; Western Australia

1. Introduction

Subtropical Eastern Boundary Currents (EBCs) are usually equatorward at the surface, with poleward undercurrents, which are forced by prevailing equatorward winds. The major EBCs such as Peru, California, Benguela and Canary are distinguished by surface dynamic height fields that decrease toward the coast and near-surface isopycnals that slope upward (Wooster and Reid, 1963; McCreary et al., 1986). These systems are characterized by climatologically weak (<10 cm/s),

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broad (~1000 km wide) surface flow toward the equator, cold upwelled water at the surface, shallow (<30 m depth) thermoclines, and high biological productivity (Parrish et al., 1983) due to regions of significant upwelling. They are one component of the subtropical anticyclonic gyres, which are driven primarily by anticyclonic wind fields.

Along the coast of Western Australia, the prevailing winds are predominantly equatorward (Thompson, 1984; Godfrey and Ridgway, 1985); however, unique to the region, is a poleward surface current known as the Leeuwin Current. Observational studies along the western coast of Australia have shown that this current is characterized by a strong (>150 cm/s at times), narrow (<100 km wide), poleward surface current that flows opposite the prevailing wind direction (Cresswell and Golding, 1980; Godfrey et al., 1986), anomalous warm water at the surface, a deep (>50 m depth) thermocline (Thompson, 1984), and lower biological productivity due to vast regions of downwelling (Batteen et al., 1992).

An anomalous EBC, the Leeuwin Current is driven by the uncharacteristically large thermohaline gradient along the Western Australian coast. The current originates near Shark Bay and flows poleward along the continental shelf (~200 m depth) off the coast of Western Australia to Cape Leeuwin (see Fig. 1A for geographical locations) and then eastward into the Great Australian Bight (Cresswell and Golding, 1980). Associated with the system are near-surface isopycnals that slope downward, surface dynamic-height fields that increase toward the coast, and an equatorward undercurrent (Thompson, 1984; McCreary et al., 1986; Smith et al., 1991). The equatorward wind stress is overwhelmed by the meridional pressure gradient created from excessive heating in the equatorial region and large amounts of cooling in the poleward region (Godfrey and Ridgway, 1985), generating the Leeuwin Current. The source for the Leeuwin Current is predominantly an alongshore steric height gradient due to tropical Pacific water from the Indonesian throughflow (Godfrey and Ridgway,

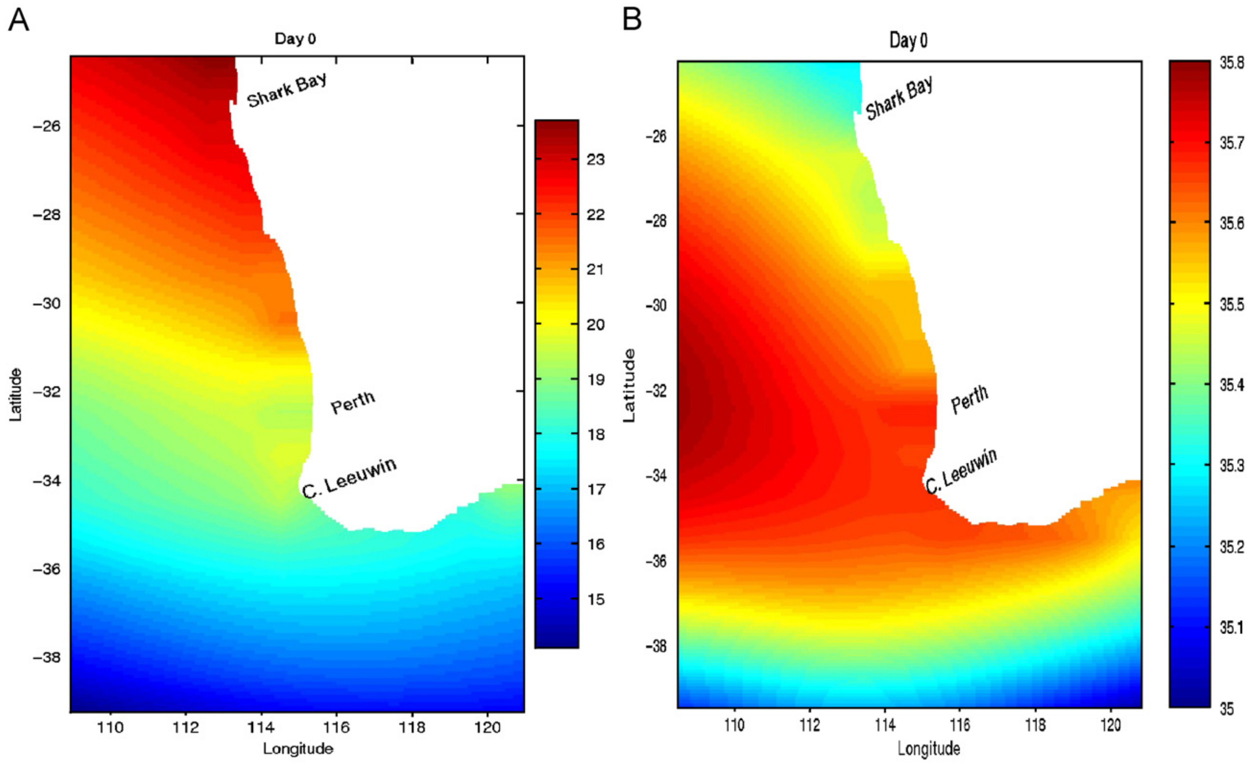

Fig. 1. (A) Annual climatological surface temperature (°C) obtained from Levitus and Boyer (1994). The model domain for the Leeuwin Current System (LCS) is bounded by 39–24.5°S, 109–121°E. The model domain has a closed boundary along the entire coast and four open boundaries. (B) Annual climatological surface salinity from Levitus et al. (1994).