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Flow separation and vertical motions in a tidal flow interacting with a shallow-water island

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Abstract

This paper reports on the case study of Rattray Island (Great Barrier Reef, northeast Australia), lying perpendicular to tidal flow in shallow waters. At ebb and flood, attached (stable) eddies develop in the wake where swirls of turbidity suggest that sediment-laden waters are brought to the surface as a result of vertical transport. Both eddy and tip upwellings are encountered in the tidal flow around Rattray Island but there is currently no clear-cut answer as to which secondary flow generates upwelling with the largest intensity. This paper addresses this specific issue through idealized and realistic high-resolution numerical experiments. The analysis is supported by physical arguments based on the theory of flow separation. Given Rattray's geometry and surrounding bathymetry, the mechanism of flow separation in shallow waters helps explain the asymmetry in size of the eddies and their intensity. The results of idealized numerical experiments also suggest that eddy and tip upwellings may be of similar intensity at Rattray Island.

Keywords: Rattray Island; island wake; flow separation; upwelling; finite elements

1. Introduction

Topographically-induced secondary circulations in the presence of islands, headlands and narrow passages can have strong effects on marine ecosystems and geology (Hamner and Hauri, 1981; Wolanski and Hamner, 1988; Coutis and Middleton, 2002; Hoitink, 2004; Suthers et al., 2004). The two-dimensional structure of these secondary circulations is often quite complex and characterized by zones of converging, diverging and curved flows. These features, combined with dominant bottom friction, lead to potential mechanisms for vertical motions (Hamner and Hauri, 1981; Wolanski et al., 1984; Geyer, 1993; Alaee et al., 2004). Over the last two decades or so, particular interest has been devoted to the understanding of the two- and three-dimensional flow in the vicinity of islands and headlands (Wolanski et al., 1984, 1996; Pattiaratchi et al., 1986; Ingram and Chu, 1987; Tomczak, 1988; Deleersnijder et al., 1992; Geyer, 1993; Alaee et al., 2004; Suthers et al., 2004; White and Deleersnijder, 2007).

This paper reports on the case study of Rattray Island in northeast Australia (Fig. 1a). Since the tidal flow is almost perpendicular to the island's main axis, flow separates and eddies develop in the wake during rising and falling tides. These eddies have been observed in aerial photographs (Wolanski et al., 1984), measured with current meters (Wolanski et al., 1984) and predicted with two- and three-dimensional numerical models (Falconer et al., 1986; Deleersnijder et al., 1992). The swirls of turbidity encountered in the wake suggest that sediment-laden waters are brought to the surface as a result

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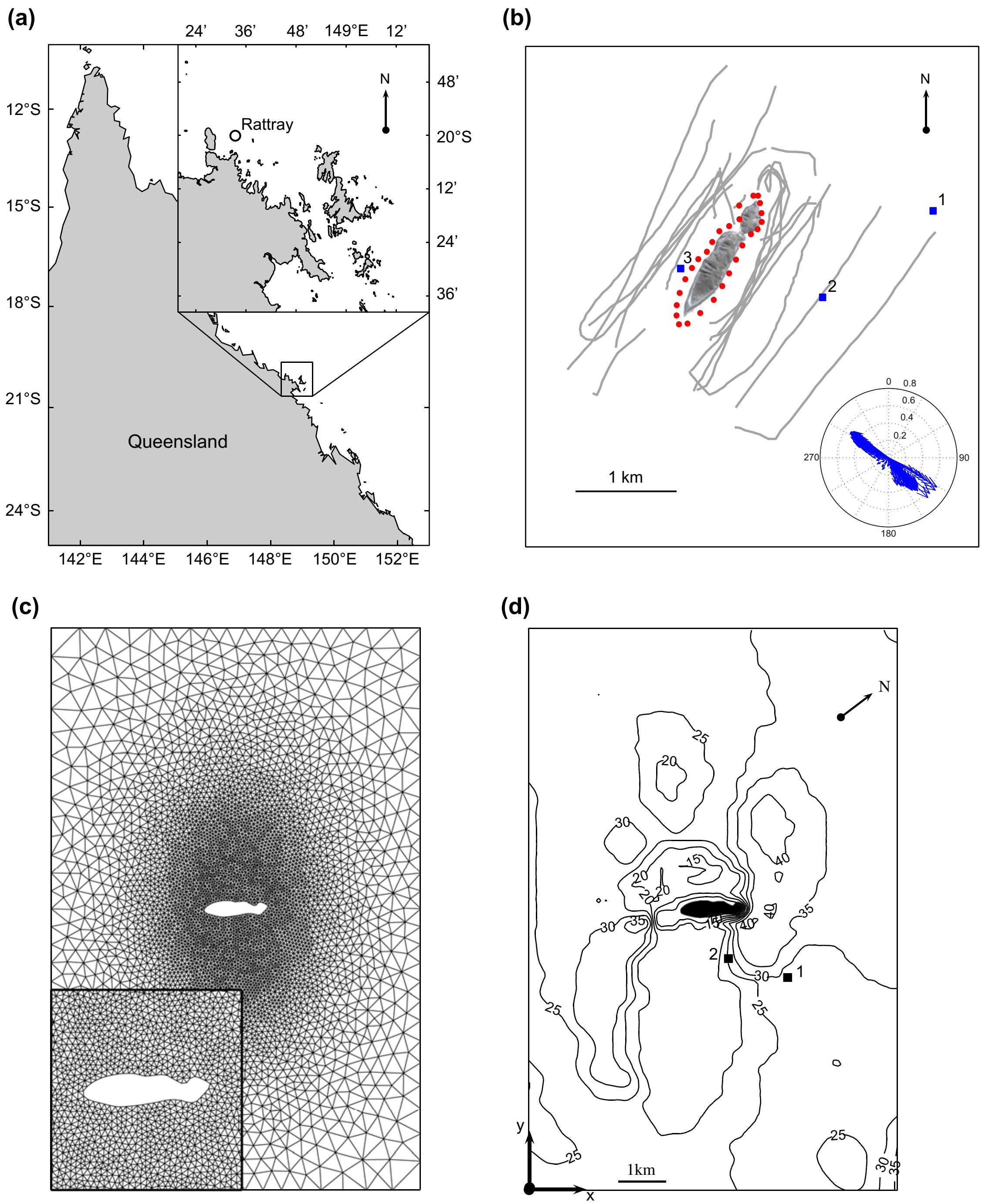

Fig. 1. (a) Rattray Island is located in the Great Barrier Reef, northeast Australia. (b) Close-up view of Rattray with locations of (1) the 2-day mooring site (4–6 December), (2) overnight ADCP (4–5 December) and CTD casts on 5 December from 3:00 to 10:30, and (3) overnight ADCP (5–6 December). ADCP transects shown in light gray. The island edge determined by GPS is represented by the red dots. The compass shows the depth-averaged horizontal velocity at site 1. (c) Mesh used for the finite element computations. The resolution varies from 800 m to 60 m in the vicinity of Rattray. The three-dimensional mesh is obtained by extruding the horizontal mesh downwards. (d) Computational domain (8 km by 11.8 km) used for all numerical simulations. The island and bathymetry (depth in meters) are rotated by an angle (52.5 degrees clockwise) such that the far-field velocity may be considered parallel to the *y*-axis. The top and bottom boundaries are open. Sites 1 and 2 identified by squares. (For interpretation of the references to color in the text, the reader is referred to the web version of this article.)

of vertical transport (by advection and mixing). The central question is whether this transport of sediments is mainly caused by eddy upwelling, upwelling along the island’s flanks where the current is the swiftest (hereafter referred to as tip upwelling) or a combination of both. Up to very recently, eddy upwelling had been considered to be the only cause for the presence of sediments in the surface layer (Wolanski and Hamner, 1988; Deleersnijder et al., 1992; Wolanski et al., 2003) whereas secondary circulations off the island’s tips had been widely overlooked.