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Summer circulation dynamics within the Perth coastal waters of southwestern Australia

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ABSTRACT

The dynamics of the summer circulation in the coastal waters off Perth in Western Australia were investigated during a two-month field experiment. The study included the deployment of an array of moorings spanning the outer shelf, the inner shelf, within the inshore Perth coastal lagoon, and in the large coastal embayment of Cockburn Sound. The results revealed highly transient coastal circulation patterns that responded to variability in both the locally- and remotely-generated forcing. Local wind forcing played a primary role in driving much of the alongshore current variability at the shallower ($<$20 m depth) inshore sites, with a well-defined peak wind forcing time scale of ~1 week that fell within the synoptic weather band in the region. Due to the mean northward wind stress that persisted during this summer period, a mean northward current of 0.05–0.1 m s^{-1} was observed at these inshore sites. Large-scale variations in alongshore water level (pressure) gradients also episodically generated strong along- and cross-shore current oscillations throughout the region. Major events were associated with the propagation of coastally-trapped waves generated by a tropical low pressure system far (~1000 km) to the north of Perth, which propagated down the Western Australia coast. On the outer shelf, local wind forcing played a minor (but still not a negligible) role in driving alongshore current variability, with this momentum balance instead dominated by the alongshore pressure gradient variability. Due to the unusually large alongshore pressure gradient that persists year round along the Western Australia coast, currents on the shelf were on average southward. However, large-scale northward reversals of the shelf flow were also observed when northward wind stresses were sufficiently large and/or the local alongshore pressure gradient became episodically weak.

1. Introduction

The southwest coastal region of Western Australia (32°S) is characterized by its unique ocean conditions, its complex coastal topography, and as a marine biodiversity hotspot (Phillips, 2001). It is also adjacent to the population center for the western half of Australia's population (Perth), which extends along the coast surrounding the Swan River. The bathymetry of the region is shaped by an extensive network of submerged offshore and fringing rocky reefs formed by Pleistocene coral reefs (Kendrick et al., 1991). The coastal region is also enclosed by three islands (Rottnest, Garden and Carnac), which form the relatively shallow ($<$20 m depth) coastal lagoon off Perth, including the large coastal embayment of Cockburn Sound (Fig. 1). The ecology of Perth's coastal lagoon is dominated by extensive seagrass meadows, kelp, and a diversity of other temperate reef communities (e.g. Carruthers et al., 2007; Kerswell, 2006; Wernberg et al., 2003).

The ocean dynamics of the shelf region of Western Australia are strongly influenced by the year-round southward (poleward) flowing Leeuwin Current, which is driven by an unusually large steric height pressure gradient that is on-average roughly an order of magnitude larger than along other eastern ocean margins (Smith et al., 1991). The strength of the Leeuwin Current seasonally varies, reaching a maximum during the austral autumn to winter period (April–July), and strengthens as it flows southward down the coast from the North West Cape (22°S). Off Perth at 32°S, the core of the Leeuwin Current is typically located near the 200 m isobath, with current speeds seasonally exceeding 0.5 m s^{-1} (Feng et al., 2003). This region is also characterized by the presence of large meandering shelf eddies which influence the coastal

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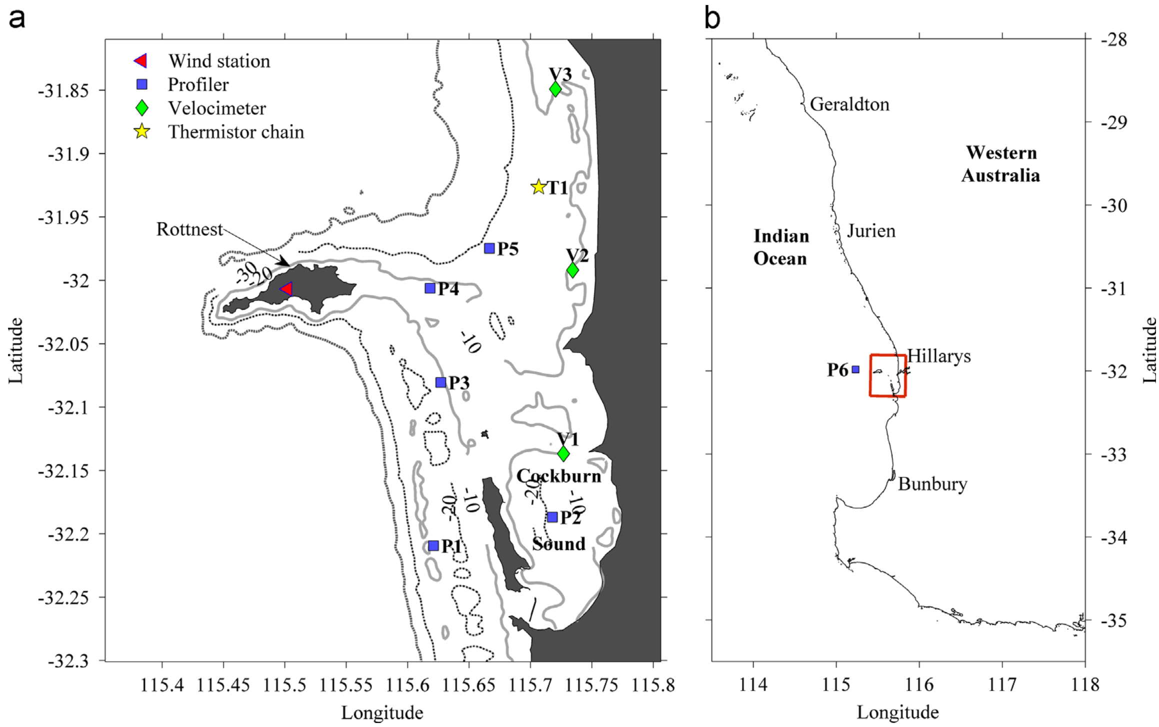

Fig. 1. (a) Bathymetry contours of the study area with the instrument locations superimposed. (b) Geographical location of the study area and location of the deep shelf mooring at P6.

Table 1
Site coordinates (in UTM zone 50) and instrument configurations. The instruments included 3 RDI Acoustic Doppler Current Profilers (ADCPs), 3 Nortek Vector acoustic Doppler velocimeters (ADVs), a Nortek Acoustic Wave and Current profiler (AWAC) and two Nortek Aquadopp Profilers (ADPs).

Site	Easting (m)	Northing (m)	Depth (m)	Sampling Period	Instrument	Bin size (m)	Sampling frequency (Hz)	Averaging interval (s)
P1	370,044	6,435,516	18	12/11/10–04/01/11	ADCP (600 KHz)	0.5	1	600
P2	379,131	6,438,124	20	12/11/10–01/01/11	ADCP (600 KHz)	0.5	0.33	600
V1	379,915	6,443,674	4	12/11/10–19/12/10	ADV	–	2	–
P3	370,419	6,449,803	13	12/11/10–04/01/11	AWAC (1 MHz)	0.5	4	1000
P4	369,488	6,458,035	8	20/11/10–04/01/11	ADP (2 MHz)	0.5	2	2000
V2	380,442	6,459,753	10	12/11/10–26/12/10	ADV	–	2	–
P5	374,009	6,461,582	16	12/11/10–04/01/11	ADCP (1200 KHz)	0.5	5	1200
T1	377,742	6,466,986	20	20/11/10–03/01/11	Thermistor chain	2	0.5	–
V3	378,928	6,475,578	9	12/11/10–25/12/10	ADV	–	2	–
P6	333,087	6,460,048	205	12/11/10–04/01/11	ADP (190 KHz)	8	1	600

dynamics and can locally promote upwelling in their core (Feng et al., 2005).

The coastal region of southwestern Australia is also strongly influenced by strong northward winds, which are greatest during the austral summer when wind speeds average more than 5 m s^{-1} and frequently exceed 15 m s^{-1}. Other processes such as tidal forcing tend to be very weak in Perth's coastal waters, given its microtidal regime (maximum tidal range of only ~0.6 m) (Lemm et al., 1999). Buoyancy forcing is also usually weak, due to the limited freshwater discharge into this region. The strong local wind stresses, which oppose the poleward pressure gradient along this coast, thus play a role in regulating the strength of the Leeuwin Current on the outer shelf. However, on the shallower inner shelf and in nearshore areas, this local wind forcing is also known to drive seasonally strong northward currents inshore of the Leeuwin Current (e.g., Gersbach et al., 1999; Lowe et al., 2012) as well as adjacent to Perth's beaches (e.g., Pattiaratchi et al., 1997). Several studies have shown how these winds drive current variability along the broader Western Australia coastline over a number of time scales, including studies focusing on the response to the strong diurnal sea breeze cycle in the region (e.g., Pattiaratchi et al., 1997; Gallop et al., 2012) and lower frequency variability associated with propagating synoptic weather systems (e.g., Cresswell et al., 1989; Lowe et al., 2012).

The detailed dynamics of Perth's inshore coastal circulation have remained surprisingly understudied, despite the great ecological, economic and social significance of this coastal region. While a number of historical studies exist, they have tended to focus on the circulation of local geographic regions as well as the circulation response to specific forcing mechanisms. Early studies of the local circulation within the Cockburn Sound embayment focused on the response of the depth-averaged currents to wind variability (Steedman and Craig, 1983), with subsequent studies providing additional insight on the vertical structure of the transport processes and their response to both wind forcing and episodic freshwater discharge during winter storms (D'Adamo, 2002). More recent studies of Cockburn Sound have been motivated by large-scale industry projects on its coast; for example, to understand the role of hydrodynamics on the dynamics of effluent plumes from a major desalination plant (Marti et al., 2011).

Other studies have focused on the sources of current variability in the Perth coastal lagoon region to the north of Cockburn Sound.