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A separated jet and coastal counterflow during upwelling relaxation off Cape São Vicente (Iberian Peninsula)

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Abstract

The circulation and structure of the coastal upper ocean during the relaxation after an upwelling event around Cape São Vicente, the southwestern tip of Iberian Peninsula, are described. Hydrographic, ADCP, wind, and remotely sensed SST data during the upwelling season reflect the interplay of two contrasting regimes in the region: coastal upwelling and a nearshore countercurrent. The observations revealed a 40 km wide jet-like flow, separated from the coast, that advected cold water southward off the west coast and eastward around the Cape. It originated prior to the cruise in the upwelling that occurred off the prominent west coast capes, north of the sampling region. Adjacent to the coast, a narrow inshore counterflow advected warm water westward along the south coast, curled anticyclonically around the Cape with velocities up to $0.4\,m\,s^{-1}$, and progressed poleward inshore of the previously upwelled water. The cold equatorward jet interacted with offshore waters and inshore countercurrent by generating small-scale instabilities, and weakened as it proceeded south and around the Cape. The inshore countercurrent was suppressed during the final part of the survey by an eastward flow associated with a return to an upwelling favourable wind off the south coast of Portugal.

Keywords: Coastal oceanography; Upwelling relaxation; Coastal countercurrents; Mesoscale features; Coastal upwelling; Eastern boundary currents; Iberian Peninsula; Portugal; Cape São Vicente

1. Introduction

The coastal transition zone near Cape São Vicente (CSV) (9°W; 37°N), where the meridional west and zonal south coasts of the Iberian Peninsula meet (Fig. 1), is markedly seasonal. During summer, the prevailing wind along the west coast blows from the north, as a consequence

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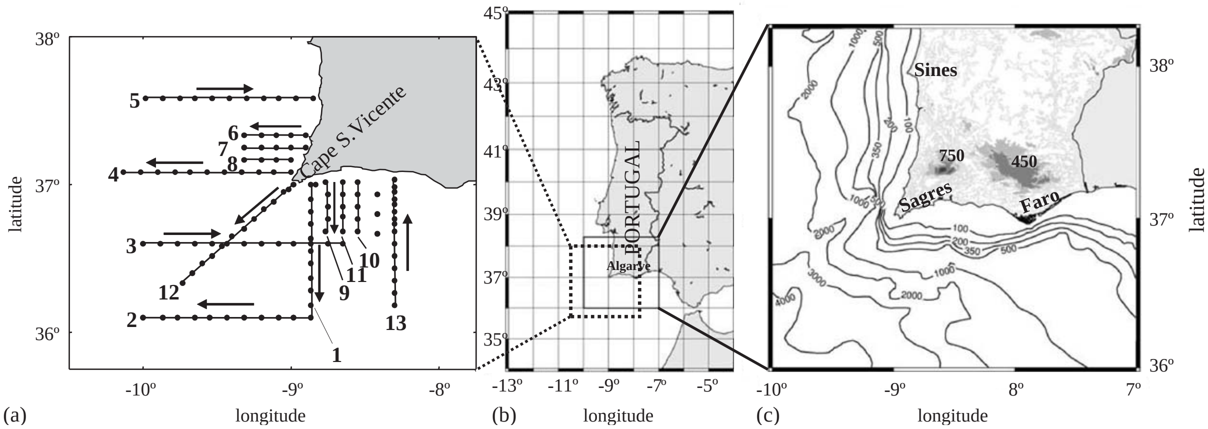

Fig. 1. Transects during the Poseidon 201/9 survey (a), the Cape São Vicente region (b) and general bathymetry and orography (c). Arrows denote the steaming direction and dots the CTD stations. Bathymetric contours are in metres.

of the strengthening Açores high-pressure cell in the central Atlantic and the weakening Iceland low-pressure cells. However, along the south coast, the summer wind is predominantly from the west. The establishment of a thermal low-pressure centre over Iberia during summer diverts the near surface wind field eastward over southern Portugal. A zonal ridge along the Algarve, highest ($\approx$ 900 m) in the west, may contribute to the deformation of the wind field. Under these winds, the coastal region off western and southern Portugal exhibits the classical circulation of eastern boundary regions—wind-forced near-surface offshore transport, upwelling of cold subsurface waters at the coast and the generation of alongshore currents.

Satellite imagery and in situ observations of the coastal ocean reveal a surface poleward current as a persistent feature of the winter circulation off western Iberia. This structure appears as a warm and saline intrusion (temperature 1–3 °C and salinity 0.2–0.3 higher than surrounding values), within about 50 km of the shelf break, 200–600 m deep, and flowing along the slope at 0.2–0.3 m s^{-1}, with transport increasing downstream (Frouin et al., 1990; Haynes and Barton, 1990). Possible generation mechanisms include density and wind forcing. The geostrophic flow of the northeast Atlantic is eastward in a broad band, north of 33°N, where a meridional density gradient, associated with the poleward cooling of the sea surface, is observed in the upper 200–300 m (Pollard and Pu, 1985). Such a density gradient can force a poleward current, intensified over the slope and increasing northward (Huthnance, 1984). Intensification of the Iceland low-pressure cell associated with a large southward displacement of the Açores high-pressure cell results in a wind pattern with a southerly component, particularly in the northern part of the Iberian Peninsula. Such a wind pattern can contribute to the generation of the observed winter poleward current off Iberia (Frouin et al., 1990).

During the March–September upwelling season, northerly winds, strongest during July–August (Wooster et al., 1976; Fiúza et al., 1982), drive an offshore Ekman transport and force subsurface waters to upwell along the coast. Upwelling responds quickly to northerly winds, particularly south of capes, appearing first along the coastline and then spreading offshore as the event progresses (Fiúza et al., 1982). During the upwelling period, the wind forcing opposes the density forcing. Upwelling causes the surface dynamic height to decrease towards the coast and the resulting equatorward geostrophic current can counter the poleward slope current at and near the surface, establishing a southward flow. However, waters below 100–200 m still flow poleward as an undercurrent (Haynes and Barton, 1990). On occasions, water upwelled on the west coast