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Surface ocean response to synoptic-scale variability in wind stress and heat fluxes off south-central Chile

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ABSTRACT

The effect of the high frequency (synoptic) variability of wind and heat fluxes upon the surface ocean off south-central Chile (west coast of South America) is investigated using a regional ocean model. We focus our analysis in austral summer, when the regional wind experiences significant day-to-day variability superimposed on a mean, upwelling favorable flow. To evaluate the nature and magnitude of these effects, we performed three identical simulations except for the surface forcing: the climatological run, with long-term monthly mean wind-stresses and heat fluxes; the wind-synoptic run, with daily wind stresses and climatological heat fluxes; and the full-synoptic run, with daily wind-stresses and daily fluxes. The mean currents and surface geostrophic EKE fields show no major differences between simulations, and agree well with those observed in this ocean area. Nevertheless, substantially more ageostrophic EKE is found in the simulations which include synoptic variability of wind-stresses, impacting the total surface EKE and diffusivities, particularly south of Punta Lavapie (37° S), where the lack of major currents implies low levels of geostrophic EKE. Summer mean SSTs are similar in all simulations and agree with observations, but SST variability along the coast is larger in the runs including wind-stress synoptic variability, suggesting a rather linear response of the ocean to cycles of southerly wind

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strengthening and relaxation. We found that coastal SST variability does not change significantly in the first tenths of kilometers from the shore when including daily heat fluxes, highlighting the prominent role of wind-driven upwelling cycles. In contrast, in the offshore region situated beyond the 50 km coastal strip, it is necessary to include synoptic variability in the heat fluxes to account for a realistic SST variability.

1. Introduction

Upwelling of cold, nutrient rich waters along much of the Chilean coast induces high primary productivity and maintains one of the major fisheries of the world (e.g., Rutllant and Montecino, 2002; Food and Agriculture Organization, 2004). Coastal upwelling is in turn locally forced by alongshore, southerly (equatorward) winds, being particularly strong around major capes at 30° S (Punta Lengua de Vaca), 33° S (Punta Curaumilla) and 37° S (Punta Lavapié) because of topographic/bathymetric effects (Figueroa and Moffat, 2000). To the north of 33° S upwelling-favorable winds prevail year round whilst off south-central Chile (35–40° S) monthly mean surface winds alternate between moderate northerlies in winter to strong southerlies in summer (DJF), following the seasonal latitudinal migration of the south Pacific anticyclone (e.g. Saavedra and Foppiano, 1992). South of 35° S synoptic variability of the winds is very pronounced in winter – when stronger northerlies are frequent due to the passage of extratropical atmospheric low-pressure disturbances. This high-frequency wind variability is still present in summer (e.g., Sobarzo et al., 2010) due to the quasi-weekly occurrences of southerly coastal low-level jet events alternating with periods of weak southerlies or even northerly flow in connection with the passage of coastal lows (Garreaud and Muñoz, 2005; Garreaud et al., 2002). These jet events are characterized by a meridionally elongated maximum of surface southerly winds over 15 $m\,s^{-1}$ generally rooted in Punta Lavapié and extending northward several hundreds of km (Muñoz and Garreaud, 2005; Montecinos et al., 2011). Consistent with the mean upwelling-favorable winds due to the southernmost position of the subtropical anticyclone and the occurrence of strong atmospheric low-level coastal jets, the region around Punta Lavapié exhibits the highest primary productivity along the Chilean coast during summer (e.g., Montecino et al., 2006).

Although the basic features of coastal upwelling, including their regional distribution and seasonal variability, have been described elsewhere (e.g., Figueroa and Moffat, 2000; Leth and Shaffer, 2001; Blanco et al., 2001; Sobarzo et al., 2007), there is less information on the surface ocean response to atmospheric low-level jet events, partly because of the scarcity of in situ data. Using satellite observations Renault et al. (2009) studied the effect of the atmospheric low-level jet on sea surface temperature (SST) off central Chile (30° S), but the blind zone close to the coast was an important limitation to capture the upwelling response to the wind forcing which is particularly important within the first 20 km off the coast (e.g., Perlin et al., 2007; Aiken et al., 2008). Modeling efforts have also been conducted to understand upwelling and ocean circulation off central Chile (Batteen et al., 1995; Leth and Shaffer, 2001; Mesias et al., 2001, 2003; Leth and Middleton, 2004; Aiken et al., 2008). However, most of these studies have used climatological (long-term-mean) wind data to force an ocean model, perhaps missing an important source of variability, particularly south of 35° S in austral summer. Only Mesias et al. (2001) and Aiken et al. (2008) used daily wind data, but the former utilized a coarse horizontal resolution (2.5° × 2.5° lat–lon grid) and the latter applied a spatially homogeneous wind stress field, as derived from records at a single coastal station. The lack of spatial structure of the near-shore winds in both studies may strongly influence the patterns of the circulation and SST (Capet et al., 2004). Recently, Renault et al. (2012) modeled the upwelling response to an atmospheric low-level jet event that occurred in spring off north-central Chile (30° S), focusing on the spatial variability of the forcing wind field.

Here, we used the Regional Ocean Modeling System (ROMS) (Shchepetkin and McWilliams, 2005) off Chile to investigate the impact of quasi-weekly atmospheric low-level jet events on the surface ocean through wind-stress and heat flux forcing. Three runs of the model were forced by different