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Surface winds off Peru-Chile: Observing closer to the coast from radar altimetry

O. Astudillo [a,b,*], B. Dewitte [a,b,f,g], M. Mallet [c], F. Frappart [b,d], J.A. Rutllant [a,e], M. Ramos [a,f,g,h], L. Bravo [f,g], K. Goubanova [a,f,i], S. Illig [b,j]

[a] Centro de Estudios Avanzados en Zonas Áridas (CEAZA), La Serena, Chile
[b] Laboratoire d'Etudes en Géophysique et Océanographie Spatiale (LEGOS), Toulouse, France
[c] CNRM UMR 3589, Météo-France/CNRS, Toulouse, France
[d] Géosciences Environnement Toulouse (GET), Toulouse, France
[e] Departamento de Geofísica, Facultad de Ciencias Físicas y Matemáticas, Universidad de Chile, Santiago, Chile
[f] Departamento de Biología Marina, Facultad de Ciencias del Mar, Universidad Católica del Norte, Coquimbo, Chile
[g] Millennium Nucleus for Ecology and Sustainable Management of Oceanic Islands (ESMOI), Coquimbo, Chile
[h] Centro de Innovación Acuícola Aquapacifico, Universidad Católica del Norte, Coquimbo, Chile
[i] CECI UMR 5318 - CNRS/CERFACS, Toulouse, France
[j] Departament of Oceanography, MARE Institute, University of Cape Town, South Africa

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ABSTRACT

The near-shore surface mesoscale atmospheric circulation in the upwelling systems off Peru and Chile is influential on the Sea Surface Temperature through Ekman transport and pumping. There has been a debate whether or not the so-called "wind drop-off", that is a shoreward decrease of the surface wind speed near the coast, can act as an effective forcing of upwelling through Ekman pumping. Although the wind drop-off has been simulated by high-resolution atmospheric models, it has not been well documented due to uncertainties in the scatterometry-derived wind estimates associated with land contamination. Here we use the along-track altimetry-derived surface wind speed data from ENVISAT, Jason-1, Jason-2, and SARAL satellites, to document the spatial variability of the mean wind drop-off near the coast as estimated from the inversion of the radar backscattering coefficient. The data are first calibrated so as to fit with the scatterometer observations of previous and current satellite missions (QuikSCAT, ASCAT). The calibrated data are then analyzed near the coast and a wind drop-off scale is estimated. The results indicate that the wind drop-off takes place all along the coast, though with a significant alongshore variability in its magnitude. Differences between products are shown to be related both to the differences in repeat cycle between the different altimetry missions and to the peculiarities of the coastline shape at the coastal latitudes of the incident tracks. The relative contribution of Ekman pumping and Ekman transport to the total transport is also estimated indicating a comparable contribution off Chile while transport associated to Ekman pumping is on average ~1.4 larger than Ekman transport off Peru. Despite the aliasing effect associated with the weak repetitivity of the satellite orbit and the high frequency variability of the winds in this region, the analysis suggests that the seasonal cycle of the surface winds near the coast could be resolved at least off Peru.

1. Introduction

Eastern Boundary Current Systems (EBUS) have drawn interest in recent years due to the societal concern on the possible changes that the rich marine ecosystems they host could experience under the influence of anthropogenic climate forcing (Bakun et al., 2015; Wang et al., 2015a). A main driver of the oceanic circulation in these regions is the along-shore momentum flux that promotes upwelling of nutrient-rich waters through Ekman dynamics. While the locally wind-forced processes that generate upwelling are well known and consist in two mechanisms, i.e. Ekman pumping and Ekman transport (Sverdrup et al., 1942) most studies of upwelling systems have focused on the investigation of Ekman transport (i.e., along-shore wind stress) and its relationship to various aspects of the regional oceanic circulation (Sea Surface Temperature (SST), productivity, fisheries) (Carr and Kearns, 2003; Chavez and Messié, 2009; Demarcq, 2009; Wang et al., 2015b; among many others). The relative contribution of both processes has in fact remained ubiquitous due to limitations of the satellite

* Corresponding author at: Centro de Estudios Avanzados en Zonas Áridas (CEAZA), La Serena, Chile.
E-mail address: orlando.astudillo@gmail.com (O. Astudillo).

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scatterometer measurements (ERS, QuikSCAT), which contain a 28 to 50-km wide blind zone along the coast limiting the description of the mesoscale atmospheric circulation within this narrow coastal fringe. The relatively low spatial resolution of these products has also resulted in uncertainty in the actual magnitude of the wind stress curl near the coast (Croquette et al., 2007). Despite recent improvements in the space resolution of the global atmospheric reanalysis products, the uncertainty in the wind stress curl estimations in the coastal band has persisted due to model biases (Wood et al., 2011) and to the scarcity of in situ observations to constrain data assimilation. This has resulted in a significant dispersion within the available products of the mean surface winds. To illustrate the latter statement, Fig. 1 presents the alongshore horizontal wind profiles at three major upwelling cells along the coast of Peru and Chile from satellite observations (QuikSCAT/ASCAT, Jason-1), the atmospheric reanalysis ERA-Interim (Dee et al., 2011) produced by the European Centre for Medium-Range Weather Forecasts (ECMWF) and the National Centers for Environmental Prediction (NCEP) Climate Forecast System Reanalysis (CFSR, Saha et al., 2010). First, it is readily apparent that reanalysis products cannot resolve the coastal zone due to their low resolution; and second, they do not agree in the magnitude and cross-shore variability of the winds in the first 200 km off the coast. In addition, regional modeling studies suggest that the wind stress near the coast in EBUS experiences a shoreward decrease in amplitude, the so-called wind drop-off, that results in a wind stress curl favorable to Ekman pumping (Capet et al., 2004; Renault et al., 2012). Observational evidence of such drop-off has been elusive due to the sparse data in the coastal fringe, although field experiments do suggest its existence in some regions, in particular off central Chile (e.g., Garreaud et al., 2011; Bravo et al., 2015).

The uncertainties resulting from the extrapolation of scatterometer winds in near-coastal regions for forcing high-resolution oceanic models have also been a limitation for gaining confidence in model results (Renault et al., 2012). Indeed, in most EBUS regional modeling studies, gridded QuikSCAT surface wind estimates have been used, implying that wind data have been extrapolated on the ocean model grid from, at best, 28 km offshore to the closest coastal grid point of the ocean model. In the process, there is the possibility that compensating effects exist between the Ekman transport and Ekman pumping on SST (e.g., a weaker (stronger) than observed drop-off would lead to a stronger (weaker) Ekman transport near the coast). Interestingly in regional simulations of upwelling systems, a mean cold bias is usually diagnosed (Penven, 2005; Penven et al., 2001; Veitch et al., 2009; Machu et al., 2009) which could reflect a bias in the balance between Ekman pumping and transport, although such a bias could be also attributed to a warm bias in some satellite based SST datasets (Dufois et al., 2012).

Moreover, coupled physical-biogeochemical coastal processes show a great sensitivity to near shore wind stress curl in upwelling regions (Albert et al., 2010) and the ecosystem dynamics is also likely critically dependent on the coastal wind pattern through its effects on mesoscale activity (Renault et al., 2016).

Therefore, there is a real need to improve our knowledge in the mesoscale atmospheric circulation in coastal regions given the need for a realistic simulation of the oceanic circulation for downstreamed applications (e.g. directed toward resources management). This is particularly true for the Peru-Chile EBUS, known as the Humboldt Current System (HCS), which hosts the most productive marine ecosystem in the world (Chavez et al., 2008). Upwelling off Chile and Peru drive an exceptionally high biological productivity (Carr and Kearns, 2003) due to the persistent equatorward low-level alongshore flow that maintains a coastal band of nutrient-rich cold waters extending from about 40°S to the equator (Hill et al., 1998; Silva et al., 2009). Measurements of surface winds over the HCS are sparse in space and time, lacking systematic,

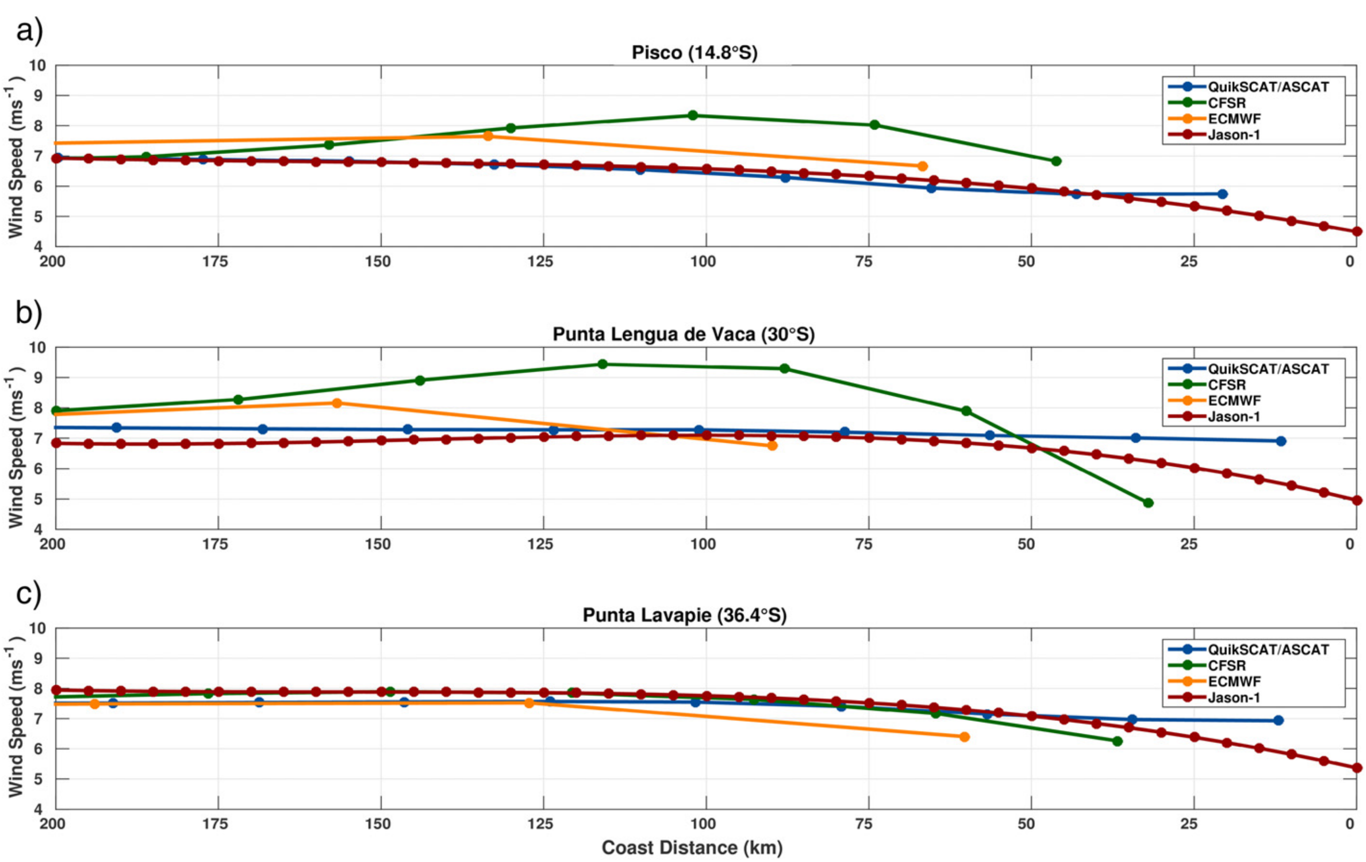

Fig. 1. Zonal mean cross-shore 10-m wind speed at (a) Pisco (14.8°S), (b) Punta Lengua de Vaca (30°S) and (c) Punta Lavapie (36.4°S) over the period 2000–2010. The blue, red, green, and orange lines are for QuikSCAT-ASCAT (0.25° horizontal resolution) scatterometers, Jason-1 (0.045°) altimeter, the CFSR (0.3°) and ERA-Interim (0.75°) reanalyses respectively. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)