2.9 WIND STRESS AND WIND STRESS CURL DURING UPWELLING SEASON ALONG THE CALIFORNIA COAST

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1. INTRODUCTION

Limitations in understanding the roles of the winds, wind stress, and wind stress curl in driving ocean dynamics are influenced by a lack of observations over the ocean. Moreover, due to the strong spatial and temporal variability of the winds, wind stress, and wind stress curl near the coast, the understanding is even more difficult in coastal zones as recognized in early work by Nelson (1977). Additional valuable but limited information is provided by buoy networks as well as short-term aircraft measurements. Satellite data are emerging as a valuable tool for surface wind estimates, but reliable estimates are based on heavy filtering that efficiently removes information on high spatial scales. In addition, there are intrinsic limitations in detecting winds in the vicinity of the coast. To complement scarce measurements over the ocean, atmospheric modeling provides estimates of the winds, wind stress, and wind stress curl over the ocean as well as an insight into the physical processes that are relevant to air sea interaction (Dorman et al. 2000; Koracin and Dorman 2001; Samelson et al. 2002; Koracin et al. 2004).

In this study, month-long Mesoscale Model 5 (MM5) simulations have been used to investigate the spatial and temporal structure of the marine-layer winds, wind stress, and wind stress curl during upwelling-favorable winds along the California and Baja California coasts. Previous work by Koracin et al. (2004) has shown that the most intense wind stress and wind stress curl are expected in the Southern California Bight. To resolve the atmospheric dynamics in this highly complex coastal zone, we have used model grids with high horizontal resolutions of 9, 3, and 1 km, respectively (Fig. 1). We have also used turbulence closure techniques to compute the wind stress and compared the results with the usual bulk computation of the stress. The study will show how these different estimations of the wind stress affect assessment of the wind stress curl.

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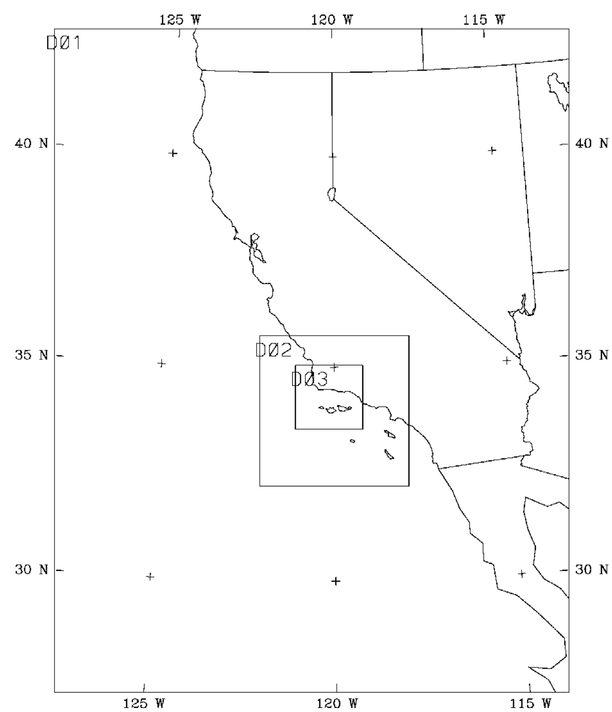

Fig. 1. MM5 setup of the modeling domains with 9, 3, and 1 km horizontal resolutions.

2. AVERAGE WINDS IN JUNE 1999

Figure 2 shows simulated wind vectors and wind speed contours averaged for all of June 1999. Expansion fans form high-speed areas in the lees of every major cape as well as on the California scale. An isotach of 6.5 ms^{-1} indicates the extension of the regional expansion scale induced by the California coastline turning from the north-south Oregon coast to northwest-southeast from Cape Mendocino to Point Conception. This regional scale expansion fan is suggested and discussed by Edwards (2000) and Koracin and Dorman (2001). As seen in Fig. 2, the most significant inshore gradients of the wind speed are in the Southern California Bight. This also implies that the stronger gradients of the wind stress curl will be in this area.

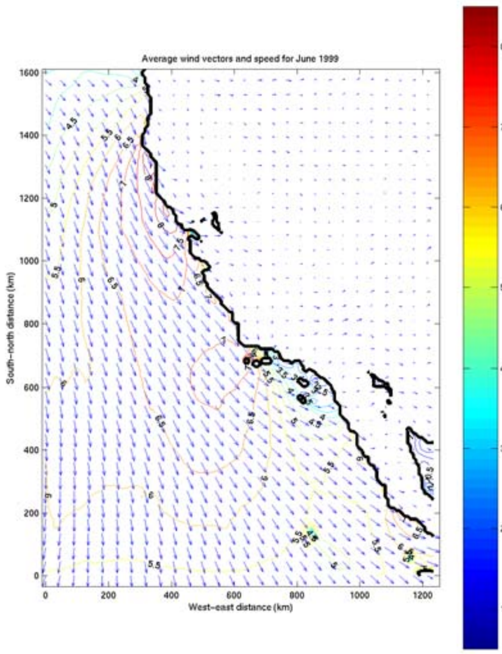

Fig. 2. Average surface wind vectors and wind speed contours for all of June 1999. Contour interval is 0.5 ms^{-1}.

3. WIND STRESS OVER THE CALIFORNIA COAST

In order to compare wind stress computed by the usual bulk method (Large and Pond 1981) with estimates using MM5 results and the level 2 second-moment closure described by Mellor and Yamada (1974), we selected 15 June 1999 as a day with strong winds on the western side and weak winds on the eastern side of the Southern California Bight. Figure 3 shows an image of the wind speed inferred from the SSM/I satellite sensor on 15 June 1999. Figure 4 confirms that MM5 was able to reproduce the observed characteristics of the wind fields along the California coast. Figure 5 shows details of the wind field in the Southern California Bight indicating significant spatial gradients of the wind speed. These gradients in the wind speed and consequently the wind stress are definitely favorable for development of the wind stress curl in this area.

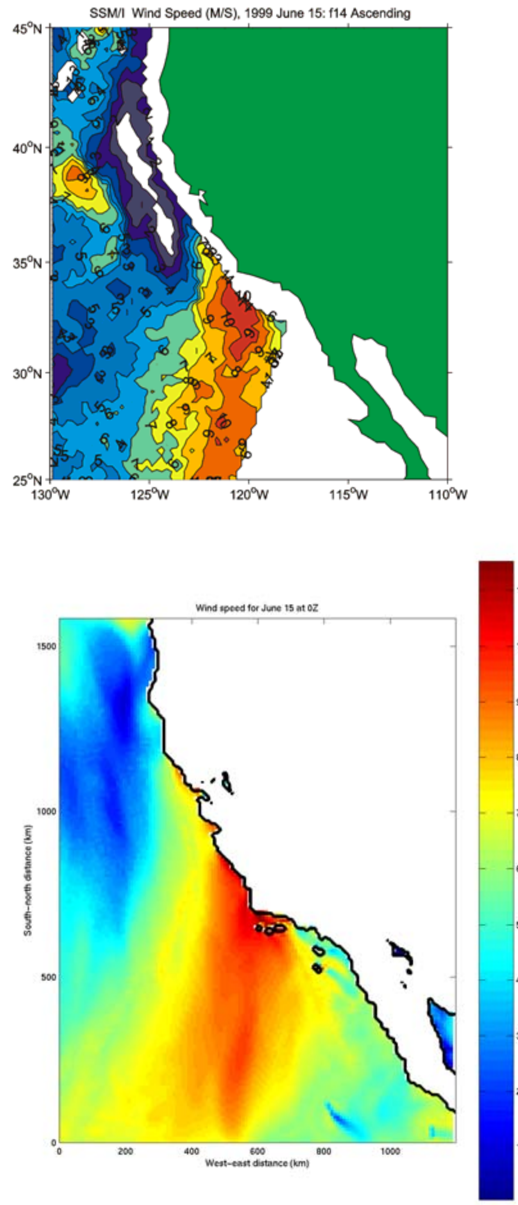

Fig. 3. Color-filled wind speed contours (ms^{-1}) derived from the SSM/I satellite (upper panel) and simulated with MM5 (lower panel) for 15 June 1999.

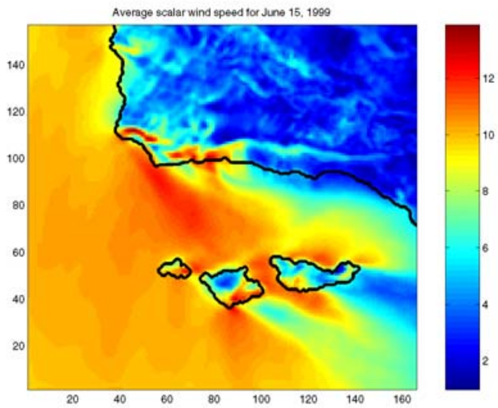

Fig. 4. Color-filled contours of the average wind speed (ms^{-1}) for 15 June 1999 simulated with MM5 (horizontal resolution of 1 km).

Figure 5 shows the wind stress averaged for 15 June 1999 and computed using the Large and Pond (1981) algorithm as well as using MM5 results and the level 2 closure (Mellor and Yamada 1974).

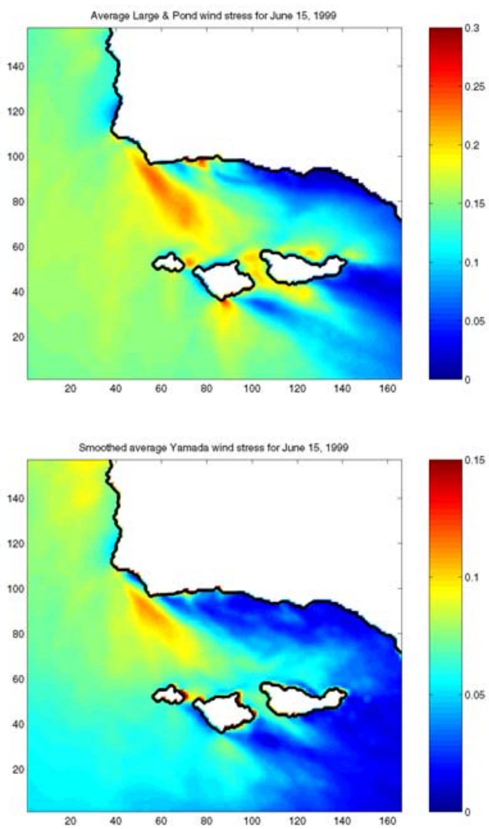

Fig. 5. Averaged wind stress (Pa) for 15 June 1999 using the Large and Pond algorithm (upper panel) and the MM5 results with the level 2 closure (lower panel).

There are also similarities between the results of these two ways of estimating the wind stress–mainly the position of the narrow maximum on the western side and the broad minimum on the eastern side of the Santa Barbara Channel and the Southern California Bight. The bulk method shows greater magnitude of stress which propagates deeper eastward in the channel following the structure of the wind field (Fig. 4). The differences in the computed stress are due to the inclusion of the atmospheric stability in the level 2 closure method as well as the selection of the first level for the stress computation. Some of the preliminary computations show that the simulated wind stress is greater at the next vertical level. It is apparent that stable atmospheric conditions impose reduction of the wind stress compared to the results from the bulk method.

4. WIND STRESS CURL

As shown in Fig. 6, the wind stress gradient will induce gradients in the wind stress curl.

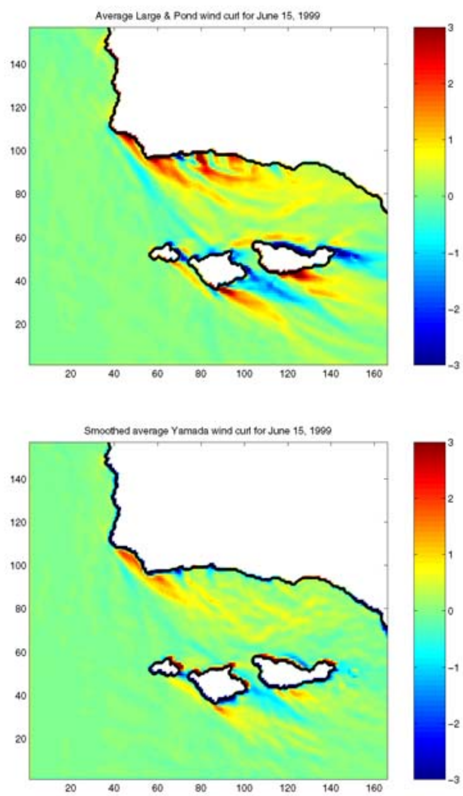

Fig. 6. Average wind stress curl (Pa $(100\ km)^{-1}$) for 15 June 1999 as estimated using the Large and Pond algorithm (upper panel) and MM5 results with the level 2 closure (lower panel).

The model results show spatial inhomogeneity of the wind stress curl near the coast in response to coastal topographic forcing. Forcing of the marine flow by the eastward curvature of the coastline generates up-welling positive wind stress curl and consequently the greatest wind stress curl is simulated in the lee of Point Conception and in the Santa Barbara Channel. Due to the offshore wind maxima near the coast, positive wind stress curl is simulated in the northern and northwestern side of the channel where the strongest wind speed and wind stress gradients exist. Model results for other days in June 1999 indicate that the wind stress exhibits great spatial variability in response to synoptic variations, while the wind stress curl has relatively small variation. The study results also suggest that atmospheric stability has a first-order impact on the estimated wind stress and wind stress curl and their effect on ocean dynamics in the Southern California Bight. Future *in situ* measurements by aircraft are needed to evaluate the differences and similarities between the bulk and turbulence closure estimates of the wind stress and the consequent wind stress curl in this and other coastal regions.

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