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FIRST LOOK AT WIND STRESS AND WIND STRESS CURL ALONG CALIFORNIA AND NORTHERN BAJA CALIFORNIA

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1. INTRODUCTION

It is well known that the wind stress and the curl of the wind stress represent an important driving force for ocean dynamics. The accuracy of estimates of the wind stress over the ocean is significantly limited by the lack of observations. The complexity of understanding air-sea interaction and observational and modeling methods of computing wind stress over the ocean is shown by Jones and Toba (2001). The problem of accurate estimates of the wind stress becomes even more apparent in coastal regions as recognized in the early work of Nelson (1977) in studying the wind stress characteristics over the California current. Significant advances in understanding the structure of the wind stress came by direct measurements of the near-surface stress using instrumented aircraft (Enriquez and Friehe 1995). In addition, advancements in atmospheric modeling and computational technology allow for new methods of investigating the wind stress and its evolution and spatial distribution over the open ocean and coastal zones.

We focus on the wind stress and the curl of the wind stress for the major wind-driven coastal upwelling zone of the coast of California and Northern Baja California. The mean summer sea-level pressure field is set up by the North Pacific Anticyclone off California and a thermal low over the southwestern US. This drives winds to the south along the coast from southern Oregon to Central Baja California; this has been established by ship measurements (Nelson 1977), near-shore buoys and coastal stations (Halliwell and Allen 1987; Dorman et al. 2000), and regional/mesoscale numerical modeling (Dorman et al. 2000; Koračin and Dorman 2001).

In order to investigate the spatial and temporal structure of the wind stress and the curl of the wind stress along the California and northern Baja California coast, we have conducted a numerical experiment using Mesoscale Model 5 (MM5) (Grell et al. 1995). Simulations with 9 km horizontal resolution were performed for all of June 1999 for the indicated region. The simulations have revealed significant modification of the flow in the coastal zone with overall dynamics characteristics similar to the results from Koračin and Dorman (2001) in simulating all of June 1996. Predicted winds over the ocean were evaluated using satellite data and used for computation of the wind stress and the curl of the wind stress along the California and northern Baja California coasts.

2. MODEL SETUP

The MM5 model grid consisted of 149x191x35 points with a horizontal resolution of 9 km. The selected physical parameterization options include Cumulus parameterization (Grell scheme), mixed-phase moisture, cloud-radiation effects, and turbulence treatment (Gayno-Seaman scheme). The entire monthly run was executed in segments of 3-4 days with 12-hour overlapping periods.

3. RESULTS

Surface winds averaged for all of June 1999 as simulated by MM5 are shown in Fig. 1.

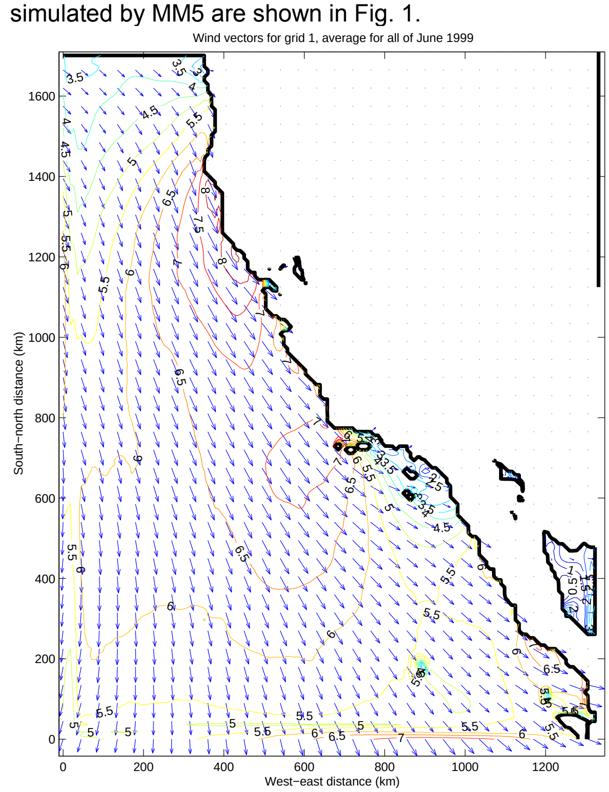

Figure 1. Surface wind vectors and contours of wind speed averaged for all of June 1999 as simulated by MM5. Contour interval is 0.5 m s^{-1}.

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The simulations indicate northerly and northwesterly flows with increased wind speed near the coast. There are distinct maxima of the wind speed in response to the coastal topography and geometry. The wind maxima are simulated in the lees of Cape Mendocino, Point Arena, Point Sur, Point Conception, and northern Baja California. It should be mentioned that the simulated monthly average wind speed in the northern lees was in excess of 8 m s^{-1}. The main characteristics of the simulated wind agree well with the simulation results for all of June 1996 as shown by Koračin and Dorman (2001).

Since the wind stress and the curl of the wind stress are the major forcing for coastal upwelling (see, e.g., Enriquez and Friehe 1995), we have investigated their properties using MM5 simulations for all of June 1999. In the first step, we have computed the wind stress using the bulk formulae without the atmospheric stability correction by Large and Pond (1981). In order to take into account atmospheric stability and to test different types of stress estimates, we have also calculated the wind stress using the level 2.0 turbulence scheme by Mellor and Yamada (1974). Figures 2 and 3 show the spatial distribution of the wind stress as calculated by the bulk method and the turbulence scheme, respectively.

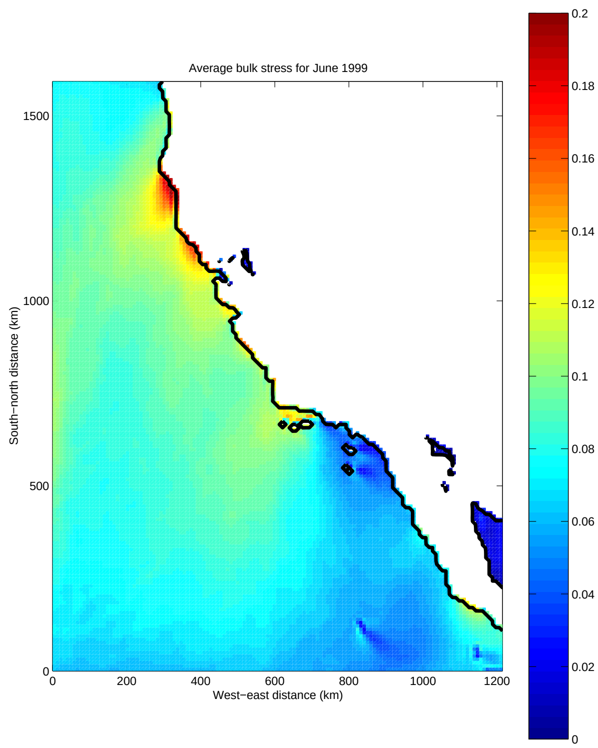

Figure 2. Wind stress (Pa) as computed using the bulk formulae and averaged for all of June 1999.

The wind stress was calculated for each hour of the month and then the average monthly stress was computed from all hourly values. The magnitude of the stress calculated by the bulk method appears to be on the same order of magnitude. Some of the main features are apparent in both figures; however, there are some differences in the spatial structure. Both schemes indicate wind stress maxima in the lee of Point Arena, in the Santa Barbara channel (on the northwestern side of California Bight), and by northern Baja California. The area of the large wind stress (greater than 0.12 Pa) is mainly near the coast and propagates to about 100 km in the offshore direction in the areas of the northern maxima and much lesser extent (about 50 km or less) for maxima in the central and southern part of the domain. However, the areas of less intense but still noticeable stress (from 0.05 to 0.12 Pa) extend much further, to about 300 km offshore. The results from the bulk method show the maximum wind stress also in the lee of Cape Mendocino, while the turbulence method shows actually the minimum wind stress in that area. One possible reason is the effects of atmospheric stability that can reduce the stress magnitude in the lee of Cape Mendocino. These effects will be further investigated in the course of this study. Both schemes show large wind stress minima on the southeastern side of the California Bight and in the lees of the Southern California islands. Since these are the monthly averages, they represent average conditions and more variation can be expected studying shorter-term wind events.

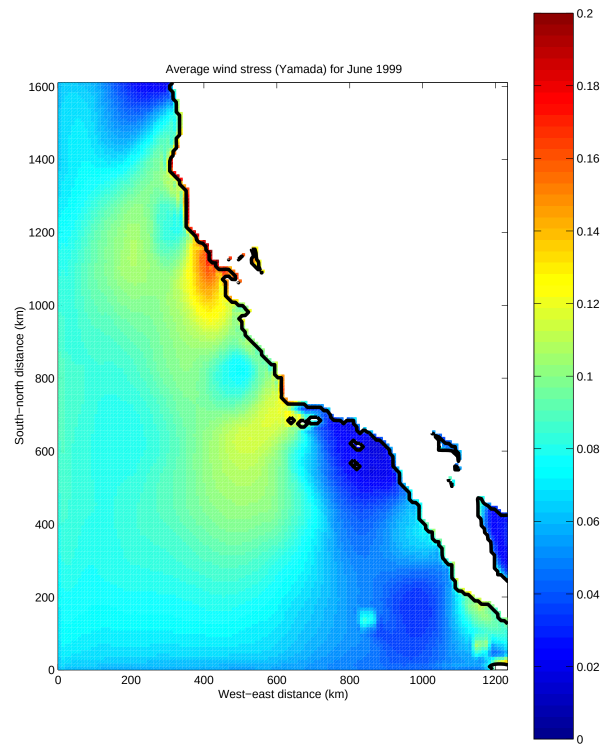

Figure 3. Wind stress (Pa) as computed using the level 2.0 turbulence scheme and averaged for all of June 1999.

The differences in the computed stress impose differences in the computation of the curl of the wind stress. The curl of the wind stress calculated from the bulk stress shows a narrow area of positive values near the coast in the lees of major capes mainly in the northern part of the domain and maximum positive values of the curl in the California Bight in relation to the large horizontal gradients of the stress in that area.

According to the preliminary model simulation, the major upwelling areas characterized with the positive curl of the wind stress are: the lees of Cape Mendocino, Point Arena, and Point Sur; an area on the northwestern side of the California Bight; northern Baja California; the Santa Barbara channel; and the lees of the islands.

4. CONCLUDING REMARKS

Numerical experiments were conducted using the MM5 model with a horizontal resolution of 9 km to simulate coastal atmospheric dynamics along California and Baja California for all of June 1999 and to compute the wind divergence, the wind stress, and the curl of the wind stress. The results show alternating zones of wind speed maxima and minima in response to forcing of the marine flow by coastal topography and the geometry of the coastline. Similarly to the results from simulations for all of June 1996 from Koračin and Dorman (2001), the simulations for all of June 1999 also show zones of high wind in the lees of major capes, while the low winds are simulated in the upwind areas of the major capes and downwind areas beyond the lees. The wind maxima (wind speed in excess of 8 m s^{-1}) are simulated in the lees of Cape Mendocino, Point Arena, Point Sur, Point Conception, and northern Baja California. In some areas, especially along the northern California coast, the monthly averaged wind speed is in excess of 8 m s^{-1}.

The wind stress was computed using a simple bulk formulation (Large and Pond 1981) and also using a level 2.0 turbulence scheme (Mellor and Yamada 1974). The wind stress estimated from the bulk formula exhibits maxima (greater than 0.2 Pa) in the lees of major capes (Cape Mendocino, Point Arena, northwestern tip of the Monterey Bay, Point Sur), in the Santa Barbara channel, and by northern Baja California. In the northern part of the domain, the area of the maximum stress exends approximately 50 – 100 km in the offshore direction, while in the central and southern part the area of maximum stress is extending 50 km or less in the offshore direction. The wind stress is still significant in the regional-scale lee extending from Cape Mendocino to Point Conception. In this regional-scale lee stress values of about 0.1 Pa are simulated up to 300 km or so from the coast in the offshore direction. The model results suggest that the significant minima of the stress are located in the southeastern side of the California Bight and in the lees of the islands in the southern California waters.

The curl of the wind stress calculated from the bulk stress is positive in a narrow belt in the lees of major capes in the northern part of the domain; beyond that there is a belt of negative curl further offshore. Based on the preliminary model results using bulk formulae, it can be concluded that the major upwelling areas characterized with the positive curl of the wind stress are mainly in the lees of Cape Mendocino, Point Arena, Point Sur, and northern Baja California, as well as in the Santa Barbara channel.

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