4.2 TOPOGRAPHICALLY-INDUCED WIND STRESS ALONG THE CALIFORNIA COAST

Clive E. Dorman*
Scripps Institution of Oceanography, La Jolla, California
Darko Koracin
Desert Research Institute, Reno Nevada

1. INTRODUCTION

To investigate the longer-term (monthly) significance of local maxima and their diurnal trends, we analyzed MM5 hourly simulations for June 1996.

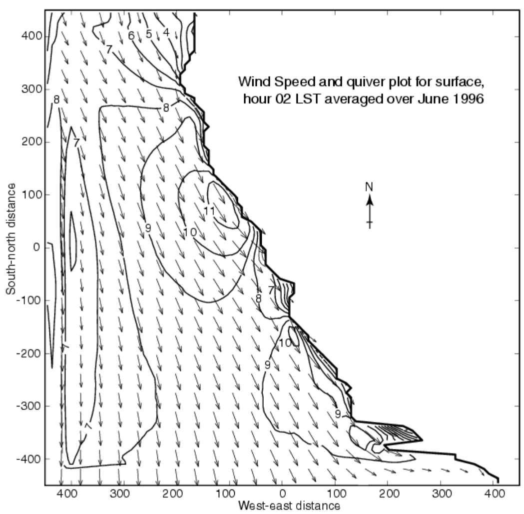

Figure 1. Sea Surface winds at 0200 LST.

Fig. 1. Shows a nighttime (0200 LST) wind vector plot overlaid with isolines of the simulated monthly averages of wind speed at the level closest to the surface (approximately equal to 20 m AGL). The flow structure indicates isolated wind speed maxima in excess of 10 m s^{-1} downwind of Cape Blanco, Cape Mendocino, Point Arena, Point Sur, and Point Conception**.**

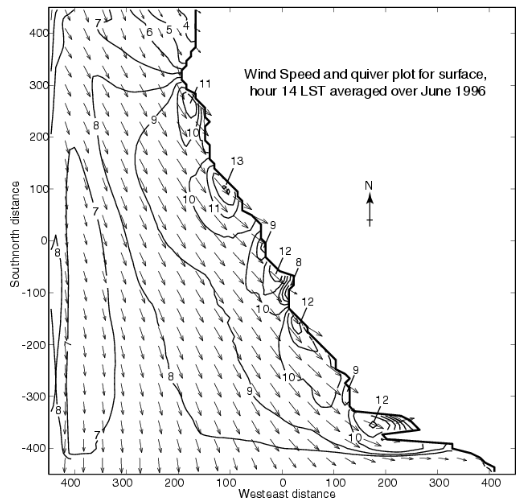

Figure 2. Sea surface winds at 1400 LST.

By the early afternoon (1400 LST), there is a significant change in the monthly averaged, near-coast flow field (Fig. 2). Five isolated maxima in expansion regions are simulated extending from the coast and in the lee of every major coastal cape and point. Paired with each maximum is an upstream minimum.

As can be seen in Figs. 3 and 4, calculated divergence of the simulated flow field is related to the wind structure illustrated in Figs. 1 and 2. The greatest late night divergence field is within the inner 100 km of the coast, while there is little beyond that distance (Fig. 3, 0200 LST). In the early afternoon (Fig. 4, 1400 LST), the surface divergence increases in the inner coastal zone, so that a sequence of isolated downstream maximum (expansion fan areas) and upstream maxima (compression bulges) are observed

*Clive E. Dorman, Scripps Institution of Oceanography, La Jolla, CA 92093-0209; e-mail; cdorman@ucsd.edu

surrounding each major cape. Due to the baroclinicity and associated thermal wind effect, there is an increase of the afternoon alongshore wind

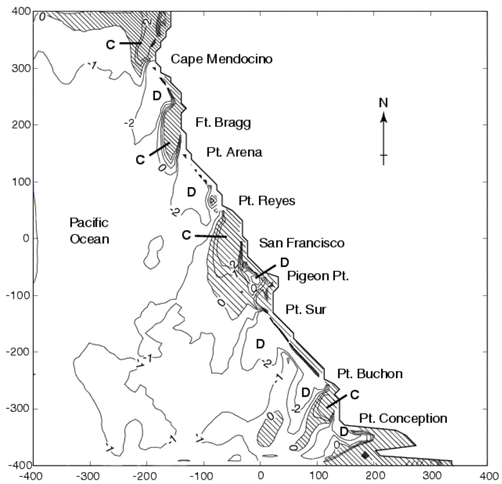

Figure 3. Sea surface wind divergence at 0200 LST.

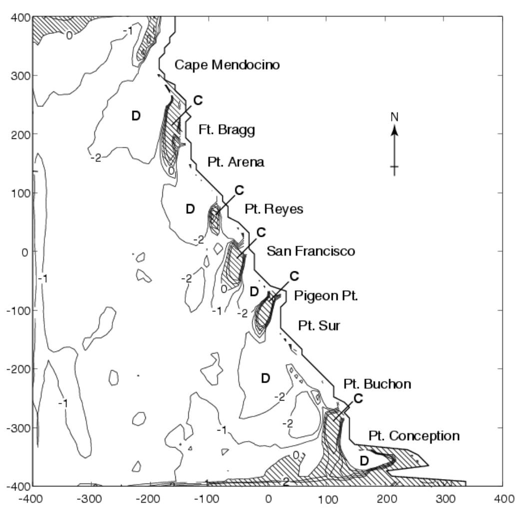

Figure 4. Sea surface wind divergence at 1400 LST.

and formation of the divergence field in the expansion fan areas that are located in the downwind side of major capes.

The general nature of the divergence diurnal variation around the other four major capes along the California-Oregon coast are similar to that around Point Arena, so they are not shown. Each cape has a large expansion fan downwind and a smaller, weaker compression bulge upwind. Near sea level, divergence is greatest in the early afternoon, and diurnal effects decrease rapidly offshore. Vertically, all tend to reverse sign at the top of the marine layer and are very weak above 1500 m (not shown).

2. MABL DEPTH AND FROUDE NUMBER

2.1. *Depth of the marine atmospheric boundary layer*

The MABL depth is a key, symptomatic variable that is closely related to the MABL divergence and supercriticality

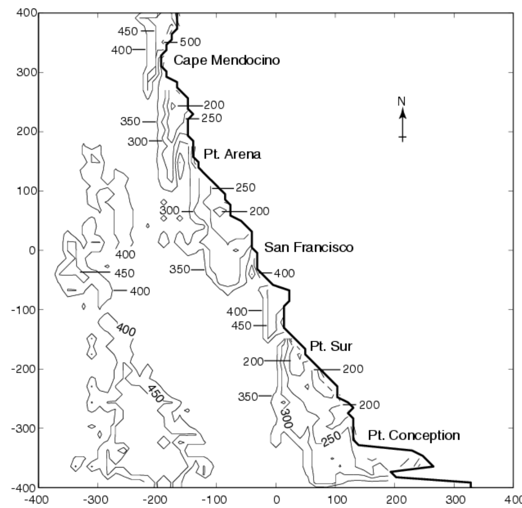

Figure 5. MABL depth (m) at 0200 LST.

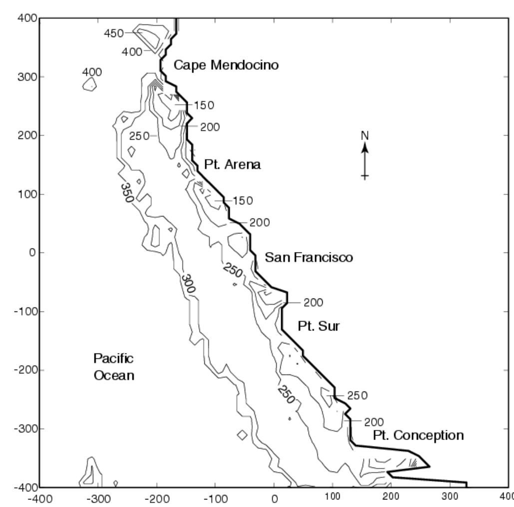

Figure 6. MABL depth (m) at 1400 LST.

as well as routinely extracted from the operational coastal sounding system. Therefore, we have examined the average properties of the MABL depth using a monthly averaged simulated temperature field. The top of the MABL is determined as the bottom of the layer that has the largest potential temperature gradient. There are five localized minima in the lees and maxima in the windward side of each major cape that are coincident with a divergent expansion fan and compression bulge respectively. With the exception of the area near San Francisco and Monterey Bay, the depth is irregular and generally less than 350 m near the coast, changes little at distances 100-200 km offshore, then increases rapidly to above 450 m in the distant offshore direction.

At 1400 LST, the MABL depth is less everywhere studied, with the greatest changes occurring near shore (Fig. 6). Around 100 km in the offshore direction, the MABL rises quickly from 300 to 350 m depth, and then increases more slowly. The greatest changes in magnitude and horizontal area covered are in the lee expansion fans, which is consistent with the greatest diurnal divergence. Of the compression bulges, the greatest decline in MABL depth is off San Francisco.

2.2. Supercriticality of the flow

The dense MABL capped by an air temperature inversion may be considered dynamically as the bottom, denser layer of a two-layer system. If the MABL is moving sufficiently fast for its depth and stability, its characteristic is that of a supercritical flow. West Coast MABL supercritical flow was first proposed by Dorman (1985), with observations and theoretical work applied to the Pt Arena area (Winant, et. al. 1988), followed by expanded new theoretical investigations (Samelson 1992; Rogerson 1997), additional coastal observations (Dorman, et. al. 2000), and confirmed by aircraft measurements over water (Rogers, et. al. 1998; Dorman, et. al. 1999).

The Froude number (Fr), expressed as a ratio between the inertial and buoyancy effects, is a measure of flow regime and its properties with respect to the propagation of gravity-wave perturbations. For Fr<1, the perturbations propagate both upstream and downstream; for Fr>1, the perturbations propagate downstream only. We follow the calculation procedure in Burk and Thompson (1996).

Here, the Froude number (Fr) calculated from the monthly averaged parameters for the entire offshore region is greater than 1 in the early morning (Fig. 7) and in the afternoon (Fig. 8). Most of the change from early morning to afternoon is in along- and cross-shore structure in the inner 100 km or so. The inshore Fr structure shows five main maxima downwind of each of the major capes corresponding to areas of high winds and shallow MABL. The opposite

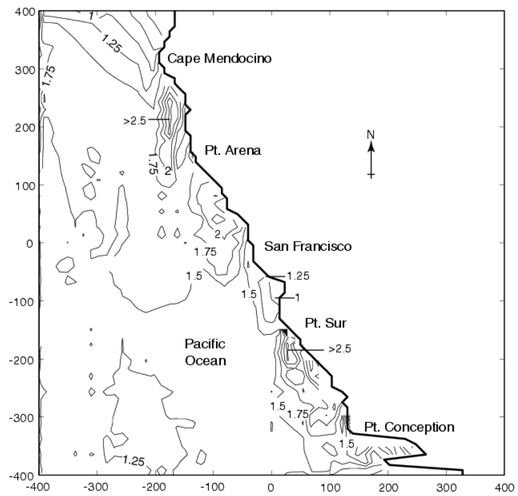

Figure 7. MABL Froude number at 0200 LST.

occurs on the upwind side that has Fr minima, lower winds, and deeper MABL. In the offshore direction, the Fr decreases due to lower wind speeds and a deeper MABL. Although Fr incorporates some uncertainty in the rather arbitrary way of determining the speed and stability within the layered MABL structure, these results generally indicate that the flow on the west coast is expected to be supercritical on rather long time and large spatial scales during the warm season. While the magnitude of Fr might be different for different formulations of input parameters, the model results suggest there are areas in the lees of Cape Blanco, Cape Mendocino, Point Arena, Point Sur, and Point Conception with a relative increase of Fr and supercriticality of the flow compared to the general background values offshore. Further, simulation results and estimated supercriticality downwind of Cape Mendocino and Point Sur resemble the pattern observed by aircraft (Rogers, et. al. 1998; Dorman 1999) on missions in June 1996.

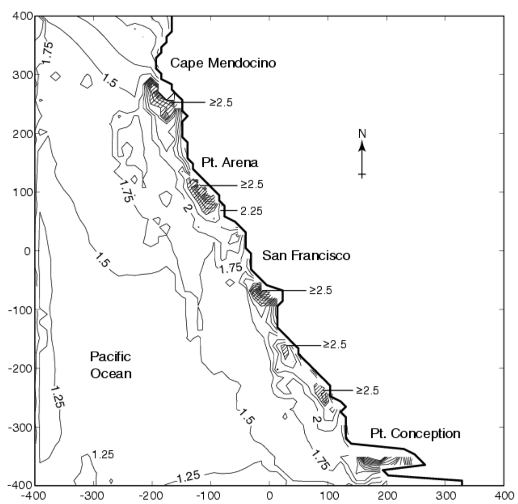

Figure 8. MABL Froude number at 1400 LST.

3. CONCLUSIONS

Based on month-long hourly simulations, this study provides support for the importance of diurnal effect on dynamics of the MABL along the coast of California and Oregon. Model results resolved a strong modification of the dynamics in the near-shore zone (order of 100 km) which is distinctly different than that farther offshore. Baroclinicity and topographic effects dominate the dynamics in the near-shore zone. The wind and divergence fields have five major sets of persistent expansion fans and compression bulges dominating the coast from mid-Oregon to Point Conception in southern California.

In the near-shore zone, extreme winds associated with strong spatial and temporal changes in the divergence fields were simulated through the entire month in the expansion fans. In contrast, weaker winds and generally convergence or order-of-magnitude smaller divergence was simulated in the compression bulges. Wind and divergence fields in the expansion fans exhibit a strong diurnal variation with the greatest divergence in midday and much smaller values at night. In the compression bulges, the divergence has the same diurnal trend but is dominantly convergent or is weakly divergent during midday.

A distinct diurnal behavior of the divergence field rapidly attenuates in the offshore direction and becomes an order-of-magnitude smaller at approximately 100 km off the coast. Farther offshore there are no organized structures in the divergence field.

The divergence field appears to be a key indicator of the dominant features of coastal dynamics. By mass conservation, the divergence field controls vertical motions and properties of the MABL, such as stability and depth. The Froude number, which is a function of wind, stability, and depth, is close to or greater than 1 along the coast from southern Oregon to Point Conception. Since the California coast south of Cape Mendocino turns away from the northerly MABL flow, this part of the California coast acts as a regional-scale expansion fan. As a consequence of the divergence field, supercriticality is greatly enhanced in the localized expansion fans and reduced in the compression bulges.

4. REFERENCES.

Burk, S. D., and W. T. Thompson, 1996: The summertime low-level jet and marine boundary layer structure along the California coast. *Mon. Wea. Rev.,* **124**, 668-686.

Dorman, C. E., 1985: Hydraulic control of the northern California marine layer (abstract), *EOS, Transactions of the American Geophysical Union*, **66**, 914.

Dorman, C.E., D. P. Rogers, W. Nuss and W. T. Thompson, 1999: Adjustment of the Summer Marine Boundary Layer Around Pt. Sur, California. *Mon. Wea. Rev*., **127**, 2143-2159.

Dorman, C. E., T. Holt, D. P. Rogers, K. Edwards, 2000: Large-Scale Structure of the June-July 1996 Marine Boundary Layer along California and Oregon. *Mon. Wea. Rev.*, **128**, 1632-1652

Dorman, C.E., C.D. Winant, 2000: The Marine Layer In and Around the Santa Barbara Channel. *Mon. Wea. Rev.,***128**, 261-282.

Rogers, D., C. E. Dorman, K. A. Edwards, I. M. Brooks, W. K. Melville, S. D. Burk, W. T. Thompson, T. Holt, L. M. Ström, M. Tjernström, B. Grisogono, J. M. Bane, W. A. Nuss, B. M. Morley, A. J. Schanot, 1998: Highlights of Coastal Waves 1996. *Bull Amer. Meteor. Soc.*, **7**, 1307-1326.

Rogerson, A.M., 1998: Transcritical Flows in the Coastal Marine Atmospheric Boundary Layer. *J. Atmos. Sci*., **56**, 2761-2779.

Samelson, R. M., 1992: Supercritical marine-layer flow along a smoothly varying coastline. *J. Atmos. Sci.*, **49**, 1571-1584.

Winant, C. D., C. E. Dorman, C. A. Friehe, and R. C. Beardsley, 1988: The marine layer off northern California: An example of supercritical channel flow. *J. Atmos. Sci*., **45**, 3588-3605.