8.4 COASTAL WIND ANOMALIES AND THEIR IMPACT ON SURFACE FLUXES AND PROCESSES OVER THE EASTERN PACIFIC DURING SUMMER

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1. INTRODUCTION

The summertime marine layer flow along the coast of California deviates occasionally from its northwesterly character, giving rise to wind reversal events. Nuss et al (2000) discussed one type of wind events, called the coastally trapped wind reversals (CTWR). Hermann et al (1990) studied the ocean response to similar events that occurred during 1984 and 1985. Examination of buoy records during June and July of 1990-2000 shows that the marine layer flow undergoes many anomalies, including the CTWRs studied so far. This is indicated by Bond et al. (1996). Some of these wind events may not be coastally trapped. More to the point, it is not known clearly what is the impact of such wind events on the surface fluxes and the wind stress at the ocean-atmosphere interface. Since, the curl of the wind stress drives the upper ocean circulation, any change in the momentum fluxes can have important implications. This paper attempts to assess quantitatively the impact of some specific wind events on surface fluxes and the wind stress, using buoy data and some of the existing schemes of calculating these fluxes.

The measurements used are that of wind speed and direction, air and water temperatures, by moored buoys at five stations along the California coast. Fig. 1 indicates the locations of these buoy stations. The months considered are June and July during 1990, 1991 and 1996. Surface momentum, heat fluxes, and wind stress are calculated using two methods: Level 2.0 turbulence closure according to Mellor and Yamada (1974), and the same according to Andren (1990).

2. WIND ANOMALIES ALONG THE CALIFORNIA COAST

Before analyzing their impact, the wind anomalies need to be identified clearly. The typical flow regime along the California coast is northerly during summer, although local features such as the baroclinicity due to land-sea temperature contrast, and the orientation of the coastline can add a significant cross-coast component to the flow (Dorman and Winant 1995). Considering these flow features, a typical day during summer would have the winds coming from the north, northwest, or the west for a majority of the time. Given that temporary fluctuations around zero or 360 degrees also occur at times, a typical flow regime can be defined as one with the wind direction being in the range 270 – 360 or 0 – 45 degrees for a majority of the period, defined here as 75 % of the day in question. At the location of San Francisco, due to changes in coastline orientation, the flow turns more westerly than at the other stations. Hence, for San Francisco, the range is taken to be 240 - 360 or 0 – 45 degrees. In other words, for 18 hours of the day, the wind direction values must lie in the ranges specified above, for the day's flow to be defined as typical. All the other days have the potential for significant wind anomalies. The basis for such a definition is borne out by buoy observations (see Fig. 2).

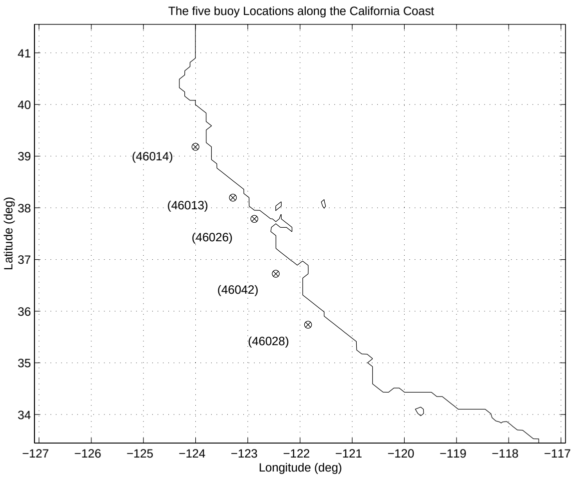

Figure 1. Locations of buoy measurements.

Examination of buoy measurements of wind direction at five stations (46014, 46013, 46026, 46042, and 46028, see fig. 1) during the days of June and July 1990-2000 shows that the marine layer flow at the different buoy locations deviates significantly (based on the above definition) from the seasonal or monthly mean on 10 – 25 % of the days. The deviations occur more in July than in June during many of the years. There appears to be fewer days with wind anomalies south of Monterey than north of it. While these are general statistics of the anomalies, here we will examine the impact of specific wind events on the surface fluxes, and the wind stress. These anomalous flow events are shown in Fig. 3

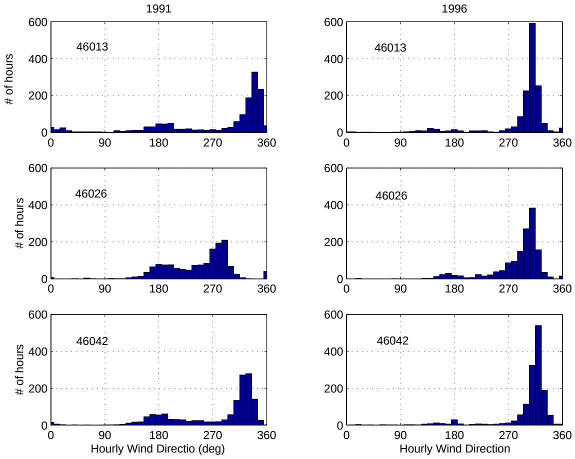

Figure 2. Histograms of measured wind directions at 46013, 46026 and 46042 during June and July of 1991 and 1996.

It is seen that during all the three events, the winds at the five buoy locations turn from northerly to southerly direction in a period of several hours, continue to go northward for many hours before being restored to their typical directions. In 1990, the flow switches to southerly in a short time and remains so for several hours at all the five locations, whereas in 1991 and 1996, there is a gradual rotation of winds from northwesterly to southeasterly direction. While these are examples of wind anomalies, many others do occur with different spatial and temporal characteristics.

3. THE METHOD OF CALCULATING THE FLUXES

The method of calculating the surface fluxes uses the level 2.0 turbulence closure scheme applied to the wind components obtained from buoy measurements of wind speed and direction, and the measured water and air temperatures. Using these quantities, wind and temperature gradients, as well as the gradient and flux Richardson numbers are calculated and the stability of the surface **layer determined.** This allows us to choose the appropriate stability dependent length scale, and calculation of momentum and heat fluxes then proceeds according to Mellor and Yamada (1974) and Andren (1990). Both the calculations give very similar results as shown by Fig. 4 for two randomly chosen days. Hence, in the next section only the results from the calculation due to Mellor and Yamada are shown.

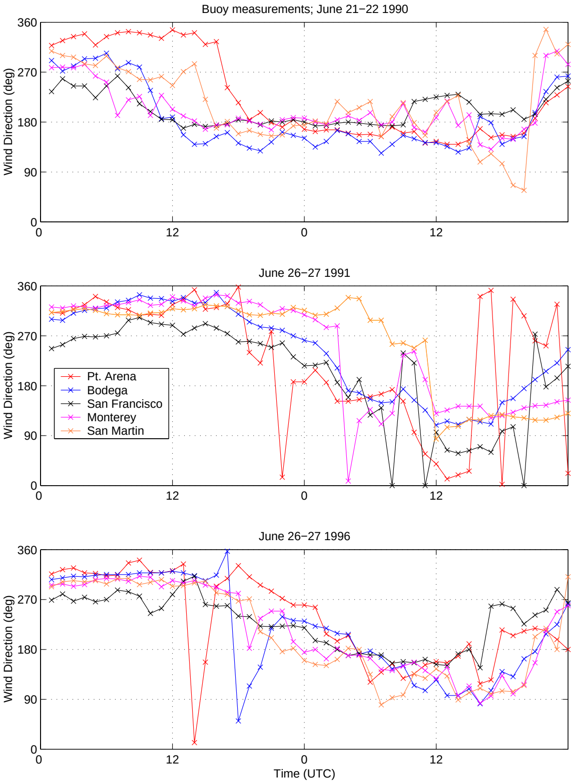

Figure 3. Wind rotation events at the five buoy locations 46014, 46013, 46026, 46042, and 4628 during some days of 1990, 1991 and 1996.

4. RESULTS

Fig. 5, 7 and 9 show the changes in the u-momentum (top panel) and v-momentum (bottom panel) fluxes during the three wind events of June 1990, 1991, and 1996, at the five buoy locations. In comparison with Fig. 3, it is seen that a somewhat quiescent period in the momentum fluxes (especially u-momentum) coincides with the initial period of wind rotation.

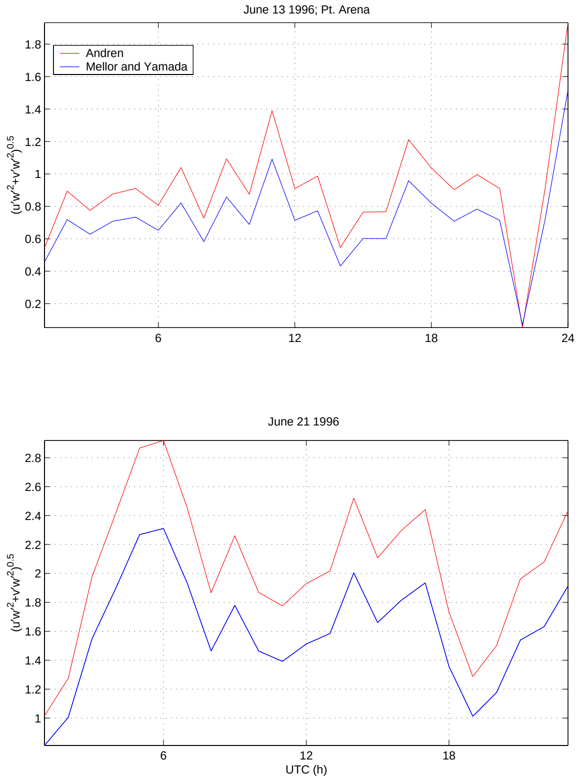

Figure 4. Surface wind stress as given by Mellor and Yamada and Andren methods.

The signs of the momentum fluxes are also reversed, indicating that the curl of the wind stress will be affected. It must be noted that the anomalies begin to develop at different times of the day during the three wind events, and also have different evolutions. Hence, the impact on the fluxes also has different temporal characteristics during the three wind events.

Let us now examine if these changes in the momentum fluxes can be linked to any response seen in the water temperature, whose evolution during the three wind events is shown in Fig. 6, 8 and 10. The general response of the water temperature can be described as a reduction in cooling after the commencement of wind rotation, as compared to a similar period prior to the wind event. The cooling occurs during a typical flow regime possibly due to factors such as upwelling and diurnal impact, although the latter can be small. The reduction in the cooling of water temperatures during the wind events indicates that processes such as upwelling are upset, which is a natural consequence of the wind rotation. Towards the end of the wind rotation period, a very significant rise in water temperatures can be noted. Apart from these features, a good degree of inhomogeneity can be found in the evolution of the momentum fluxes, thus indicating that the impact of the wind events on the ocean surface can be different at different locations along the coast.

Figures 6, 8 and 10 also show the evolution of the sensible heat flux during the three wind events. Here the calculation involves air and water temperatures, which are themselves coupled by the surface fluxes. During the 1996 event, there is a gradual reduction, followed by a reversal of the surface heat flux, while during 1990 and 1991, the changes are more complicated.

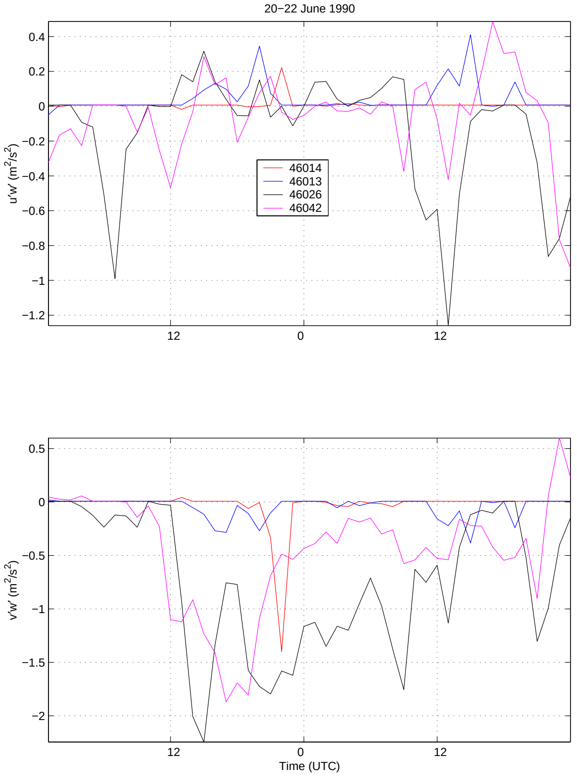

Figure 5. Momentum fluxes during 21-22 June 1990 at four buoy locations (46028 data missing)

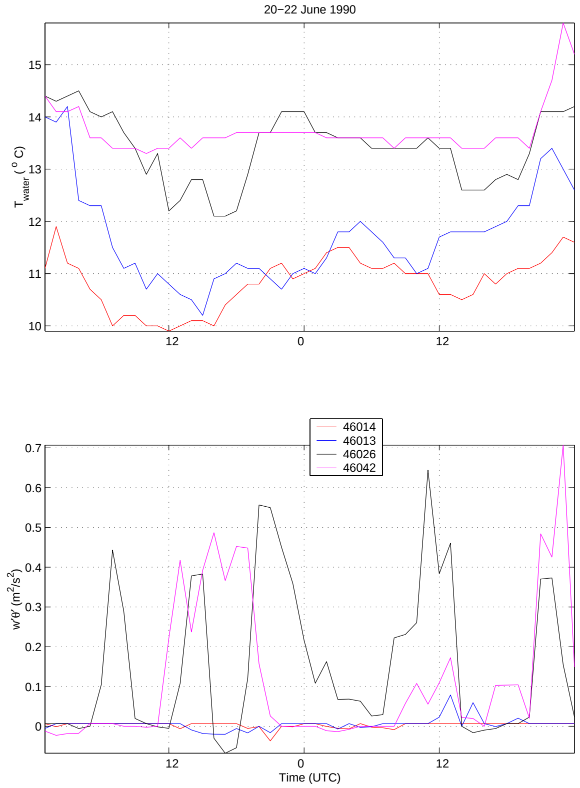

Figure 6. Water temperature and surface heat flux during 21-22 June 1990 at four buoy locations.

5. SUMMARY

Three wind events along the coast of California in June during 1990, 1991 and 1996 are examined for their impact on surface fluxes and possible correspondence to upper ocean processes. Calculations using two Level 2.0 turbulence closure schemes show that the surface fluxes are indeed significantly altered during the wind events, and these changes have apparent correlation with the evolution of water temperature. Further studies based on ocean-atmosphere models must reveal the mechanisms for such impact and the associated time scales involved.

6. REFERENCES

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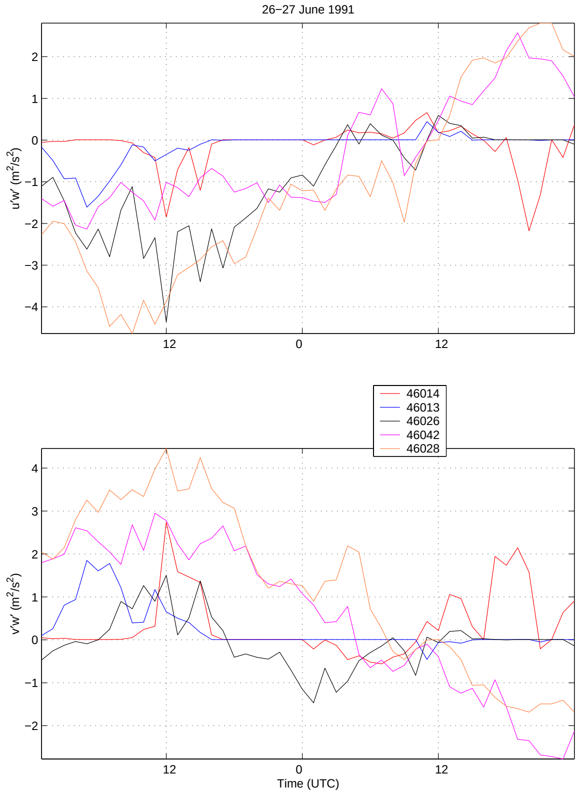

Figure 7. Momentum fluxes during 26-27 June 1991 at four buoy locations.

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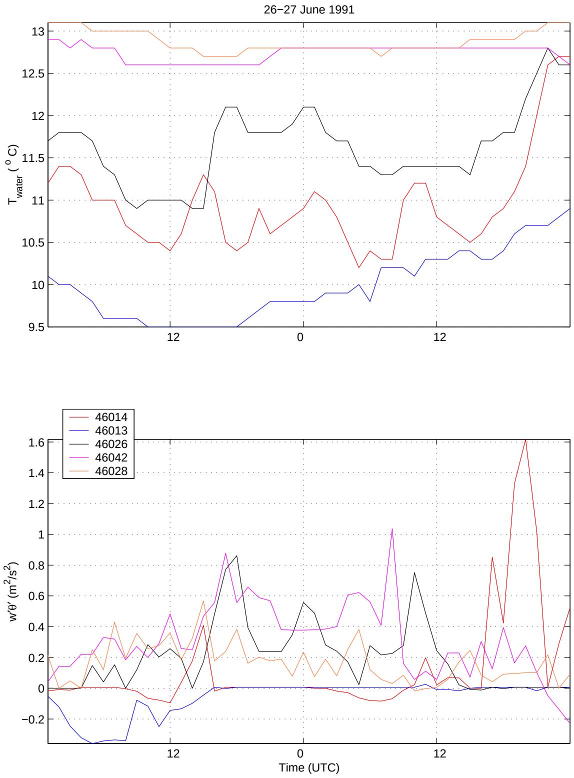

Figure 8. Water temperature and surface heat flux during 26-27 June 1991.

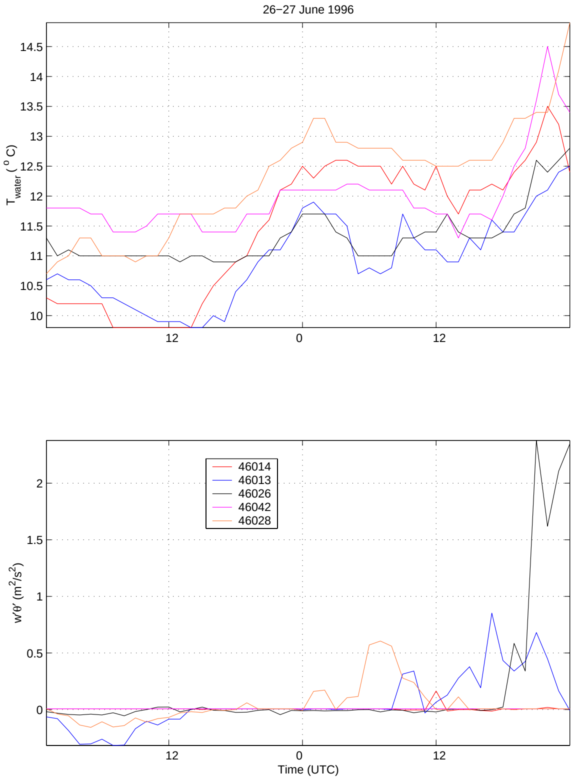

Figure 9. Momentum fluxes during 26-27 June 1996.

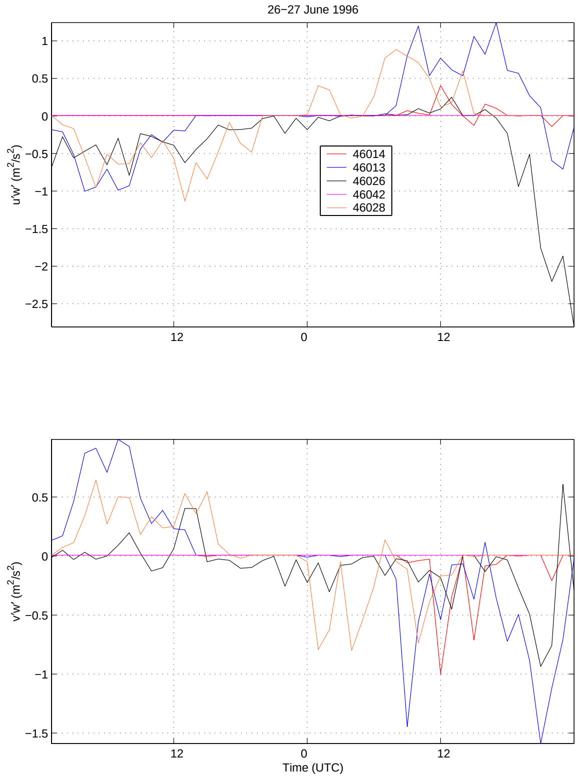

Figure 10. Water temperature and surface heat flux during 26-27 June 1996.

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