9.10 VARIATIONS OF SEA SURFACE FLUXES IN THE COASTAL REGION

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1. INTRODUCTION

In this paper we examine the validity of bulk parameterization schemes (we used the COARE algorithm) for estimation of surface turbulent fluxes and their spatial variability in a costal region. This is a critical issue in numerical models in order to predict correctly the boundary layer evolution in a complex environment like costal areas. In the area of measurements (Monterey Bay, California) intense topographical effects like flow channeling due to coastal topography and thermal flows between land and sea in combination with stratocumulus cloud and coastal upwelling contribute to the complexity of the wind flow near the coast.

High-rate 10 Hz measurements of turbulence were obtained with the CIRPAS/NPS Twin Otter aircraft in Monterey Bay throughout the year 2003 in the framework of Autonomous Ocean Sampling Network (AOSN-II) project. Data include about forty flights carried out during midday with a flight pattern consisting of dense near sea surface (30 m above sea surface) straight legs and slant soundings north and south of the coverage area. Wind turbulence was estimated from radome data after a careful calibration using flight maneuvers (Kalogiros and Wang 2002). Fast temperature and humidity measurements were obtained with a Rosemount platinum resistance thermometer and an IRGA sensor, respectively. A variety of different patterns of near surface flow was recorded including downcoast and upcoast strong or weak flow as well as offshore flow. Measured surface turbulent fluxes were systematically lower than bulk estimations probably due to the significant non-homogeneity of the flow and limited validity of surface similarity functions or roughness length parameterization especially under stable atmospheric conditions in the coastal area.

2. DATA PROCESSING

Turbulence quantities like momentum, sensible heat, and latent heat fluxes were calculated with the eddy correlation method and a horizontal averaging length of 5 km. Using ogive (co-spectrum) analysis we found that this averaging length is sufficient and includes all the energy containing scales. After a quality control of all available data a total of 3695 flux measurements with most of stability z/L values (L is the Monin-Obukhov length) ranging in the range -2 to 0.2 was obtained. Wind stress was calculated from $\tau=\rho(\langle w'u'\rangle^2+\langle w'v'\rangle^2)^{1/2}$ and sensible and latent heat fluxes from $H_s=\rho C_p\langle w'\theta'\rangle$ and $H_l=\rho L_v\langle w'q'\rangle$, respectively, where θ is air potential temperature and q is the water vapor mixing ratio. Transfer coefficients C_d, C_h, and C_e for momentum, sensible heat, and latent heat flux were calculated from $\tau=\rho C_d SU$, $H_s=\rho C_p C_h S(\theta_s-\theta)$, and $H_l=\rho L_v C_e S(q_s-q)$. Sea surface temperature T_s (θ_s is the corresponding potential temperature) was measured with a radiative thermometer and q_s at sea surface was estimated by T_s including the about 2% salinity effect. The parameter S is actually the wind speed U but includes also the gustiness factor and average bulk quantities were reduced to a common reference height of 10 m using the flux-profile functions of Fairal et al. (2003). Bulk estimates of τ, H_s, H_l, C_d, C_h, and C_e were obtained from COARE version 3.0 algorithm (Fairal et al. 2003). Transfer coefficients were reduced to neutral conditions using the same flux-profile relations with an iterative method which considers the difference between roughness length at measurement conditions and neutral stability (Enriquez and Friehe 1997).

3. TURBULENCE STATISTICS

Figure 1 shows scatter plots of measured and estimated from bulk algorithm near surface fluxes including all the data points. The majority of flux values are small (below 0.2 Nm^{-2} for stress, 30 Wm^{-2} for H_s and 60 Wm^{-2} for H_l) as expected due to the small stability z/L values. It is clear that stress and latent heat fluxes are systematically overestimated by the bulk algorithm. Sensible heat flux bulk estimates predict well on average the measured values for positive values (unstable conditions) but fail under stable conditions where measurements indicate small values. The possibility of flux divergence between sea surface

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and the measurement height could be a factor that contributes to the observed discrepancies but probably it cannot totally explain these large differences. Similar results have been reported by Enriquez and Friehe (1997), Rogers et al. (1998), and Brooks et al. (2001) but for a different area in the California coast or for a limited dataset.

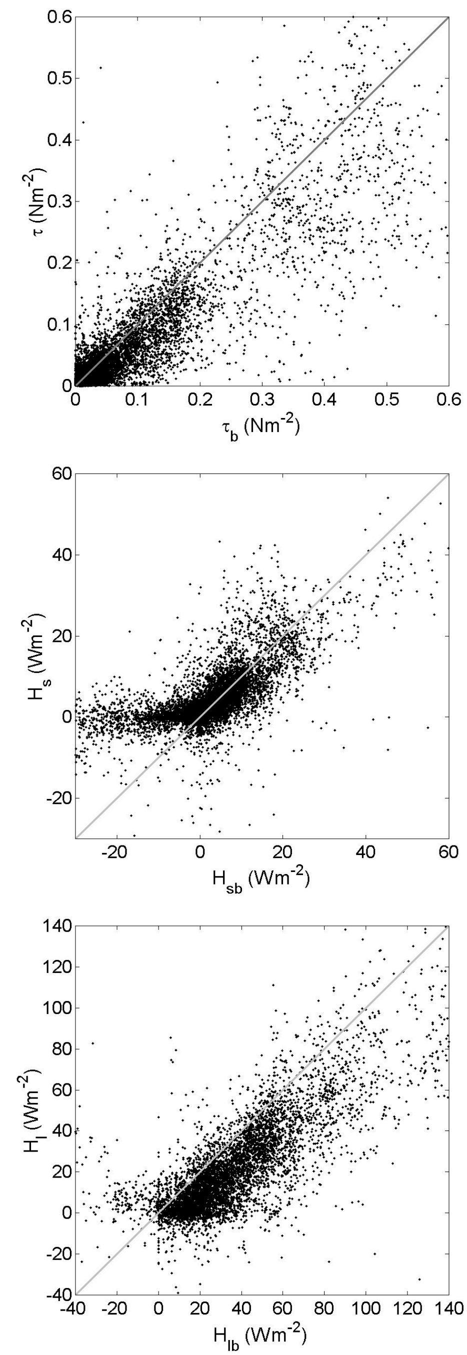

Figure 1. Scatter plots of stress (τ), sensible heat flux (H_s) and latent heat flux (H_l). Subscript b indicated bulk estimate and the solid line is the equality line.

A further insight of the differences between measured and bulk fluxes is provided by the analysis of neutral transfer coefficients. We note that the COARE profile functions were used for the conversion to neutral conditions but the conversion effect is small due to small z/L values.

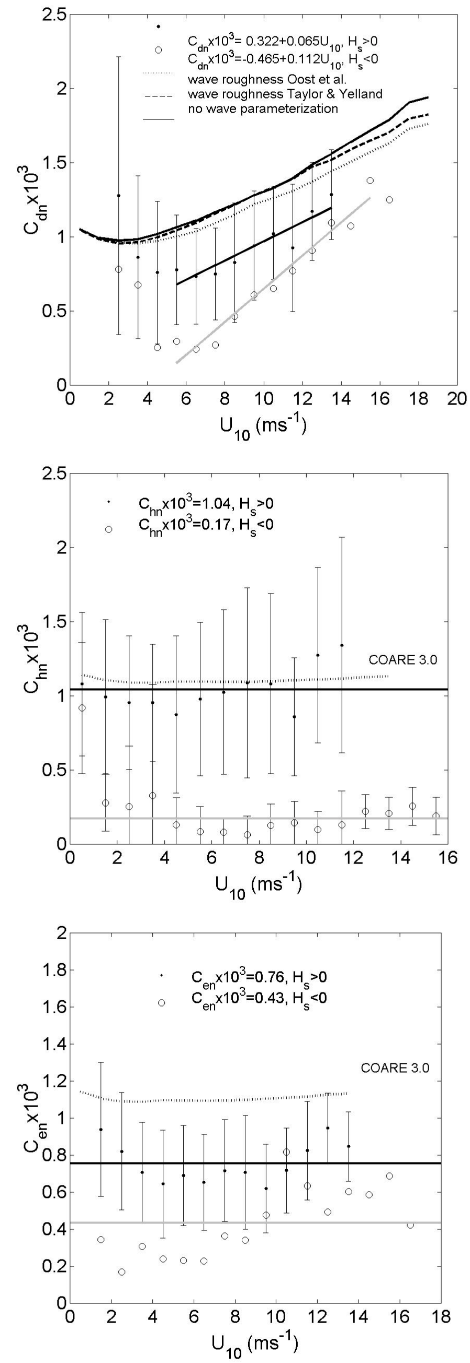

Figure 2. Neutral transfer coefficients against wind speed at reference height (10m). Stability differences of measured values (error bars correspond to standard deviation) and bulk estimates from COARE 3.0 are given.

Figure 2 gives measured and estimated neutral transfer coefficients against wind speed at 10 m reference height. We see again the general differences noted in the comparison of flux values and that wave parameterizations used in COARE may improve but not significantly the bulk stress estimates. We note that dominant wavelength and time period of waves were estimated from wind speed as described in Fairall et al. (2003) using formulas for fully developed sea. Furthermore, measured transfer coefficients in stable conditions regime (corresponds to low measured flux values) are significantly lower (especially C_{hn}) than the unstable case and show a larger increase with wind speed. Thus, the usual surface similarity functions or roughness length parameterizations used in bulk algorithms are probably not valid especially under stable atmospheric conditions in the complex environment of our measurements.

4. SPATIAL VARIABILITY OF SURFACE FLUXES

The spatial pattern of fluxes and transfer coefficients is of interest because conclusion could be drawn for the mechanisms that control them. Next we show the results from an experimental day with strong downcoast wind and significant effects of the topography of the coast. Figure 3 shows the wind speed pattern on 13th of July 2003 in the experimental area.

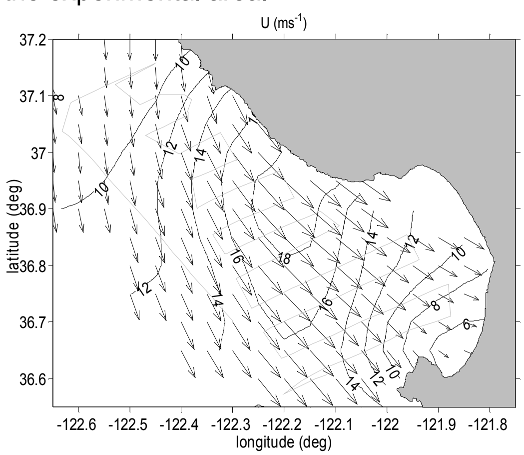

Figure 3. The flow pattern on 13th of July 2003 in Monterey Bay. The gray line is the flight track part about 30 m above sea surface in the time period 12:39 to 15:17 LST.

On that day flow channeling turns and speeds up the wind at the northern part of the bay and an expansion fan-supercritical flow occurs (Winant et al. 1988). Wind stress also increases significantly in this area and wind stress curl is significant leading to enhanced local upwelling and colder sea surface temperature (not shown here). Stable stratification that develops in this area leads to negative sensible flux as shown in Fig. 4.

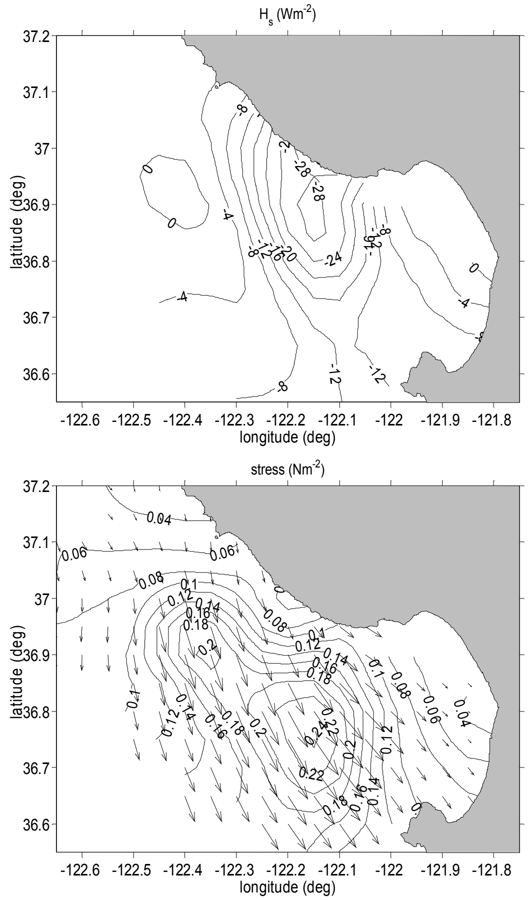

Figure 4. As in Fig. 3, but for sensible heat flux and wind stress.

Figure 5 shows spatial distribution of the neutral measured transfer coefficients. The bulk estimated transfer coefficients (not shown here) have a pattern similar with wind speed because they increase with wind speed (especially C_{dn}) as seen in Fig. 2. The measured C_{dn} pattern has lower values towards the coastline that is parallel to the wind speed (similar with wind stress) and higher values offshore and at the coastline that is facing the wind (around Monterey peninsula). This general pattern suggests that C_{dn} (and, thus, the velocity roughness length) may be strongly connected with the wave field which is expected to be more well-developed at the coastline with alongshore wind (Enriquez and Friehe 1997). This pattern is locally disturbed (with extension of lower values further away from the coastline) by the presence of local wind speed maximum and negative heat flux at the area of expansion fan according to the behavior shown in measured C_{dn} in Fig. 2. The pattern of measured C_{hn} is more complex because of the quite significant effect of stability and the more significant increase with wind speed compared to the bulk estimate (Fig. 2).

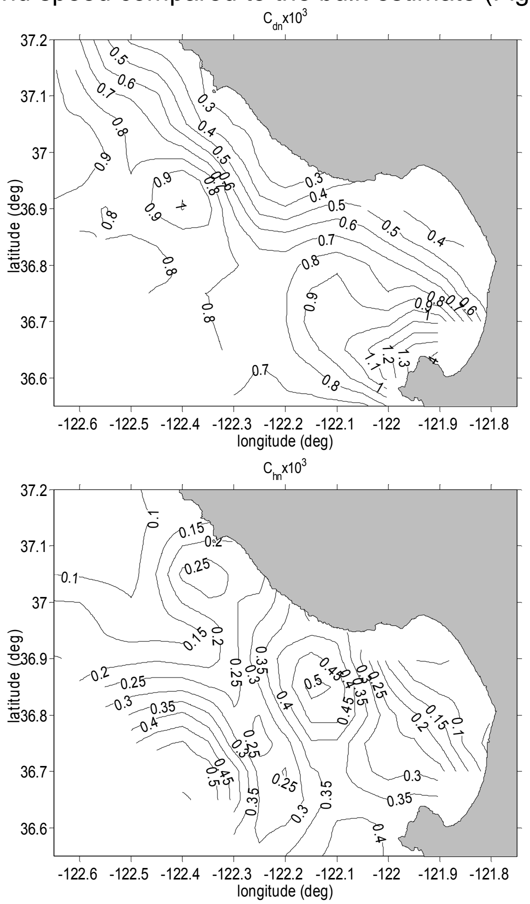

Figure 5. As in Fig. 3, but for neutral momentum and sensible heat flux coefficients.

Far offshore where the effect of wind speed maximum and stability is less we can see that C_{hn} starts to increase.

5. CONCLUSIONS

The results presented in this work suggest that surface similarity functions may not be valid in a complex coastal environment as discussed by Edson et al. (2000) for the case of downward latent heat flux and that the wave roughness parameterization is also significant. Advection effects in this non-homogeneous environment are probably significant especially under stable conditions when the boundary layer adjusts slowly to changes of the surface forcing (sea surface temperature). Finally, the wave field reacts slower than the boundary layer turbulence in changes of the wind speed. Thus, more experimental data focused in the coastal area is needed in order to better understand the structure of the surface layer in this critical region.

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