J2.10 CHARACTERISTICS OF AIR-SEA INTERACTION IN SURFACE AND WAVE LAYERS DURING CBLAST-LOW

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1. INTRODUCTION

Early studies indicate that air-sea interactions are wave-age-dependent (e.g. Drennan et al. 2003). The wave age is commonly defined as the ratio of the wave phase speed over the friction velocity. Mahrt et al. (2003) pointed out that by doing so, the self-correlation between the momentum transfer and the friction velocity used in the wave-age dominates correlations between air-sea interaction parameters and the wave age. Whether Monin-Obukhov (MO) similarity theory is applicable over oceanic waves has been investigated in the literature, for example, the RASEX (Risoe Air Sea Experiment) field experiment. Recent studies indicate that wave layers could be much deeper than previously thought when swell exists (Smedman et al. 1994). Conceptually the wave layer is similar to the roughness sublayer over land, where MO similarity theory does not work. Therefore, it is crucial to investigate air-sea interactions in the surface and wave layers separately since the spatial heterogeneity of the wave layer could lead to much scattered relationships between wave status and air-sea energy transfer.

We will show some results on the characteristics of the air-sea interaction in the surface and wave layers from the CBLAST-Low (Coupled Boundary Layers Air-Sea Transfer under low wind) main field campaign conducted in 2003, off coast of Martha's Vineyard, MA, USA.

2. OBSERVATIONS

The data used at the time of the writing were from the Air-Sea Interaction Tower (ASIT), which is about 2 miles south of Martha's Vineyard, MA and is in 15 meters of water. During the experiment, there were 6 levels of three-dimensional sonic anemometers for turbulence measurements; 7 levels of relative humidity and air temperature measurements, and the sea-surface temperature estimated from an infrared radiometer.

The wave height was monitored by an Riegl laser altimeter. The wave period and peak wave speed are estimated from the laser altimeter and a microwave altimeter. The wave propagation direction was from Martha's Vineyard Coastal Observatory (http://www.whoi.edu/mvco/description/description2.html).

The tower's prevailing wind direction is from SW. In this study, we only examine when the wind and wave came from SW and the directional difference between the two is less than 10 deg. In addition, we only examine the data when the observations were available at all the levels. The data were averaged every 20 min. The wind from SW were dominated by the stable conditions.

3. VERTICAL STRUCTURES OF TURBULENCE AND WAVE AGE

To avoid the self-correlation mentioned in the Introduction, we define the wave age as the ratio of the peak wave phase speed over the wind speed extrapolated to the water surface. The extrapolation is based on the lowest two observation levels. This wave age represents the relative speed difference between the peak wave and the wind better than the wave age defined by the standard 10-m wind. We divide the data into five wave-age (wa) categories: $wa < 1$, $1 < wa < 2$, $2 < wa < 3$, $3 < wa < 4$, and $4 < wa$. The relationship between the averaged peak-wave phase speed within each wave age category and the wave age (Fig. 1) indicates that the wave age is dominated by the peak-wave phase speed. Therefore, the large wave age is associated with swell.

In addition, we also examined the relationship between the roughness height and the wave age. Here the roughness height is derived using MO theory from wind and stress at each observation level. The final roughness height at each time is the average of the roughness heights derived at all the levels. We found that the standard derivation of the roughness length within each wave-age category was smallest for the wave age less than 1 (Fig.2). In other words, the large variation of

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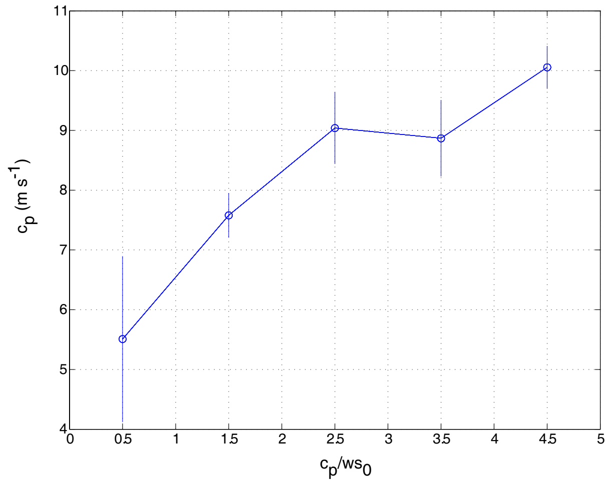

Figure 1: The bin-averaged peak-wave phase speed as a function of the wave age.

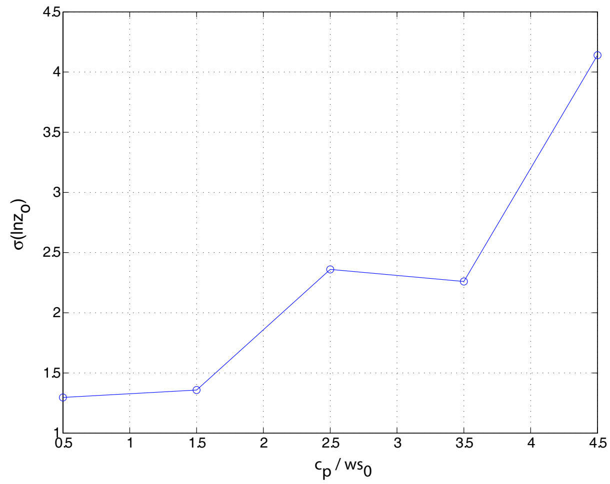

Figure 2: The standard deviation of the natural-logged roughness length ($\ln z_o$) within each wave-age bin as the function of the wave-age.

the roughness length within the large wave age category could be due to the invalidity of MO within the tower observation layer.

The wind profiles for the five wave-age categories show that as the wave-age increases, the wind speed tends to be weak at the surface, but not high-up (Fig.3). The corresponding momentum transfer along the wind direction also demonstrated a large variation at the large wave-age (Fig.4). Based on Sullivan et al. (2000), the marine wave layer with swell (which is equivalent to the roughness sublayer over land) can be much deeper than the tower layer.

For the small wave age, the variation of the roughness length and the vertical structure of wind and momentum transfer imply that during the wind wave generation stage, the marine boundary layer is more or less like the surface layer over land. As longwave developed in the sea, and as swell moves in, the assumption of the MO surface layer may not be applicable over the tower layer. Other parameters play significant roles in the air-sea interaction.

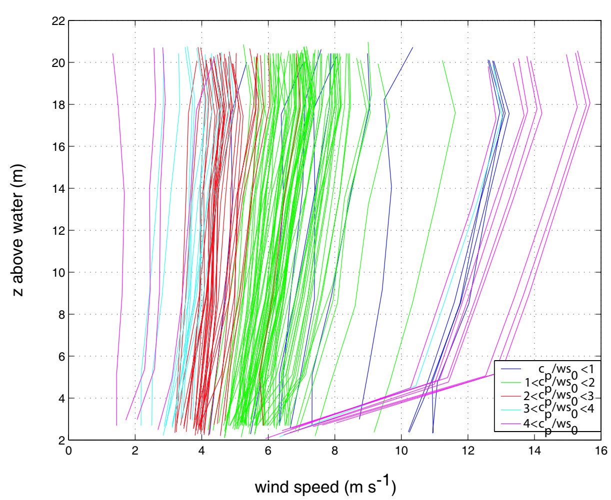

Figure 3: The wind profiles for the five wave-age categories.

4. VERTICAL STRUCTURE OF TURBULENCE WITHIN THE WAVE LAYER

To investigate the marine boundary layer characteristics within a wave layer, we focus on the vertical wind and turbulence structure when the peak-wave speed is larger than 10 ms^{-1}, which corresponds to the swell dominant regime. The wind profiles under this condition are summarized to three groups (Fig.5). We found that the three groups are associated with the three different air-sea temperature differences (Fig.6). Figure 6 implies

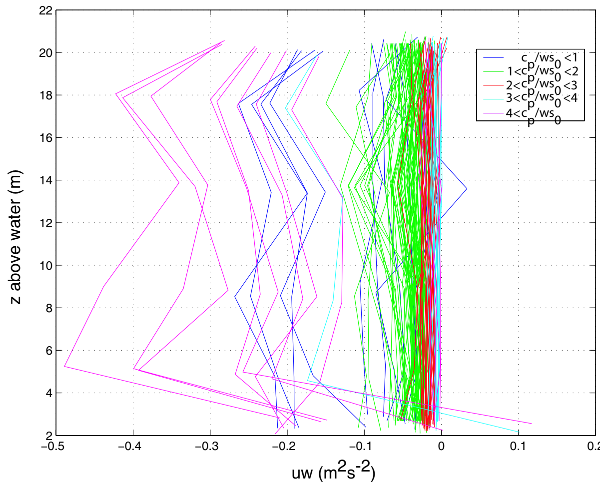

Figure 4: Momentum transfer along the wind direction (uw) for the five wave-age categories.

that under unstable conditions, convective mixing leads to a well-mixed wind regime. As the air becomes slightly stable, the air-sea energy transfer is less. However, the fast moving wave can still accelerate the wind close to the water surface, as shown in group 2 where the normal increase of the wind speed with the height was altered close to the surface, showing a wind increase toward the water surface. As the wind speed at the water surface is very weak as shown in group 3 (extrapolated from the observation levels), the fast moving waves could transfer momentum upward as shown in the positive uw close to the water surface. The large vertical momentum convergence induces a low-level jet. Associated with this upward momentum transfer, the sensible heat flux is upward close to the water surface, which is opposite from the sensible heat transfer under stable conditions (Fig.7). The upward transfer of heat close to the water surface and the downward heat transfer further away from the surface under stable conditions leads to the vertical heat convergence. The convergence could lead to warmer air close to the water surface, and further uncoupling between the turbulent heat and momentum transfer.

5. SUMMARY

It is physically meaningful to define the wave-age in terms of the wind close to the water surface. The wind at 10 m does not represent how fast the wind travels relative to the wave since local jets may develop under weak wind and swell situations. The wave-age defined by the wave speed and the friction velocity represents how much the air and sea interact, and does not represent the environmental condition of the air-sea interaction.

As the wind travels much faster than the wave, the

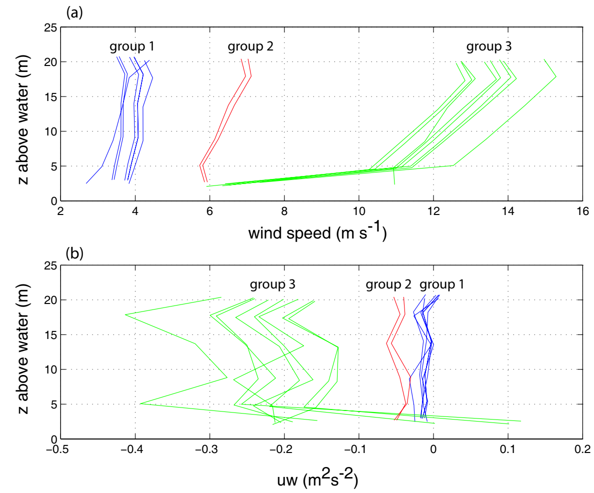

Figure 5: Wind (a) and momentum transfer along the wind direction (uw, b) for the peak-wave speed larger than 10 ms^{-1}.

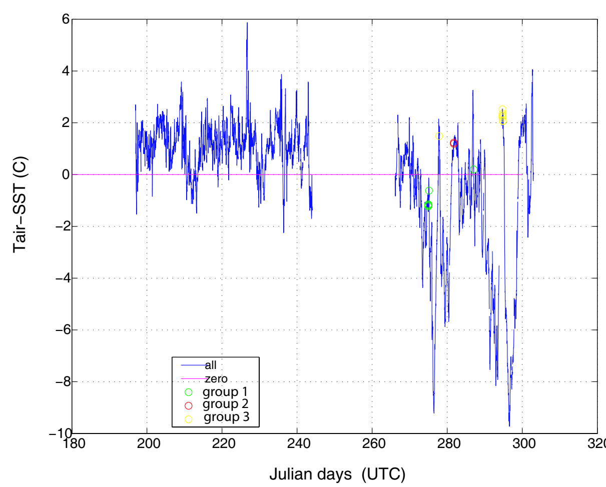

Figure 6: The air-sea temperature difference as a function of time, where the air temperature at the lowest observation level was used. The three groups for the peak-wave phase speed larger than 10 ms^{-1} are marked with circles.

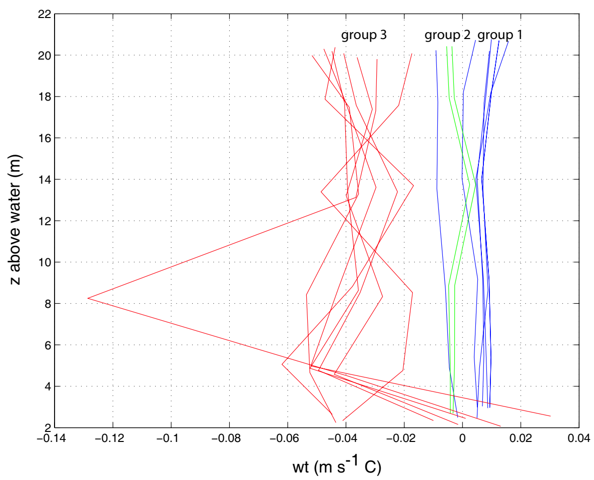

Figure 7: The sensible heat flux transfer (wt) for the three groups under the swell condition.

variation of the roughness length is relatively small and the momentum transfer is relatively constant with height, indicating MO-similarity theory may be applicable and the tower layer is within the surface layer. As the wave travels much faster than the wind such as swell, the momentum transfer can be upward, inducing a low-level jet. At the same time, the sensible heat flux close to the water surface was observed upward close to the water surface, which is opposite to the downward heat transfer further away from the sea surface under stable conditions. We will further investigate the characteristics of the wave layer.

Acknowledgements

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