

Surface Fluxes and Wind-Wave Interactions in Weak Wind Conditions

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LONG-TERM GOALS

We investigate air-sea transfer of momentum, heat, and moisture under weak wind conditions. We focus on effects of swell on turbulence transfer since unlike wind sea, swell generation is independent of local wind and its phase speed can be much faster than local weak wind. Improved understanding of wave effects on marine atmospheric turbulent fluxes, especially under weak wind conditions, can lead to better understanding of air-sea interactions, which in turn leads to better bulk aerodynamic formula for numerical models.

OBJECTIVES

The scientific objectives for analyzing the CBLAST-Low experiment data are to understand air-sea interactions especially under weak wind conditions by mainly focusing on vertical variations and magnitudes of atmospheric turbulence over oceanic waves within wave boundary layers and marine atmospheric surface layers using the unprecedented dataset. Our objective for FY2007 is to finalize our CBLAST-Low data analysis with many cases as possible, which includes both pilot and main experiment, and both tower and aircraft data. We are in the final stage of preparing a manuscript to be submitted to a journal.

APPROACH

To ensure the data quality from the Pelican aircraft, we concentrated on tower-aircraft turbulence comparisons based on the days when the CIRPAS Pelican aircraft flew on the level runs along the east-west track near the ASIT tower and the wind direction was good for the tower sonic performance (6 days in total) during the CBLAST-Low main field experiment in 2003. We then extend our data analysis to the Pelican aircraft flight days during the main experiment when the ASIT tower data cannot be used because wind direction was from behind the tower structure. We also included the LongEZ aircraft data from the pilot experiment in 2001 when the ASIT tower was not there yet. Those aircraft cases allow us to understand air-sea interactions when swell travels in opposite directions of wind, which leads to cases with negative wave age if the wave age is defined by the relative difference between the peak-wave phase speed in the wind direction and the wind speed.

WORK COMPLETED

We have analyzed momentum, and sensible and latent heat fluxes using the LongEZ aircraft data collected during the pilot experiment and using the ASIT tower and the Pelican aircraft data collected during the main field experiment. We investigated influences of swell on these fluxes as functions of

various wave and weather conditions. We found evidences of large drag coefficients under weak winds due to effects of swell on air-sea momentum transfer. A manuscript is about ready to be submitted to a journal.

RESULTS

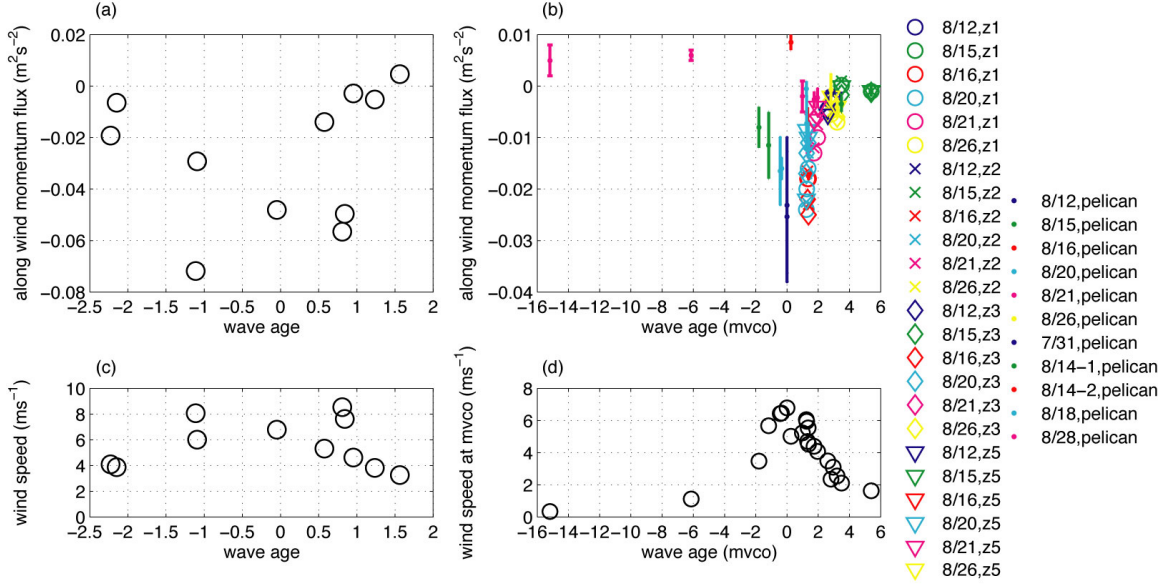


Figure 1: Along-wind momentum fluxes and wind speed as functions of wave age at the flight level during the Pilot (a and c) and the main (b and d) experiments. The wave age is calculated as the phase speed of the peak energy wave in the wind direction over the wind speed at the flight level for the pilot experiment, and as the phase speed at the wave energy peak in the wind direction over the wind speed at 10 m at MVCO for the main experiment. The range of the along-wind momentum flux from each Pelican flight mission is marked as the vertical line in (b).

We found that over all, turbulent momentum fluxes based on the Pelican aircraft data compare well with ones using the ASIT data. We found that swell has significant impacts on air-sea momentum fluxes under weak winds (Figure 1). As wind blows in the same direction as swell travels, low-level jets are commonly observed due to vertical convergences of momentum (Figure 2). As wind blows in the opposite direction as swell travels on 28 August 2003, we found the increase of wind speed towards the sea surface and upward momentum transfer in the wind direction over most of the sea surface south of Martha's Vineyard. In general, vertical variations of the momentum flux are small over the swell-dominant-sea since in this situation wind sea is commonly under the

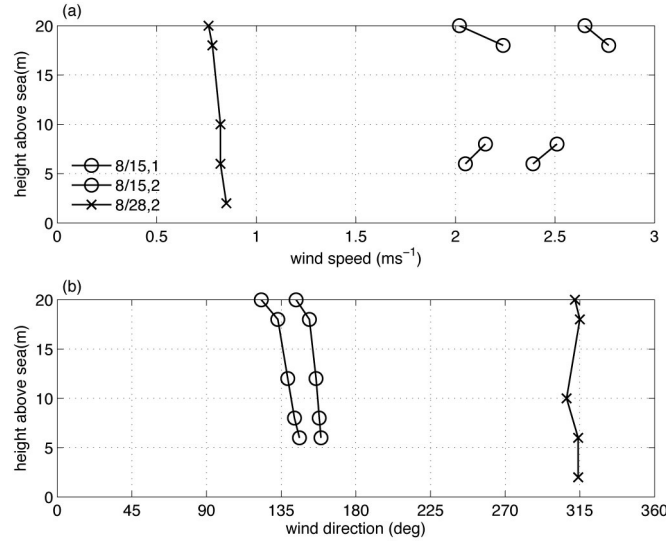


Figure 2. Wind speed (top) and direction (bottom) profiles for the two weak wind days, 15 and 28 August 2003. On 15 August, the wind is in the direction of swell, and on 28 August, the wind is in the opposite direction of swell.

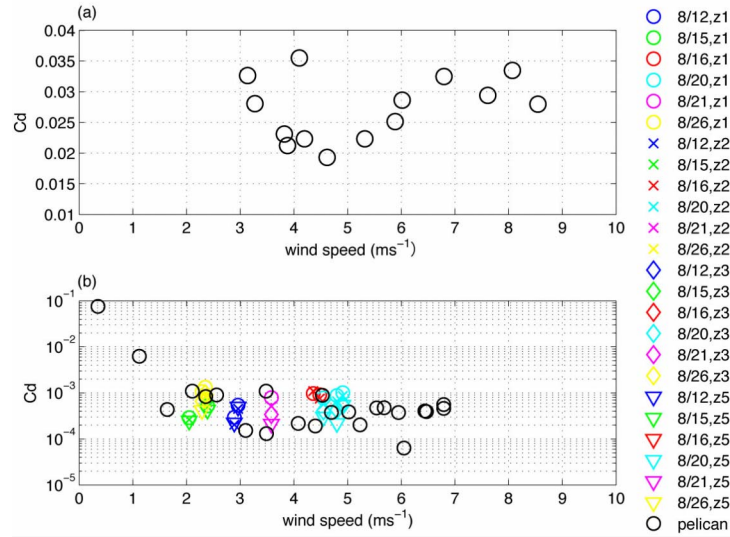


Figure 3. The local drag coefficient (C_d) as a function of wind speed during (a) the pilot and (b) the main experiments. Each symbol in (a) represents C_d from flight-averaged momentum flux and wind speed. C_d from ASIT is calculated using the momentum flux and wind speed at each observation level. C_d from the Pelican is calculated using flight averaged momentum fluxes and wind speeds at 10 m above the sea level at MVCO.

influence of weak wind. Under weak winds, the drag coefficient is larger over the swell-dominant-sea than over wind sea. As a result, the drag coefficient is found to increase with decreasing winds under weak winds (Figure 3). The above result is well known but was never been explained satisfactorily. As the influence of swell, the air-sea interaction observed by the LongEZ and the Pelican aircraft, and the ASIT tower cannot be explained by the traditional Monin-Obukhov (M-O) similarity theory. Therefore, we cannot follow M-O to convert the drag coefficients in Figure 3 to their neutral conditions, as commonly practiced in the community.

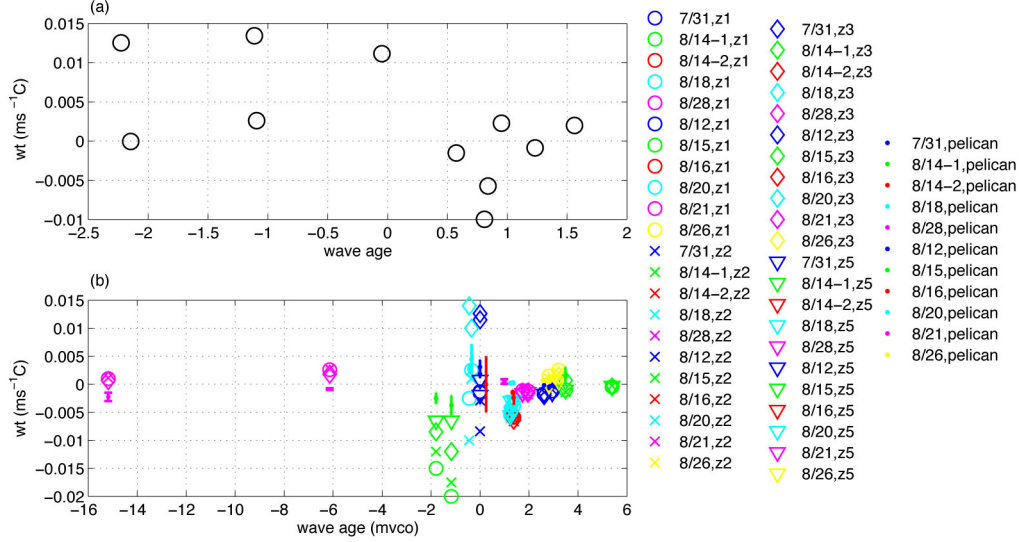


Figure 4: Observed heat fluxes as functions of the wave age from the LongEZ aircraft during the pilot experiment (a) and from both ASIT and the Pelican aircraft during the main experiment (b). Here the wave age is calculated as the same as in Figure 1.

We found that both heat and moisture fluxes are weak over swell-dominant-sea since the wind is normally weak (Figures 4 and 5). The atmospheric stability is another factor on the magnitude of turbulent fluxes; however, we do not have enough data to separate the stability and the wave effects. Under windy conditions, wind shear close to sea surface is strong and the influence of swell on turbulence is relatively small.

IMPACT/APPLICATIONS

We found evidences of large drag coefficient under weak winds over swell, which explained the puzzle that led to the CBLAST-Low. Swell can have significant impacts on air-sea momentum transfer, which is more evident under weak winds than under strong winds when windsea dominates. Up to even today, the air-sea turbulence transfer is commonly investigated as a function of wave age or Charnock coefficient, which is defined by the turbulence itself, leading to serious self-correlation problems (Klipp and Mahrt, 2003; Mahrt, 2007). Our results indicate that without careful examinations of oceanic wave frequency distribution and their directional propagation, we would not be able to understand air-sea interactions. Our results also indicate that air-sea interactions are different from air-land interactions because of swell. As a result of the deep wave layer with swell, the traditional Monin-Obukhov similarity theory, which is widely used

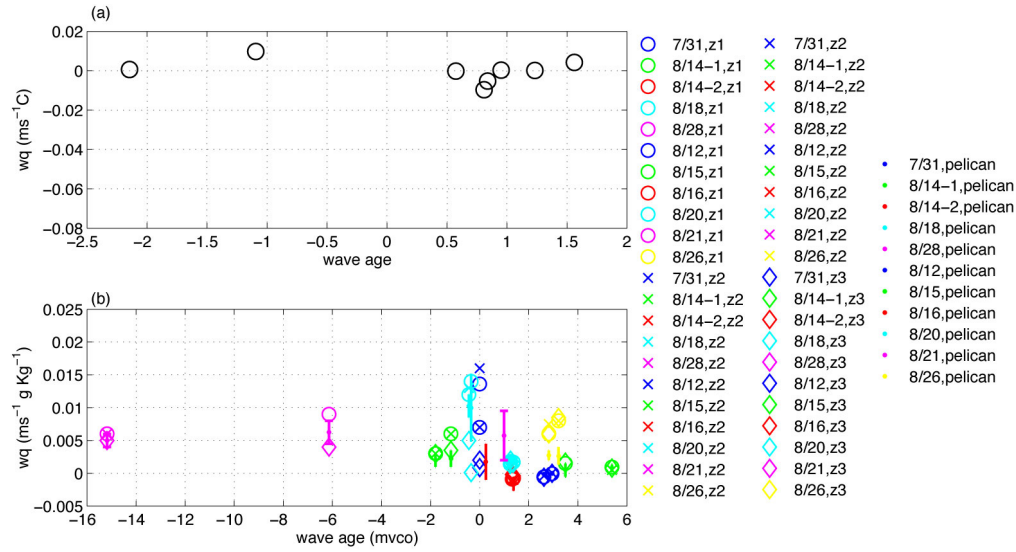


Figure 5: Observed moisture fluxes as functions of wave age from the LongEZ aircraft during the pilot experiment (a) and from both ASIT and the Pelican aircraft during the main experiment (b).

in numerical models, is not valid in the marine atmospheric boundary layer. Blindly converting drag coefficients to their neutral value, calculating surface roughness based on one-level of turbulence and wind measurements, and converting relevant air-sea interaction variables to their 10-m values using M-O similarity theory only lead to scattering relationships and confused results. The existence of swell and its interactions with other oceanic waves can be the key factor in differences in air-sea interaction studies between laboratory and field experiments. With the existence of swell, most of the marine atmospheric boundary layer could be within the wave layer, which is essentially a roughness sublayer. As we know from the air-land interactions, there is no similarity theory available, at least up to now, for any roughness sublayers. Since the boom direction of the ASIT tower is pointed to south where swell comes in, we cannot use tower data to investigate cases when wind blows in the opposite direction of swell. We need more field data with both high vertical resolutions of atmospheric turbulence measurements and detailed directional wave information available to understand air-sea interactions under various wind and wave conditions.

REFERENCES

Klipp, C.L., and L. Mahrt, 2004: Flux-gradient relationship, self-correlation and intermittency in the stable boundary layer. *Quart. J. Roy. Meteorol. Soc.*, **130**, 601B, 2087-2103.

Mahrt, L., 2007: The influence of nonstationarity on the turbulent flux-gradient relationship for stable stratification. *To appear in Boundary-Layer Meteorol.*

PUBLICATIONS

Edson, J., T. Crawford, J. Crescenti, T. Farrar, N. Frew, G. Gerbi, C. Helmis, T. Hristov, D. Khelif, A. Jessup, H. Jonsson, M. Li, L. Mahrt, W. McGillis, A. Plueddemann, L. Shen, E. Skillingstad, T. Stanton, P. Sullivan, J. Sun, H. Trowbridge, D. Vickers, S. Wang, Q. Wang, R. Weller, J. Wilkin, D.

Yu, and C. Zappa, 2007: The Coupled Boundary Layers and Air-Sea Transfer Experiment in Low Winds (CBLAST-LOW). *Bull. Amer. Meteorol. Soc.*, **88**, 341-356.

Sun, J., S. Burns, J. Edson, A. Plueddemann, D. Khelif, H. Jonsson, J.R. French, G.H. Crescenti, D. Vickers, L. Mahrt, T. Hristov, C. Zappa, 2007: Energy transfer through air-wave interactions. *To be submitted to J. Geo. Res.*