Surface Fluxes and Wind-Wave Interactions in Weak Wind Conditions

Jielun Sun
Microscale and Mesoscale Meteorology
National Center for Atmospheric Research
phone: (303) 497-8994 fax: (303) 497-8171 email: jsun@ucar.edu

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LONG-TERM GOALS

We will investigate air-sea transfer of momentum, heat, and moisture under weak wind conditions. We will focus on effects of swell on turbulence transfer since swell phase speeds can be much faster than weak wind and swell can have significant impacts on air-sea interactions. Improved understanding of wave effects on marine atmospheric turbulent fluxes under weak wind conditions will be used to modify the existing bulk aerodynamic formula for numerical models.

OBJECTIVES

Our objectives for FY2004 is to analyze the Pelican aircraft data and compare them with the ASIT tower data for the flight days collected during the CBLAST-Low main field campaign. The scientific objectives for analyzing the CBLAST-Low experiment data are to understand air-sea interactions under weak wind conditions by mainly focusing on vertical variations of air-sea interactions within wave boundary layers and marine atmospheric surface layers.

APPROACH

During the CBLAST-Low main field campaign, the CIRPAS Pelican aircraft was deployed to replace the LongEZ aircraft. We have participated in the CBLAST-Low main field campaign conducted off coast of Martha's Vineyard, MA in August 2003. Since the Pelican level-flights along the east-west track were over the ASIT tower, we only investigated the repeated flights along the track and compared them with the ASIT tower data during the flight period. We first compared the Pelican level-runs at 30 m along the east-west track with ASIT data using the spectral analysis method and noticed some aircraft data problems. Dr. Djamal Khelif at University of California, Irvine resolved the Pelican data issues in the spring of 2005. Because the boom direction on the ASIT tower, and the limited Pelican aircraft flights, there are totally six good comparison days: 8/12, 8/15, 8/16, 8/20, 8/21, and 8/26. To ensure the data quality, we only analyzed the ASIT data from the lowest three levels, and the one at 17.8 m.

In this funding period, we mainly focused on the Pelican and ASIT data comparison during the CBLAST-Low main field campaign period to investigate vertical characteristics of air-sea interactions by examining variable spectra and ogive momentum fluxes in relation to sea status, such as wave phase speed, wave direction from MVCO, and wave age, and atmospheric environment, such as Obukhov length for atmospheric stability.

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14. ABSTRACT

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WORK COMPLETED

The work on derivations of directional surface-wave spectra using the laser altimeters on board the LongEZ aircraft was published in Journal of Atmospheric and Oceanic Technology, SHOWEX special issue (Sun et al. 2005).

We have analyzed momentum fluxes from both ASIT tower and the Pelican aircraft, and related them to the wave age and atmospheric stability. We also checked the influence of swell on the exchange coefficient for momentum under weak wind conditions. We found that the most important features that are associated with weak winds are atmospheric stability and influences of swell.

RESULTS

1) Pelican aircraft data

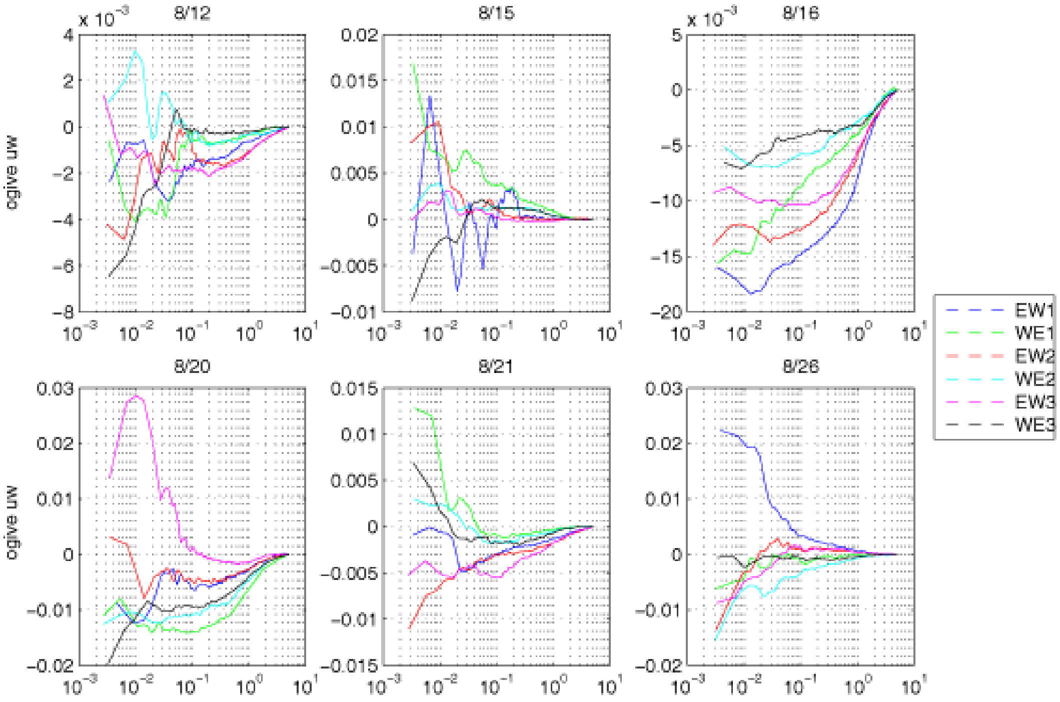

Figure 1. The ogive momentum fluxes along wind directions from the Pelican east-west track for six comparison days during the CBLAST-Low main field campaign. Here EW and WE represent flight headings from east to west and from west to east, respectively.

We found that momentum flux from the Pelican aircraft is flight-direction dependent (Fig.1). This problem has been existed for all the aircraft data and has just started to gain the community attention recently. Dr. Lenschow at NCAR and his colleagues are actively working on this problem. Their preliminary results indicate that aircraft pressure calibration is one of the factors. The problem won't be solved easily through post-experiment data process. Nonetheless, our comparison results are encouraging (see below).

2) Comparison between Pelican and ASIT data

a) W spectral peak and wave states

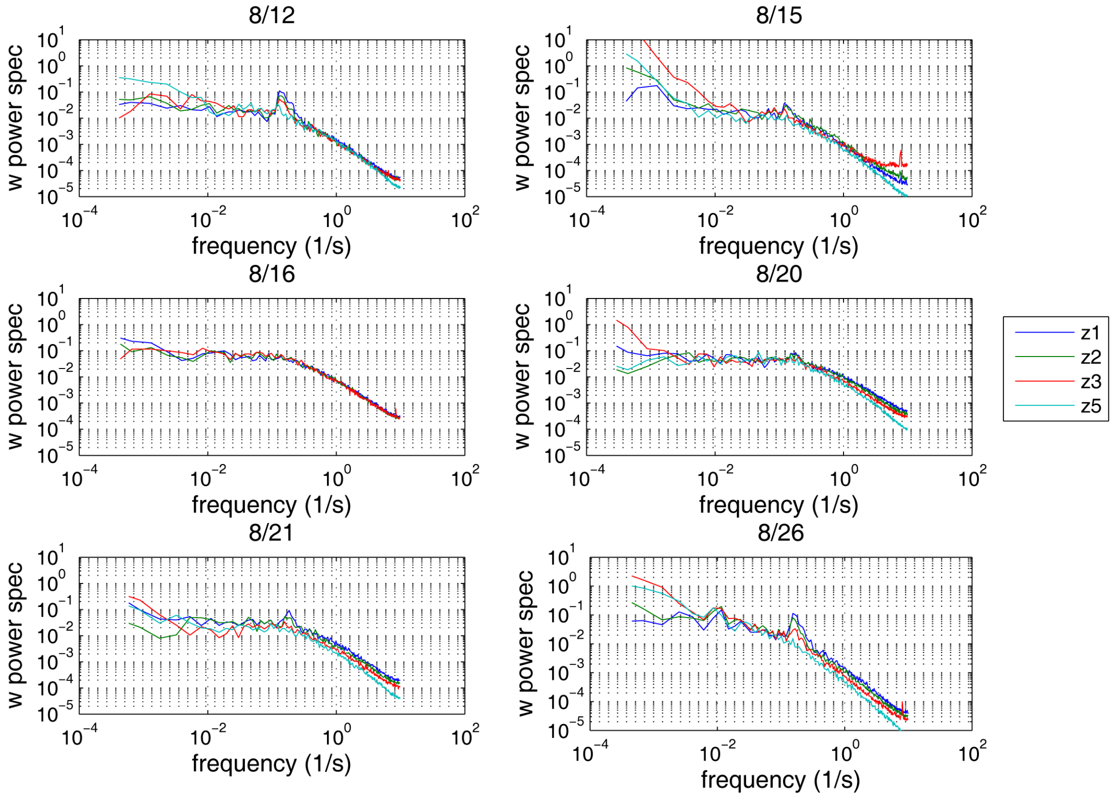

Figure 2. The power spectra of the vertical velocity from the sonic anemometers at 4 levels on ASIT for the six comparison days. Here z5 was at 17.8 m, and z1, z2, and z3 were 5.86 m, 8.29 m, and 12.03 m before 8/19, and 3.59 m, 6.02 m, and 9.76 m, after.

During the six flight days, we found that sometimes there are spectral peaks at the frequency of 0.2 s^{-1} in the vertical velocity power spectrum from the ASIT tower data (Fig.2). We found that the appearance of the spectral peak is related to the wave age (Fig.3) defined as the ratio of the peak wave phase speed from the laser altimeter at the ASIT tower and the wind speed at 17.8 m (since the sonic anemometer there was never moved during the CBLAST-Low main field campaign). We found that the amplitude of the w spectral peak increases with the wave age except for 8/15 (Fig.3b) when the marine atmosphere was most stable among the comparison days and atmospheric disturbances were strongly suppressed (Fig.3a). In addition, the depth of the vertical layer where the w spectral peak was found increasing with the wave age as well (Fig.3c). Here the depth is defined as the middle of the two observation levels where the w spectral peak is observed at the lower level, but not at the adjacent level above, or the highest level where the w spectral peak is observed if the w peak is observed at all the levels (e.g. 8/12 and 8/15). We assume that the spectral peak is associated with swell based on their occurrence under large phase speed. Notice that five out of the six comparison days were stable.

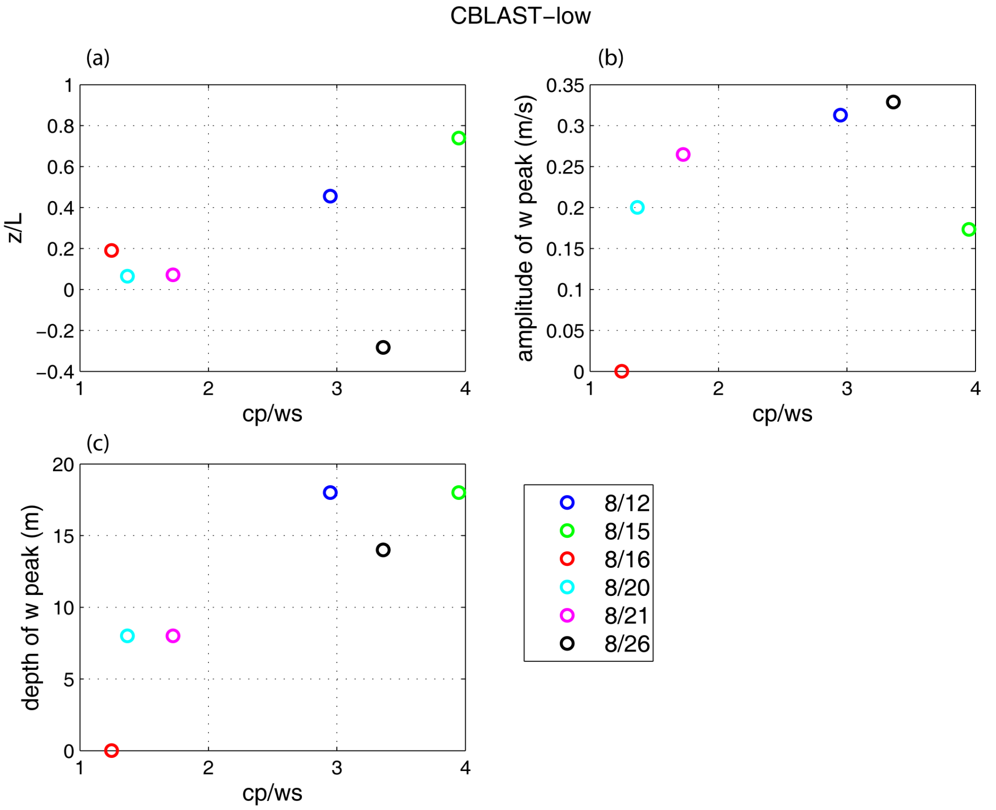

Figure 3. Correlations between (a) the atmospheric stability at the lowest ASIT observation level (z/L), (b) the amplitude of the w spectral peak at the lowest ASIT level, and (c) the depth of the observed w peak as a function of the wave age (see the text for the definition). Here z is the observation height and L is the Obukhov length calculated using the fluxes at the lowest observation level.

b) momentum flux as a function of wave states

The magnitude of the momentum flux is determined as the ogive momentum flux at the cut-off frequency of 0.01 s^{-1} for ASIT and 0.2 s^{-1} for the Pelican aircraft. We found that the magnitude and the vertical variation of the ASIT momentum flux are much smaller for the swell case than for the wind-wave case (Fig.4). This result indicates that the swell and wind-waves cases are in two different regimes, although the overall momentum flux for the swell case is negative. The momentum flux comparison between the Pelican and ASIT is reasonable (Fig.5). The variation of the Pelican momentum flux between the repeated east-west flights is large for the wind-sea case and seems to increase with the magnitude of the momentum flux. In general, the momentum flux is smaller from the Pelican aircraft than from the ASIT data, which is cocnsistent with the vertical variation of the momentum flux with height based on the ASIT tower data. Since the vertical variation of the momentum flux for the swell case is small, the Pelican momentum flux is close to the ASIT one for the swell case.

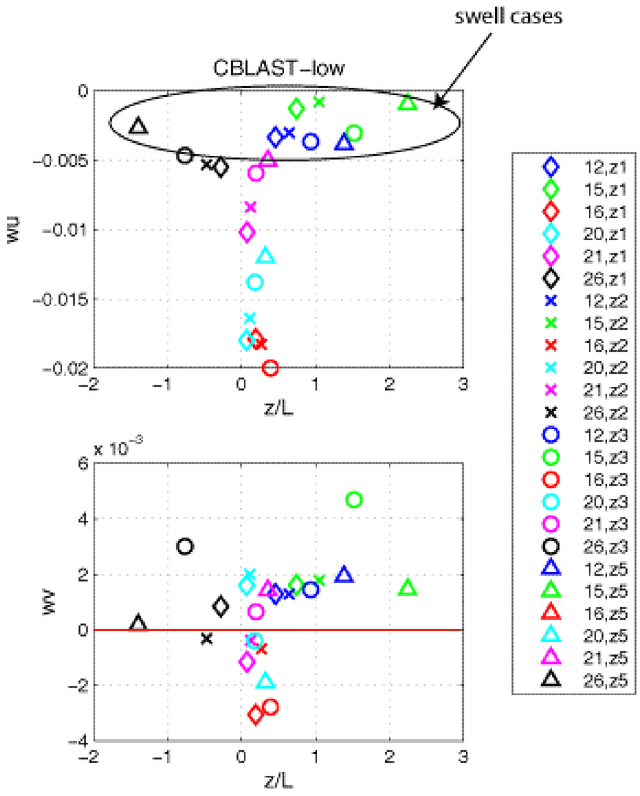

Figure 4. The ogive momentum fluxes along (top) and cross (bottom) wind directions from the 4 levels on ASIT as functions of the atmospheric stability (z/L). Symbols represent observation levels and colors represent flight days.

By normalizing the momenutm flux with wind speed, we found that the exchange coefficient does increase with decreasing wind speed except at low wind speed. To understand the special weak wind regime is one of the motivations for the CBLAST-Low field campagin. We found that the high exchange coefficient at low wind here is associated with the swell case (Fig.6). The result implies that as swell becomes important under weak wind conditions due to the large difference between wind and wave phase speed, the exchange coefficient for the swell case may be much larger than the one for wind sea. Here the atmospheric stability is not removed from Fig.6 yet, since no stability functions are available for swell cases.

IMPACT/APPLICATIONS

In the low-wind regime over oceans, swell can travel much faster than wind. Under this situation, the influence of swell on air-sea interactions is evident. Swell can transport energy into the atmosphere, although the observed momentum flux integrated from small to large eddies is negative. It is well known that the momentum exchange coefficient increases with wind speed, except for wind is less than about 4 m/s. Our preliminary results imply that the swell effect contributes significantly to the weak wind regime. The CBLAST-Low data provide us a unique opportunity to investigate how waves influence air-sea interactions. Many questions remain and our effort on data analysis is on going.

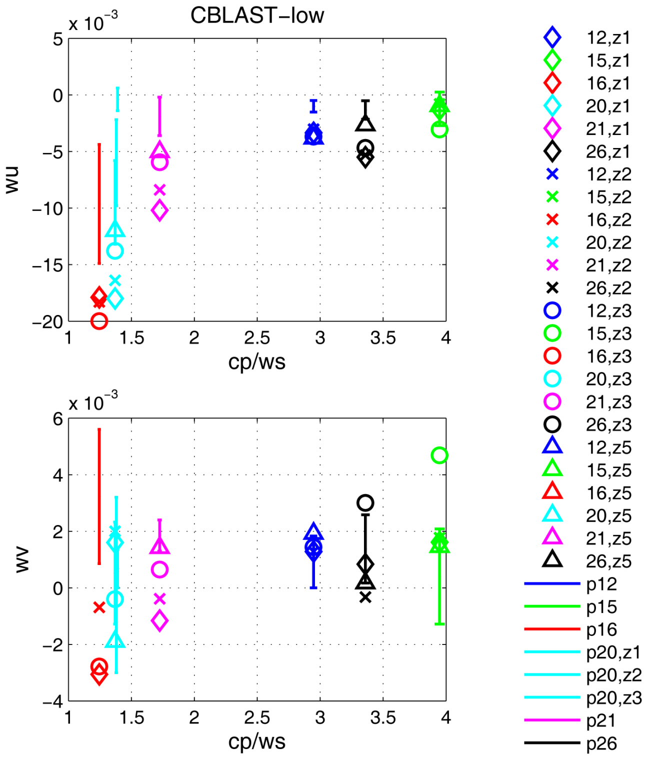

Figure 5. The ogive momentum fluxes along (top) and cross (bottom) wind directions from the 4 observation levels on ASIT and the Pelican aircraft (vertical lines) as functions of the wave age. Each vertical line represents the variation of the Pelican momentum fluxes between the repreated east-west runs for each flight. The Pelican aircraft flew at three altitudes on 8/20: 30 m, 50 m, and 90 m. The momentum- flux variations from the low to high altitudess are marked by three vertical lines from left to right.

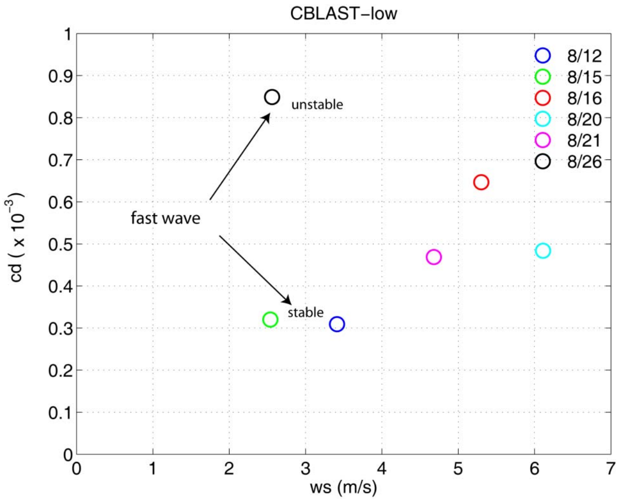

Figure 6. The momentum exchange coefficient (cd) at the lowest observation level on ASIT as a function of wind speed at 17.8 m for the six comparison days.

RELATED PROJECTS

REFERENCES

Sun, J., S. P. Burns, D. Vandemark, M.A. Donelan, L. Mahrt, T. L. Crawford, G.H. Crescenti, J.R. French, 2005: Measurement of directional wave spectra using aircraft laser altimeters. *J. Atmos. Oceanic Technol.,* **22**, 869-885.

PUBLICATIONS

Sun, J., S. P. Burns, D. Vandemark, M.A. Donelan, L. Mahrt, T. L. Crawford, G.H. Crescenti, J.R. French, 2005: Measurement of directional wave spectra using aircraft laser altimeters. *J. Atmos. Oceanic Technol.,* **22**, 869-885.

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