MOMENTUM AND HEAT FLUXES ACROSS THE AIR-SEA INTERFACE DURING CBLAST-LOW

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INTRODUCTION

Direct measurements of the vertical fluxes of momentum and heat were obtained simultaneously on both sides of the air-sea interface during the low-wind component of the Coupled Boundary Layers and Air-Sea Transfer (CBLAST-low) program. The purpose of the measurements is to elucidate the processes responsible for vertical fluxes of momentum and heat near a wind-driven sea surface, in order to improve the subgridscale parameterizations that are used in numerical simulations of atmospheric and oceanic processes. Of particular interest are effects of stable and unstable stratification, wave breaking, and Langmuir circulations.

The analysis reported here has the limited objective of comparing direct measurements of momentum and heat fluxes just above and just below the air-sea interface. Momentum and heat fluxes on opposite sides of the air-sea interface should nearly balance, with small discrepancies produced by the fluid acceleration and the pressure gradient (in the case of momentum) and by storage and horizontal advection (in the case of heat). These small effects can be estimated by means of the CBLAST-low measurements.

To our knowledge, a successful closure of momentum and heat balances across the air-sea interface has not previously been achieved in a seagoing study. A test of momentum and heat balances is essential in order to establish the validity of direct measurements of turbulent fluxes. Of particular importance is determination that the measurements resolve all of the important flux-carrying scales in both the atmosphere and the ocean.

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MEASUREMENTS AND ANALYSIS

The measurements were obtained at the Martha's Vineyard Coastal Observatory, a site exposed to the open sea (Figure 1). The sensors were deployed on an air-sea interaction tower, which spans the 15-m water column and extends 22 m into the atmosphere (Figure 2).

The atmospheric turbulence measurements were obtained from a vertical array of coherently sampled sonic anemometers, temperature sensors, humidity sensors, and static pressure sensors. The downwelling radiative heat fluxes were measured by solar and infrared radiometers. The skin temperature and the upwelling infrared radiative heat flux were obtained from a pyrometer. The vertical momentum fluxes are calculated as density times the covariance of horizontal and vertical velocities. The sensible and latent heat fluxes are calculated from the covariance of the vertical velocity with temperature and humidity, respectively. The various components of the vertical heat flux are summed to determine the net heat flux into or out of the ocean.

The oceanic turbulence measurements were obtained from near-surface arrays coherently sampled acoustic Doppler velocimeters and thermistors. Turbulent fluxes of momentum and heat are computed as direct covariances of turbulent velocity and temperature fluctuations. Direct covariance estimates of turbulent fluxes on the water side of the air-sea interface are problematic because of spurious contributions from surface gravity waves, which produce velocity fluctuations that are orders of magnitude more energetic than the turbulence. Spatial and temporal filtering techniques for removing spurious wave effects from estimates of water-side turbulent fluxes are being developed as part of this project. Results to date are based on a simple-minded high-pass spatial filter, which is based on the assumption that the spatial scales of the surface waves are large in comparison to the spatial scales of the turbulence.

RESULTS AND DISCUSSION

A comparison of vertical fluxes of momentum just above and just below the sea surface indicates the importance of filtering the effects of surface waves from the water-side measurements. Without filtering, the estimates of the water-side momentum fluxes are two orders of magnitude larger than the air-side momentum fluxes (Figure 3a). With filtering, the air-side and water-side momentum fluxes are roughly equal, although the water-side estimates are noisy, and discrepancies between air-side and water-side fluxes clearly exist (Figure 3b).

A comparison of air-side and water-side of the net vertical heat flux is similar. Without filtering, estimates of the water-side heat flux are much larger than estimates of the air-side heat flux. With filtering, estimates of the water-side heat flux are more nearly equal to estimates of the air-side heat flux, although discrepancies exist, particularly during periods with larger waves (Figure 4).

CONCLUSIONS

Turbulence measurements obtained just above and just below the air-sea interface during CBLAST-low indicate eventual good agreement between direct estimates of the vertical fluxes of momentum and heat on opposite sides of the interface. Future work will focus on improved estimates of the water-side fluxes. Subsequent analysis will address the processes responsible for accomplishing vertical fluxes, and will focus, in particular, on effects of stable and unstable stratification, wave breaking, and Langmuir circulations.

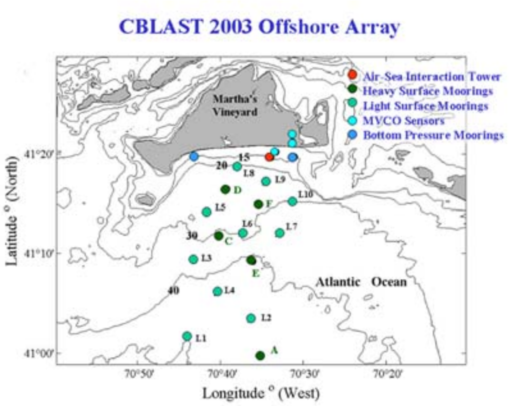

Figure 1. Diagram of the CBLAST study area at the Martha's Vineyard Coastal Observatory.

Figure 2. Photograph of the air-sea interaction tower, constructed as part of the CBLAST-low program. The tower is at a water depth of 15 m. The deck is approximately 12 m above the water surface, and the mast extends approximately 22 m into the atmosphere. Turbulence sensors were deployed on the air-side and the water-side of the air-sea interface.

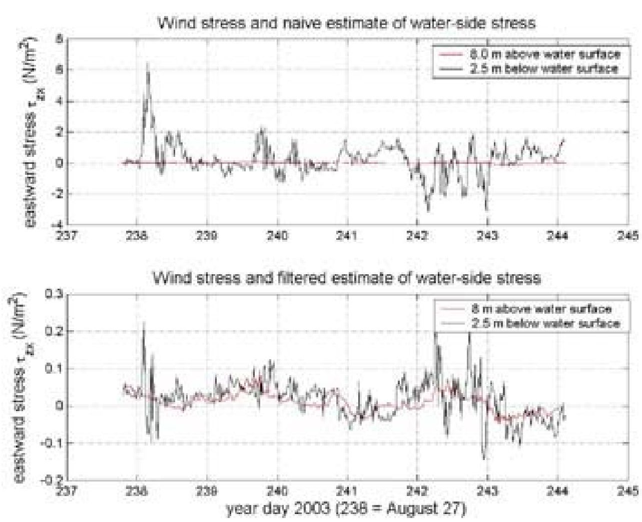

Figure 3. Comparison of Reynolds stress estimates obtained just above and just below the air-sea interface (a) without filtering and (b) with filtering effects of surface gravity waves from the water-side estimates. Note the difference in the scales of the vertical axis in (a) and (b).

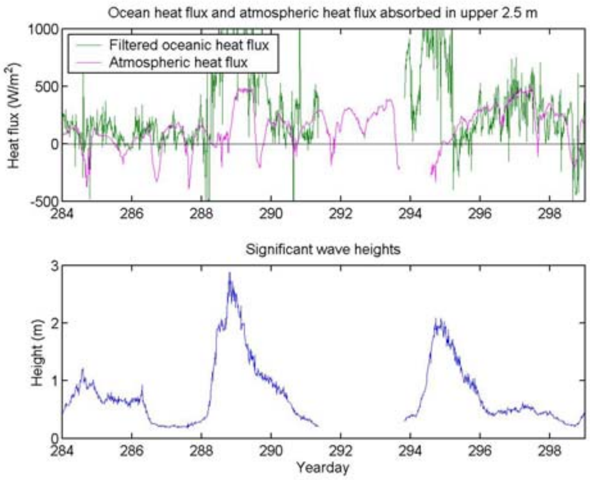

Figure 4. Estimates of (a) atmospheric and oceanic heat fluxes and (b) significant wave height.