Observations of Velocity Fields Under Moderately Forced Wind Waves

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LONG TERM GOALS

Long term goals are to observe and model turbulent transfer of momentum and heat between the atmosphere and ocean in the presence of surface gravity waves. Surface gravity waves play a unique role in the coupling of wind stress into the ocean mixed layer as they gather wind kinetic energy and deliver momentum to the ocean interior through several mechanisms, including micro breaking and full wave breaking. The resulting momentum transfers have both continuous stress components and highly episodic, strong events which significantly effect vertical distribution of kinetic energy dissipation and turbulent stress in the water column.

OBJECTIVES

The primary scientific objective of this project is to measure the turbulent stresses, shear and kinetic energy dissipation rates in the crest-trough region of wind forced surface gravity waves. It is crucial to measure these properties right up to the wave surface as micro-breaking and gentle spilling breaking events produce disturbances in the water column that change rapidly with distance from the wave surface, and are suspected to generate coherent rotational flows immediately below the surface. Separating out small turbulent signatures from the large amplitude, mostly irrotational flow under ocean waves presents a significant observational challenge. Consequently this study is focused on moderately forced local wind waves, with 10m height winds ranging from 4-10ms^{-1} in ocean environments with low swell climates. Detailed near-surface observations over this range of wind forcing, which spans the transition into wave breaking, will be used to evaluate the role of competing momentum transfer processes in order to formulate improved parameterizations of wind stress transfer into the ocean mixed layer.

APPROACH

While many of the hypotheses for stress transfer under wind waves have been developed from controlled laboratory experiments, the approach taken here is to make direct, noninvasive measurements of the velocity structure under oceanic wind waves without the restrictions imposed by laboratory tanks. Field observations of sub-wave velocity profiles, 2D wave slope and local wave breaking will be made over differing wind and wave conditions at sites with minimal swell, to measure the response of the near-surface ocean to the wind forcing. In laboratory tank experiments phase averaging techniques, where nearly identical surface waves are propagated through the tank, allow

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14. ABSTRACT
Long term goals are to observe and model turbulent transfer of momentum and heat between the atmosphere and ocean in the presence of surface gravity waves. Surface gravity waves play a unique role in the coupling of wind stress into the ocean mixed layer as they gather wind kinetic energy and deliver momentum to the ocean interior through several mechanisms, including micro breaking and full wave breaking. The resulting momentum transfers have both continuous stress components and highly episodic, strong events which significantly effect vertical distribution of kinetic energy dissipation and turbulent stress in the water column.

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turbulent motions to be separated from wave motions by ensemble averaging of the flow fields. Since this important analysis technique is not available in field observations under truly random wave fields, other techniques are being used to identify turbulent momentum fluxes below the waves.

A unique high resolution Bistatic Coherent Doppler Velocity Profiler (BCDVP) developed in my research group at NPS (Stanton 1996, 2001, 2002) is being used to measure 1 cm-resolution profiles of three component velocity vectors and backscatter levels over a 1.2m vertical span immediately below the water surface under wind waves. The bistatic geometry provides a small sample volume, determined by the short acoustic pulse length and narrow transmitter beamwidth, to determine the 3 component velocity vector and backscatter level at each range bin through the water column. This small (2 cm diameter, 1.5cm high) sample volume is critical when sampling close to the highly curved wave surface (and resulting velocity field) immediately below wind waves. The continuous, dense, profile of velocity vectors allow Reynolds stresses to be estimated through the water column in a surface-following coordinate system.

These measurements will be made from a deep water coastal tower south of Marthas Vineyard (MV) during the summer of 2003 as a component of the CBLAST Low Wind experiment (http://www.whoi.edu/science/AOPE/dept/CBLAST/lowwind.html). The sub-wave observations will be made in the context of comprehensive wind profile measurements and vector velocity measurements in the mixed layer and pycnocline being measured by other CBLAST investigators. I will also deploy a 5 beam ADCP at the base of the observation tower to measure Langmuir circulation signatures deeper in the mixed layer in collaboration with side scan measurements of larger scale coherent structures being made by Al Pludemann. Preliminary sub-wave observations are currently being made at a site outside the surf zone in Monterey Bay.

WORK COMPLETED

Delays in fabrication of the MV tower changed the focus of this years CBLAST activity. Effort has been focused on instrumentation and development of data processing and analysis techniques, and making short measurements from a portable frame deployed just offshore from the surf zone in Monterey Bay. A wide baseline BCDVP instrument is being constructed to provide a more optimal geometry for this application, and a data concentrator / power distribution module is being used for local experiments in Monterey Bay and tested for the 2003 field work at Martha's Vineyard. An optical 2D wave slope measurement system is being evaluated in laboratory measurements and is being integrated into the MV sub-surface measurement system. An underwater winch and profiling CTD system underwent a 10 day trial at the MISO cabled node at 12m depth in preparation for continuous stratification measurements at the Martha's Vineyard site in 2003. The system profiles under remote computer control from 1m above the bed to the surface every 2 minutes, resolving rapid stratification changes due to tidal currents, internal waves, bores and solitons. These full water column T/S measurements are critical in understanding near-surface turbulence in rapidly changing coastal regimes

Analysis techniques have been developed to robustly estimate Reynolds stresses in a surface following coordinate system in the presence of large amplitude irrotational wave motions. These methods are being applied to BCDVP data gathered in Monterey Bay field trials that use a portable frame deployed outside the surf zone in 3m nominal depth, typically for 24 hour periods.

RESULTS

The BCDVP has been used to measure the velocity fields using a non-optimal configuration at a site dominated by wind waves, providing data sets to develop processing techniques for the velocity profiles. These preliminary measurements have been made using a portable frame (Figure 1) that is wheeled out past the surf zone in Monterey Bay at low tide then anchored and left for the following high tide. Diurnal summer-time north west winds ensure moderate to strong afternoon breezes across the frame allowing the velocity fields below wind waves to be measured by the instruments on the mobile platform. While the longer waves are shoaling, this deployment system has provided a useful platform for sub-wave measurements.

Figure 1. The BCDV velocity profiling instrument and optical wave slope sensor deployed on a mobile frame prior to a shallow water deployment in Monterey Bay.

Techniques to minimize the contribution of large irrotational flow components in the estimation of the turbulent stress timeseries $\rho\langle u'w'\rangle(z_{\eta,},t)$ and $\rho\langle v'w'\rangle(z_{\eta},t)$, where z_{η} is the distance down from the wave surface, are being used to identify stress events associated with incipient and spilling breaking. The η-following reference frame allows Reynolds averages of these stress timeseries to be formed over appropriate averaging times to within1 cm of the surface the surface despite the large vertical excursion of the surface. An example of a 16 second subsurface section of BCDVP observations in Figure 1 illustrates the high resolution measurements below small wind waves. In this deployment the total range was limited to 50cm, and consequently the wave amplitude frequently exceeded the measurement range. The upper panel shows $\log_{10}$ backscatter levels, which result from organic scatterers and small bubbles in the water column, with the z axis extending up from the instrument face. The following two panels show the cross-shore velocity component and $\langle u'w'\rangle$ turbulent velocity correlation profile timeseries, both in a surface-following coordinate system. At t=8 seconds, on the leading face of the wave, the cross-shore velocity (and vertical, longshore components, not shown) appears strongly structured and there is a corresponding rapid magnitude increase in cross-shore stress. This event was correlated with a small roller breaking event captured by a co-located video camera.

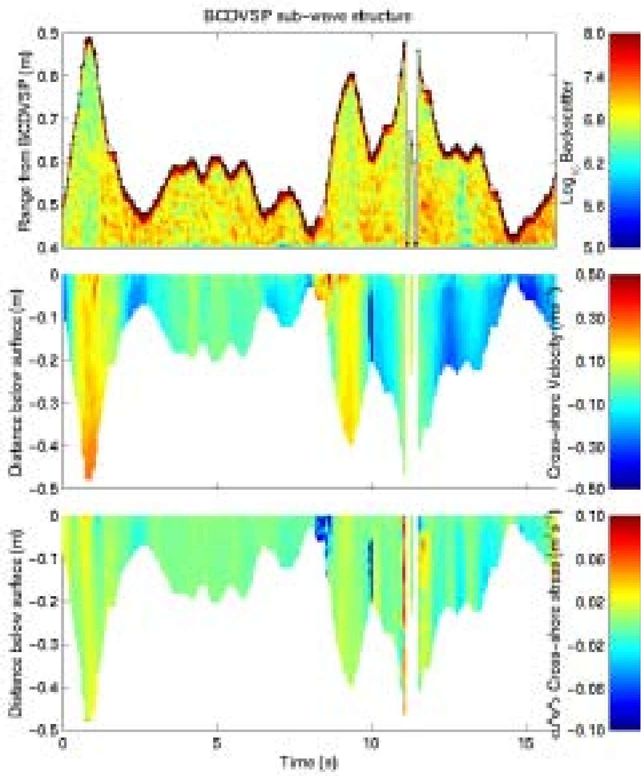

Figure 1. A 12 second profile timeseries of shows log$_{10}$ backscatter levels (upper panel), cross-shore velocity (middle panel), and (u'w') (lower panel). The middle and lower panels are mapped in a surface-following coordinate system.

Observations in Figure 1 illustrate the high resolution velocity measurements below small wind waves. In this deployment the total range was limited to 50cm, and consequently the wave amplitude frequently exceeded the measurement range. The upper panel shows log$_{10}$ backscatter levels, which result from organic scatterers and small bubbles in the water column, with the z axis extending up from the instrument face. The following two panels show the cross-shore velocity component and <u'w'> turbulent velocity correlation profile timeseries, both in a surface-following coordinate system. At t=8 seconds, on the leading face of the wave, the cross-shore velocity (and vertical, longshore components, not shown) appears strongly structured and there is a corresponding rapid magnitude increase in cross-shore stress. These large episodic stress events were seen throughout the one hour observation and were visually correlated with gently spilling breaking waves. Results from three sets of preliminary measurements were presented at the 2002 ocean Sciences meeting.

IMPACTS/APPLICATIONS

Improved observations of the processes responsible for stress transfer into the ocean wind momentum transfer into the ocean have broad application to air-sea interaction and gas exchange studies. There is a clear need for improved drag coefficient parameterizations, in both atmospheric and oceanic models, particularly in very high resolution littoral modeling efforts including COAMPS.

RELATED PROJECTS

This research is closely coordinated with other CBLAST investigators including Jim Edson (atmospheric boundary layer), Al Pludemann (Langmuir circulations), Jean Terray and John Towbridge (mixed layer velocities), Chris Zappa (surface thermal signatures) and Brain Ward (Near surface temperature gradients and stratification).

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