The Coupled Boundary Layers and Air-Sea Transfer Experiment in Low to Moderate Winds (CBLAST-LOW): Flux Profile Relationships Across the Coupled Boundary Layers

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LONG-TERM GOALS

The long-range goal of the proposed research is to understand air-sea interaction and coupled atmospheric and oceanic boundary layer dynamics at low wind speeds where the dynamic processes are driven and/or strongly modulated by thermal forcing. The low wind regime will extends from the extreme situation where wind stress is negligible and thermal forcing dominates up to wind speeds where wave breaking and Langmuir circulations are also expected to play a role in the exchange processes. Therefore, the CBLAST-LOW investigators seek to make observations over a wide range of environmental conditions with the intent of improving our understanding of upper ocean and lower atmosphere dynamics and of the physical processes that determine both the vertical and horizontal structure of the marine boundary layers.

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OBJECTIVES

The short-range objectives are to obtain direct measurements of vertical fluxes (transfer) of momentum, heat and mass across the coupled boundary layers (CBLs); to map the 3-D structure of the CBLs over a range of spatial and temporal scales, to identify the processes that drive the flux and CBL structure; to develop and evaluate parameterizations of the flux-producing processes; and to test the mean and variance budgets for momentum, heat, mass, and kinetic energy. Observational components of this program will investigate the temporal and spatial evolution of the CBLs over vertical scales of from centimeters to 100’s of m, horizontal scales of from 10 m to 10’s of km, and time scales of minutes to months. Mesoscale models, large eddy simulations (LES), and direct numerical simulations (DNS) will provide nowcasts, forecasts, and simulations over similar scales. The numerical results will provide a context for interpreting our measurements, while our measurements will provide a means to initialize and evaluate the estimates of turbulent fluxes and dissipation rates calculated by these models.

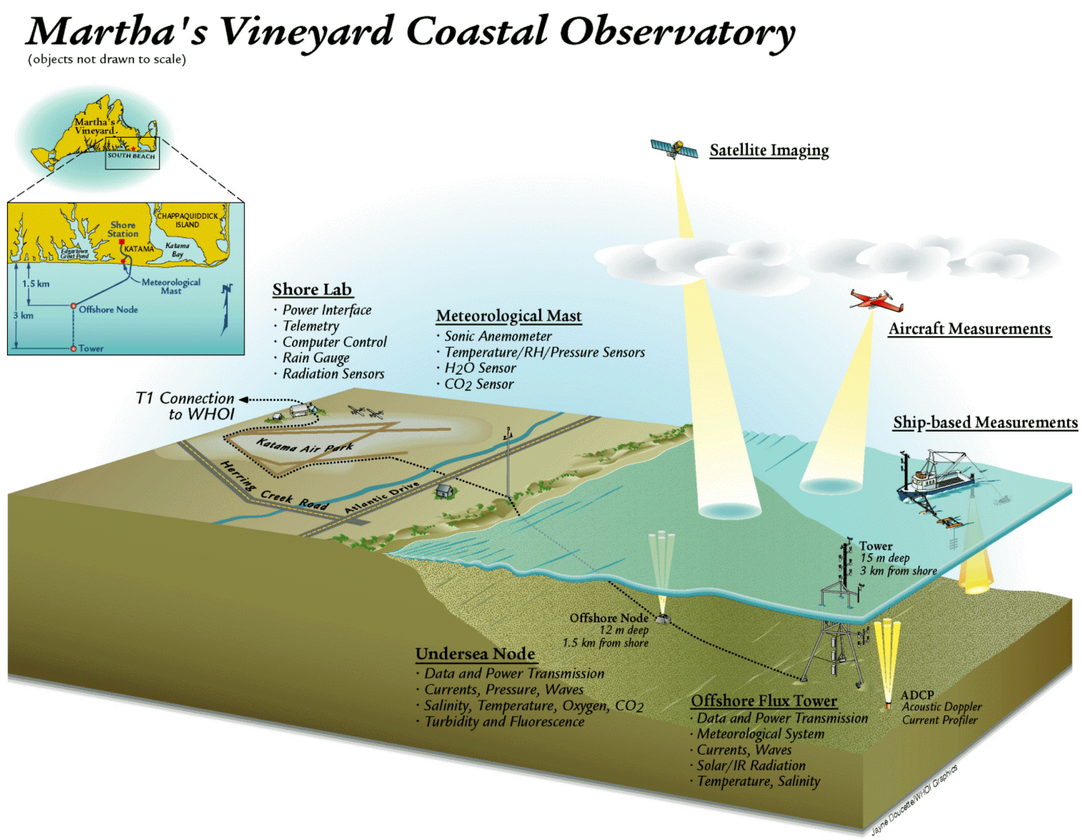

Figure 1. An image of the CBLAST region showing some of the assets that will be deployed in the main experiment in summer 2003.

APPROACH

To achieve some of these objectives, we have deployed an Air-Sea Interaction Tower (ASIT) spanning the water column and the lower 22-m of the atmosphere at a water depth of 15-m at the Martha's Vineyard Coastal Observatory (MVCO) as shown in Figure 1. The tower will be complemented by subsurface platforms at five other locations to provide estimates of horizontal gradients. The 37-m tower will be instrumented with velocity, temperature, conductivity, pressure, humidity, solar radiation, turbidity, precipitation and wave sensors. The tower is being connected directly to land using a fiber-optic-conductor cable, which will provide Gbyte bandwidth and kWatts of power to the researchers. The velocity and temperature arrays will span horizontal and vertical scales of O (1-10) m to resolve vertical structure and to permit separation and quantification of processes associated with shear- and buoyancy-generated turbulence, surface waves, and Langmuir-like coherent structures. The second component of the WHOI effort (see Upper Ocean Dynamics and Horizontal Variability in Low Winds, Robert Weller, PI for details) will deploy an innovative 3-D array to simultaneously observe the horizontal and vertical structure of the oceanic surface boundary layer near the tower. Using the large diurnal cycles in forcing and in response and the strong sensitivity of the shallow ocean surface layer to atmospheric and oceanic processes, these studies will seek answers to unresolved questions about how the horizontal as well as the vertical structure of the upper ocean evolves.

A pilot experiment at the Martha's Vineyard site was conducted during the summer 2001. An experiment designed to provide observations for the regional modeling efforts was conducted in the summer of 2002. The main experiment is planned for the summer 2003. The final year of the program will consist of analysis and publication of results. This field work has involved substantial collaborations with Tim Stanton at NPS (deploying complementary sensors on our tower); Tim Crawford and Jerry Crescenti at NOAA/, Doug Vandemark at NASA/GSFC and Larry Mahrt at OSU (obtaining atmospheric measurements of turbulent fluxes, vertical profiles and horizontal variability from the LongEZ aircraft); and Andy Jessup at UW and Chris Zappa at WHOI (obtaining IR remote-sensing measurements). In addition, we have had substantial collaborations with regional-scale modeling groups at Rutgers University and NRL-Monterey, as well as LES investigations by Eric Skyllingstad at OSU and Peter Sullivan at NCAR. The regional-scale models are providing a context for interpreting our measurements, and our measurements will provide a means of testing estimates of turbulent fluxes and dissipation rates calculated by these models. Our tower measurements of horizontal and vertical variability will span a range of scales similar to those resolved by LES simulations and will permit a quantitative evaluation of LES model calculations. The proposed study will produce a unique set of simultaneous measurements of turbulent fluxes and dissipation rates on both sides of the air-sea interface, as well as critical evaluations and improvements of turbulence parameterizations used in atmospheric and oceanic models.

WORK COMPLETED

We have collected historical data from field experiments, NOAA archives, and satellite imagery that provide information about the physical forcing and ocean structure in the region. Additionally, we conducted one CTD transect offshore in early spring to examine the vertical structure in the region near the proposed tower site. The results from these efforts were presented at the CBLAST-LOW planning meeting at WHOI in May 2001. Offshore surveys of the ocean bottom were also conducted in preparation for the cable burial. These data was also used to secure the necessary permit to deploy the ASIT.

In July and August 2001 we participated in the pilot experiment. A string of temperature sensors were deployed beneath a surface mooring located at the proposed ASIT location at depths spanning the water column. Bottom-mounted pressure, temperature and salinity sensors were deployed from July through August to measure the horizontal gradient in these fields for the anticipated process and modeling studies. Data from the MVCO were collected beginning in early July. The MVCO data includes near continuous direct measurements of the momentum, heat, moisture, and radiative fluxes from a meteorological mast at the ocean's edge and wave spectra, current profiles, and water column properties from an underwater node located 1.6 km offshore. Four 1-day survey cruises were conducted from the R/V Asterias in support of the surface moorings activities and LongEZ operations. These surveys consisted of direct covariance flux measurements, rawinsonde launches, surface skin temperature measurements, CTD casts, and continuous ADCP measurements. Additional ADCP and CTD surveys were conducted from a small vessel during this period. This data was analyzed and made available to other CBLAST investigators in 2002.

The main accomplishment in FY02 was the design, construction, and successful deployment of the ASIT offshore of Martha's Vineyard. Various stages of the tower's deployment are depicted in Figure 3. The ASIT is located 3 kilometers due south of Edgartown Great Pond in 15 m of water, and extends approximately 22 m into the marine atmosphere. The ASIT was designed by Appledore Engineering Inc. and deployed by RDA Construction Corp. under the supervision of CBLAST PIs. Upon completion, it will be directly connected to the Martha's Vineyard Coastal Observatory (MVCO) to provide data transmission and power directly from shore. Data from the ASIT will be integrated with the MVCO data and made available to all users via the CBLAST web site. The data will include wind speed and direction, air and sea temperature, wave height and direction, and currents at the offshore site. More importantly, the sensors it supports will ultimately provide direct and remotely sensed measurements of the momentum, heat, and mass fluxes across the coupled boundary layers.

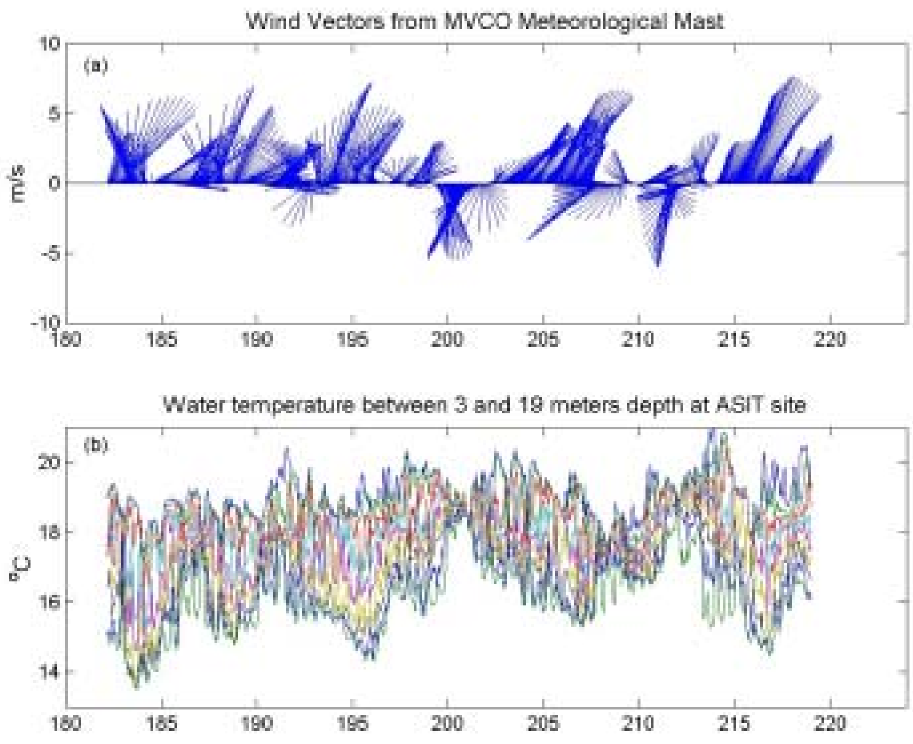

Figure 2. Timeseries of velocity vectors (a) and temperature profiles (b) from the 2001 Pilot Experiment. The velocity measurements are taken from the MVCO meteorological mast shown in Figure 1, while the temperature measurements were deployed beneath a guard buoy located at the proposed ASIT site.

Several of the Flux-Profile PIs also participated in the summer 2002 field program. A bottom lander outfitted with several instruments was deployed by Al Plueddemann near the central ASIMET mooring (site "E") of the Weller-Pritchard moored array (see Upper Ocean Dynamics and Horizontal Variability in Low Winds, Robert Weller, PI for details). A "fanbeam" ADCP with upward-looking beams imaged the near-surface velocity field over a horizontal range of about 100 m with resolution of a few meters. Thirty-eight days of data (28 July - 4 September) were recovered from the fanbeam. The data are being processed to examine horizontal convergences associated with Langmuir circulation. Strong convergences associated with solitons are also expected. A current meter and a conductivity-temperature-pressure (CTP) sensor were mounted on the lander at about 1.5 m off the bottom. The current meter operated for the same interval as the fanbeam, while the CTP sensor operated for the duration of the moored array deployment (20 June - 4 September). The near-bottom data from these sensors will complement the water column observations from the mooring. The fanbeam ADCP and near-bottom current meter sampled at 1.5 min intervals, sufficient to resolve solitons that may have passed through the array. The CTP sensor combined hourly samples of all variables with high-frequency burst samples of pressure that were used to estimate surface wave height for periods of 5 sec and longer as shown in Figure 4.

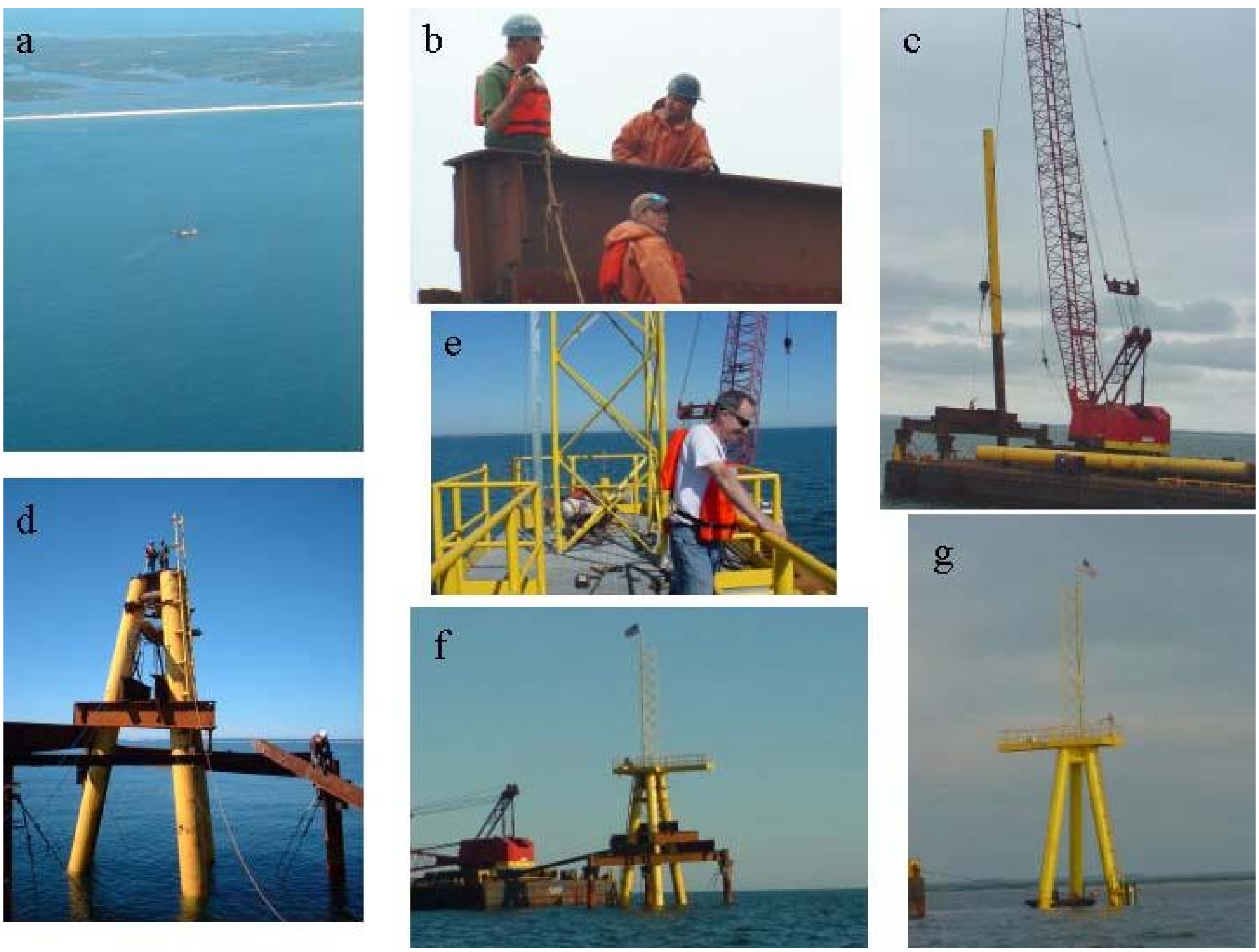

Figure 3a. View of the ASIT/barge from the IR aircraft, b. Sandy Williams helps position the first leg from false work, c. the first leg is driven 50' into the bottom, d. Jim Edson and RDA foreman stand atop welded tripod, e. John Trowbridge inspects ASIT platform and met mast, f. the completed tripod, platform, and met mast, g. the ASIT with falsework removed.

Jim Edson collaborated with Qing Wang of the Naval Postgraduate School to deploy measurements at the Nantucket island field site. Dr. Wang and her colleagues deployed mean and turbulence sensors on a meteorological mast near the shoreline, launched rawinsondes, and operated a SODAR to profile the atmospheric boundary layer. Dr. Edson supported these efforts by providing measurements of solar radiation, infrared radiation, and atmospheric pressure, as well as redundant measurement of temperature, humidity, and wind speed.

RESULTS

Timeseries from Martha's Vineyard Observatory are shown in Figure 2. The timeseries include (a) the wind vector (with oceanographic orientation) from the MVCO meteorological mast and (b) water temperature at depths between 3 and 19-m, which spans the water column at the CBLAST ASIT site. Figure 1a shows that the wind events have timescales of days and typically vary between 1 and 8 m/s. As expected, the predominant wind direction is from the southwest. Stratification in the water column, based on top-to-bottom temperature difference, varies over a wide range. For example, calculations of N^2 vary between 1e-06 s^{-2} and 5e-04 s^{-2}. Our preliminary analyses of the current velocities above the MVCO node at the 12-m isobath indicate that the currents are polarized in the alongshore direction and are dominated by semidiurnal tides. Periods of strong and weak stratification correspond to temperature records in panel (b) that are widely and closely spaced in the vertical, respectively. Our analysis will investigate the relative importance of diurnal heating versus tidal advection in describing the variability of the temperature record. A qualitative examination of these time series also suggests that weak stratification occurs as a result of warming of the bottom water that coincides with downwelling-favorable alongshore winds and fetch-limited conditions (associated with the northeasterly winds shown in panel a), near days 201, 208, and 212. Strong stratification is observed during the extended periods of southwesterly winds from the open ocean. Observations of the subtidal alongshore currents have the same sign and phase as alongshore winds, indicating that nontidal oceanic flows are driven by local winds.

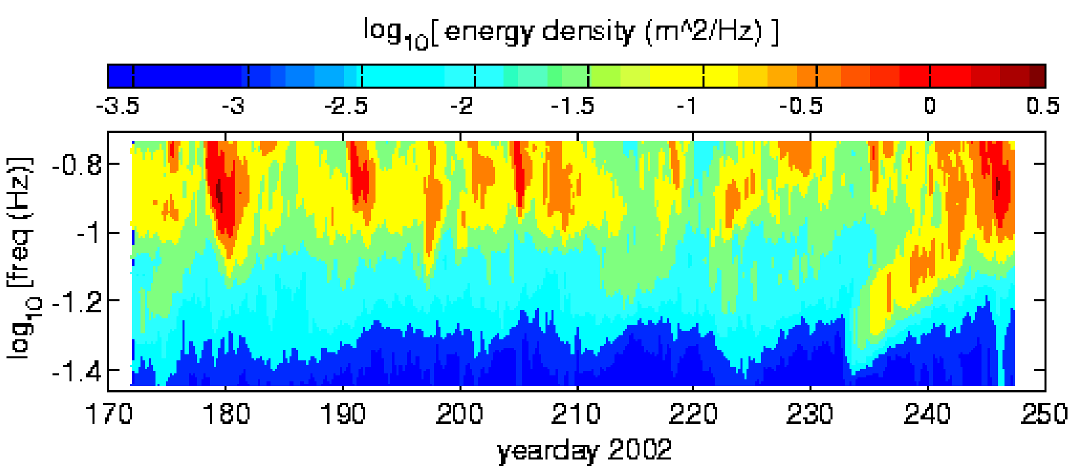

Figure 4. Surface wave height spectra determined from the pressure sensor on a bottom lander at 39 m depth near site E of the Weller-Pritchard moored array. The high-frequency cutoff at about 5 sec period is due to attenuation of the pressure signal at the instrument depth.

The combination of the Nantucket field site, the MVCO, and the 6 moorings deployed by Drs. Weller and Pritchard has provided the CBLAST PIs with 8 spatially separated locations with meteorological data and 7 locations with oceanographic data. Analysis of this data has begun, as has interaction with the CBLAST-LOW oceanic and atmospheric modelers about their ability to replicate the observations.

IMPACT/APPLICATIONS

The data collected during the pilot experiment have been combined with the mooring data to characterize the CBLAST-LOW region. The ASIT and horizontal moorings and array deployed around MVCO as part of CBLAST-LOW will provide a unique observing system for studying coupled boundary layers.

TRANSITIONS

The data will be used in the modeling and simulation studies to begin to evaluate and improve their forecast and help in our preparations for the main experiment.

RELATED PROJECTS

This research is closely tied to the development of the MVCO supported by the NSF (http://www.whoi.edu/science/AOPE/airsea/observatory.htm). The MVCO provides infrastructure and long-term observations of relevant parameters. CBLAST is also expected to benefit from ongoing analyses investigating flux-profile relationships as part of the ONR sponsored FAIRS program and the NSF/NOAA sponsored GASEX 01 campaign (http://www.pmel.noaa.gov/co2/gasex2/).

REFERENCES

PUBLICATIONS

Edson, J. B., 2001. The coupled boundary layers and air-sea transfer (CBLAST) experiments at the Martha's Vineyard coastal observatory, AGU 2001 Fall Mtg., San Francisco, CA, OS32B-0482.

PATENTS