# Analysis of Near-Surface Oceanic Measurements Obtained During CBLAST-Low

John H. Trowbridge
Woods Hole Oceanographic Institution, MS#12, Woods Hole, MA 02543
phone: (508) 289-2296 fax: (508) 457-2194 email: jtrowbridge@whoi.edu

Albert J. Plueddemann
Woods Hole Oceanographic Institution, MS#29, Woods Hole, MA 02543
phone: (508) 289-2789 fax: (508) 457-2163 email: aplueddemann@whoi.edu

Award Number: N00014-03-1-0681
Award Number: N00014-06-1-0178

## LONG-TERM GOALS

- To quantify and understand the processes that control the vertical transport of momentum and heat beneath the ocean surface.

- To evaluate and improve subgridscale parameterizations of vertical transport processes.

- To incorporate the improved parameterizations into routinely-applied numerical simulations of oceanographic processes.

## OBJECTIVES

- To close momentum and heat budgets spanning the air-sea interface using direct-covariance measurements of the turbulent fluxes on both sides of the interface.

- To quantify the characteristics of Langmuir circulations and understand their relationship to wind and wave forcing.

- To quantify and understand the relative importance of shear-generated turbulence, buoyancy, Langmuir circulations, and wave breaking in accomplishing vertical transport of momentum and heat beneath the air-sea interface.

- To quantify the dominant balances in the turbulent kinetic energy and temperature variance equations.

- To evaluate the Mellor-Yamada, k-ε, KPP, and k-ω turbulence closure models.

## APPROACH

Atmospheric and oceanic measurements obtained during the low-wind component of the Coupled Boundary Layers and Air-Sea Transfer program (CBLAST-Low) are being used to address the Objectives. Trowbridge and Plueddemann are focusing on turbulence statistics and Langmuir

# Report Documentation Page

*Form Approved*
*OMB No. 0704-0188*



| 1. REPORT DATE | 2. REPORT TYPE | 3. DATES COVERED |
|---|---|---|
| **30 SEP 2007** | **Annual** | **00-00-2007 to 00-00-2007** |

| 4. TITLE AND SUBTITLE | |
|---|---|
| **Analysis Of Near-Surface Oceanic Measurements Obtained During CBLAST-Low** | 5a. CONTRACT NUMBER |
| | 5b. GRANT NUMBER |
| | 5c. PROGRAM ELEMENT NUMBER |
| 6. AUTHOR(S) | 5d. PROJECT NUMBER |
| | 5e. TASK NUMBER |
| | 5f. WORK UNIT NUMBER |
| 7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Woods Hole Oceanographic Institution, MS#12,Woods Hole,MA,02543** | 8. PERFORMING ORGANIZATION REPORT NUMBER |
| 9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) | 10. SPONSOR/MONITOR’S ACRONYM(S) |
| | 11. SPONSOR/MONITOR’S REPORT NUMBER(S) |

12. DISTRIBUTION/AVAILABILITY STATEMENT
**Approved for public release; distribution unlimited**

13. SUPPLEMENTARY NOTES
**code 1 only**

14. ABSTRACT
**Atmospheric and oceanic measurements obtained during the low-wind component of the Coupled Boundary Layers and Air-Sea Transfer program (CBLAST-Low) are being used to address the Objectives. Trowbridge and Plueddemann are focusing on turbulence statistics and Langmuir 1 circulations, respectively.**

15. SUBJECT TERMS

| 16. SECURITY CLASSIFICATION OF: | | | 17. LIMITATION OF ABSTRACT | 18. NUMBER OF PAGES | 19a. NAME OF RESPONSIBLE PERSON |
|---|---|---|---|---|---|
| a. REPORT | b. ABSTRACT | c. THIS PAGE | | | |
| **unclassified** | **unclassified** | **unclassified** | **Same as Report (SAR)** | **6** | |

**Standard Form 298 (Rev. 8-98)**
Prescribed by ANSI Std Z39-18

circulations, respectively. Greg Gerbi, a doctoral student in physical oceanography in the educational program offered by the Massachusetts Institute of Technology (MIT) and the Woods Hole Oceanographic Institution (WHOI), who is funded by this project and is working under the supervision of Trowbridge. Tobias Kukulka, a WHOI Postdoctoral Scholar appointed in the fall of 2007, is working on CBLAST-Low under the supervision of Plueddemann. Collaboration is ongoing with Jim Edson (University of Connecticut), who is focusing on the analysis of atmospheric turbulence measurements. Collaboration is anticipated with Ming Li (University of Maryland), who is carrying out large-eddy simulations.

## WORK COMPLETED

The CBLAST-low measurement program was conducted at the Martha's Vineyard Coastal Observatory (MVCO), a site exposed to forcing from the open ocean and located off the southern coast of the island of Martha's Vineyard, in Massachusetts. The MVCO consists of a shore laboratory, a meteorological mast located on the beach, a bottom-mounted "seanode" at a water depth of 12 m, and the Air-Sea Interaction Tower (ASIT; Fig. 1), at a water depth of 15 m, which was constructed with CBLAST-low funding during 2002. The intensive observational period for the CBLAST-low program occurred during summer and fall of 2003.

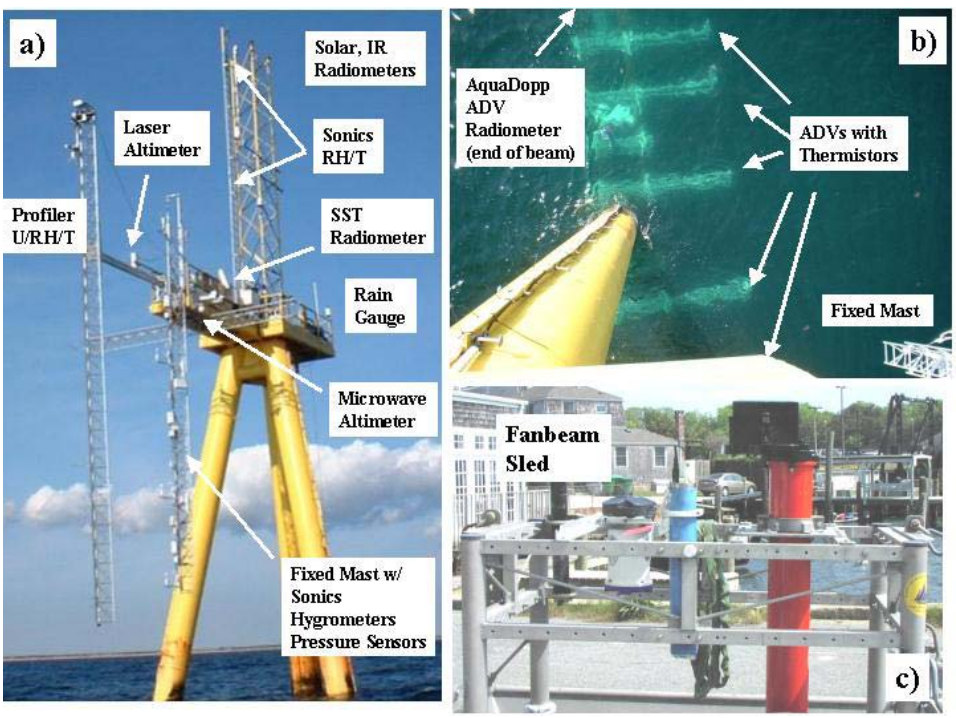


***Figure 1. Experiment setup at the ASIT during CBLAST. ( a) The air-side instrumentation deployed on the meteorological tower, fixed array, and profiling mast. b) The ocean-side instrumentation deployed on a horizontal beam 4 m below the water surface. The acoustic Doppler velocimeters (ADVs) were 2 to 4 m below the ocean surface, depending on the tide. c) The Fanbeam sled that was deployed at 15 m depth on a bottom frame just south of the ASIT.***

Atmospheric measurements from the ASIT during CBLAST-Low were obtained from a vertical array of sensors that provided vertical profiles of momentum flux, sensible and latent heat flux, kinetic energy, pressure and scalar variance, as well as dissipation rates for turbulent kinetic energy, temperature variance, and humidity variance (Fig. 1a). Mean profiles of temperature, humidity and velocity were obtained from a profiling package and additional fixed sensors. The downwelling radiative heat fluxes were measured by solar and infrared radiometers. The heat fluxes were combined to compute the net heat flux into or out of the ocean.

Oceanic measurements during CBLAST-low were obtained from instruments mounted on and near the ASIT, and from sensors routinely maintained as part of the MVCO. Estimates of dissipation rates for turbulent kinetic energy and temperature variance, as well as direct covariance estimates of turbulent momentum and heat fluxes were obtained from near-surface and near-bottom horizontal arrays of co-located coherently sampled acoustic Doppler velocimeters (ADVs) and thermistors (Fig. 1b). Estimates of Langmuir circulation intensity and cross-wind spatial scale were obtained with a "fanbeam" acoustic Doppler current profiler (ADCP, Fig. 1c). Vertical profiles of horizontal velocity were obtained from ADCPs on and near the ASIT, and at the nearby MVCO seanode. Stratification was determined from conductivity-temperature-depth (CTD) sensors at the ASIT.

Directional wave spectra were estimated from the ADCP measurements at the seanode. These spectra were partitioned into dominant swell and locally generated wind-wave components following the method of Hanson and Phillips (2001). As part of this approach, the validity of the ADCP-derived spectra was assessed by comparing them with one-dimensional spectra derived from laser altimeter measurements. This comparison identified a high-frequency cutoff beyond which the ADCP-derived wave field is suspect. The directional wave data are described in Churchill et al. (2006) and available from the MVCO website (http://www.whoi.edu/mvco/data/user_data.html ).

## RESULTS

The first objective has been met by producing the first (to our knowledge) successful closure of a turbulent momentum budget spanning the air-sea interface (Fig. 2; Gerbi et al., accepted), improving on the closure of the heat budget by D'Asaro (2004). This is an important observational milestone because it means that we can begin to characterize and quantify the flux-carrying processes on the water side of the air-sea interface. Several steps towards other project objectives have been made by Gerbi et al. (accepted). They show that the shapes of cospectra characterizing subsurface turbulent transport of momentum and heat are represented accurately by means of a simple model developed for the bottom boundary layer of the atmosphere, in which the controlling parameters are the relevant flux and a scale representing the characteristic size of the flux-carrying eddies. This suggests similar spectral shapes for atmospheric boundary layer and ocean surface boundary layer turbulence. In contrast to atmospheric observations, the length scale of heat and momentum carrying eddies in the ocean was the same, suggesting that both properties may be transported by the same set of turbulent eddies. Observed temperature gradients were significantly smaller than those predicted by Monin-Obukhov theory (Fig. 3), suggesting that turbulence in the ocean surface boundary layer is generated by mechanisms in addition to those found in the bottom boundary layer of the atmosphere. Likely candidates for these additional mechanisms are Langmuir circulation and wave breaking.

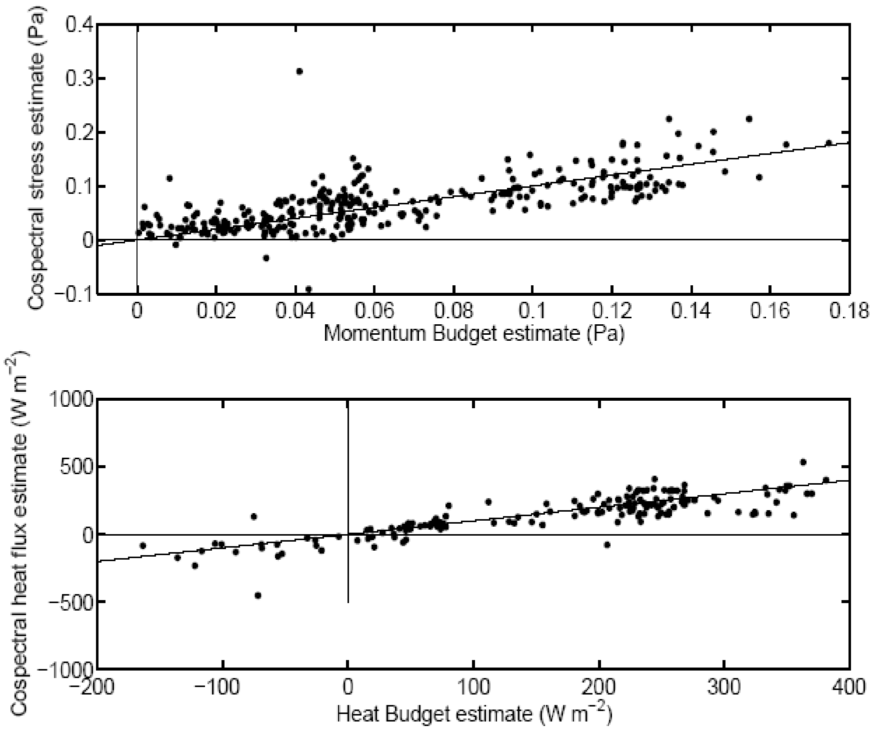


***Figure 2. Comparison of atmospheric and oceanic observations showing successful closure of momentum and heat budgets spanning the air-sea interface. The y axes are the fluxes measured by water-side turbulence sensors, and the x axes are the fluxes measured by atmospheric sensors.***

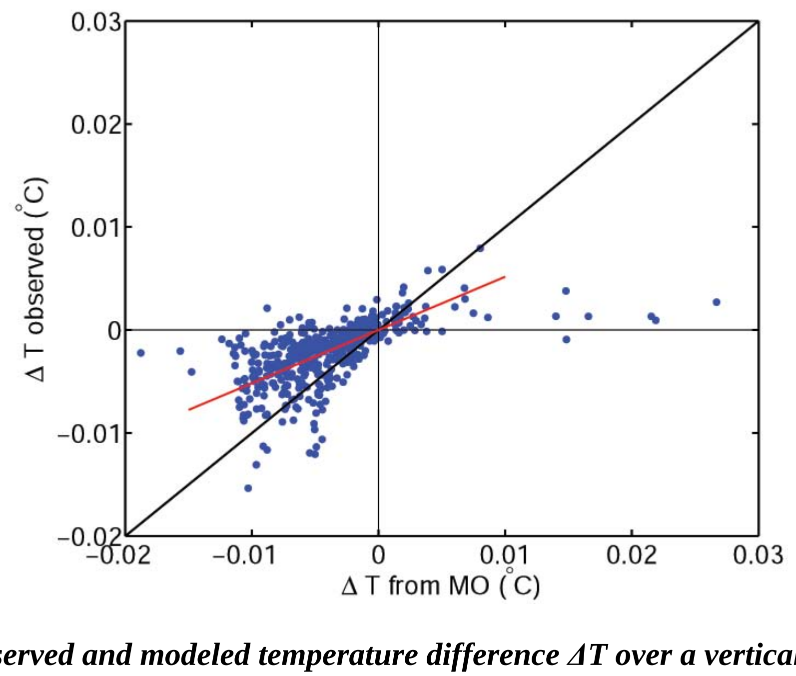


***Figure 3. Observed and modeled temperature difference $\Delta T$ over a vertical separation of approximately 2 m. The model includes shear and buoyancy generation of turbulence. Observed $\Delta T$ is smaller than predicted by approximately a factor of two under unstable conditions (negative $\Delta T$) and a factor of six under stable conditions (positive $\Delta T$) indicating an important role of processes not included in the model, possibly including wave breaking and Langmuir circulation.***

The third and fourth objectives are being addressed together, using the turbulent kinetic energy (TKE) equation to evaluate the relative importance of the different turbulence generation mechanisms (shear, buoyancy, Langmuir, and wave breaking). Estimates of the dissipation rate of TKE are in agreement with previous observations and show enhancement over those expected near a rigid wall (such as in the bottom boundary layer of the atmosphere). In addition to dissipation, estimates have been made of other terms in the TKE balance (Fig. 4). In the absence of Langmuir circulation and wave breaking, previous work has shown that local shear and buoyancy production approximately balance dissipation. In contrast, our estimates suggest that a balance between dissipation and local production does not exist, even when the local production of turbulence through Langmuir instabilities is included (in this context, “local” refers to the measurement depth of approximately 2 m). The excess dissipation at 2 m depth suggests that TKE is generated elsewhere, likely by wave breaking or Langmuir instabilities near the surface, and is transported to the measurement depth by turbulence and/or pressure work. Efforts are ongoing to develop a more complete understanding of the effects of wave breaking and Langmuir circulation on the TKE balance.

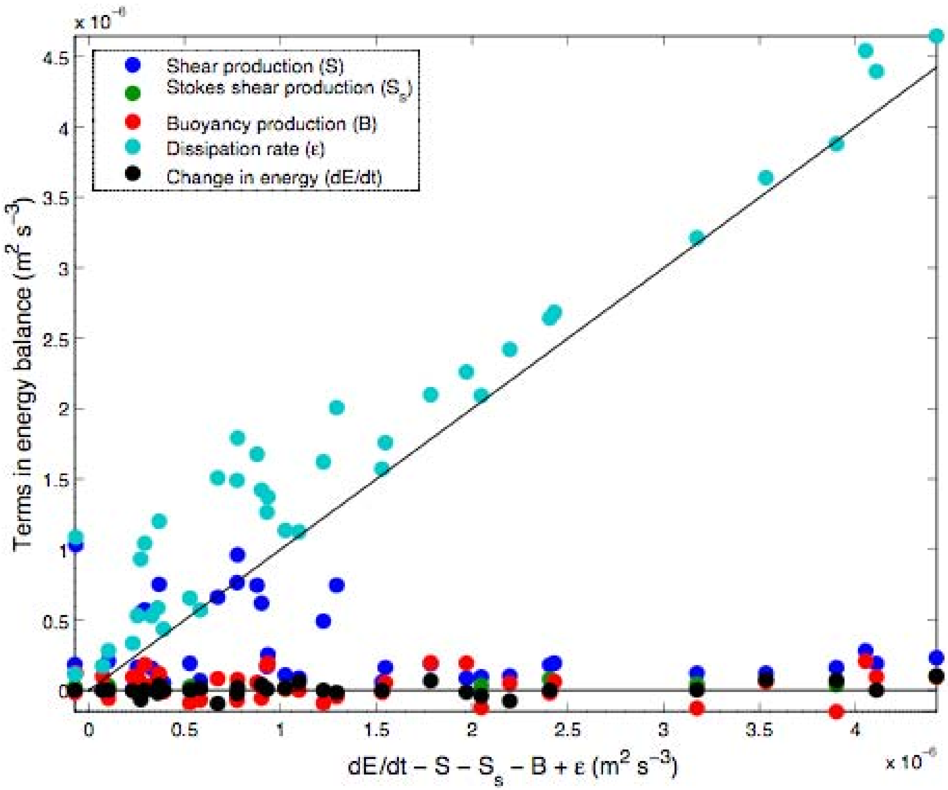


***Figure 4. Comparison of terms in the turbulent kinetic energy balance. Symbols indicate production by shear instabilities (S, blue), production by Langmuir (Stokes drift) instabilities ($S_s$ , green), production by buoyancy instabilities (B, red), dissipation ($\varepsilon$, light blue), and rate of change of TKE (dE/dt, black). The comparison shows that more TKE is dissipated than can be explained by local production and the rate of change of TKE. Terms that quantify the transport of TKE were not measured, and are assumed to balance the dissipation.***

## REFERENCES

D’Asaro, E. A., 2004. Air-sea heat flux measurements from nearly neutrally buoyant floats, J. Phys. Oceanogr., 21, 1086-1094.

Hanson, J.L. and O.M. Phillips (2001) Automated analysis of ocean surface directional wave spectra. J. Atm. Oceanic Technol., 18, 277-293.

## PUBLICATIONS

Churchill, J. H., A. J. Plueddemann and S. M. Faluotico, 2006. Extracting wind sea and swell from directional wave spectra derived from a bottom-mounted ADCP, Woods Hole Oceanographic Institution Technical Report WHOI-2006-13, 34 pp. [published]

Edson, J. B. et al., 2007. The Coupled Boundary Layers and Air-Sea Transfer Experiment in low winds (CBLAST-Low), Bull. Am. Met. Soc., 88(3), March 2007, 341-356. [published]

Gerbi, G.P., J.H. Trowbridge, J.B. Edson, A.J. Plueddemann, E.A. Terray and J.J. Fredericks, Measurements of momentum and heat transfer across the air-sea interface, J. Phys. Oceanogr. [in press, refereed]