

# **Extended Analysis of Near-bottom Turbulence Measurements Obtained During the Coastal Mixing and Optics Experiment**

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## **LONG-TERM GOALS**

The long-term goals associated with this project are to quantify turbulence and to understand the mechanisms and implications of turbulent mixing in the bottom boundary layer of the coastal ocean.

## **OBJECTIVES**

The specific objectives of this project are to test, in the continental shelf bottom boundary layer, (1) simplified budgets for turbulent kinetic energy and scalar variance, (2) flux-profile relationships for momentum and scalars, and (3) vertically integrated momentum and heat balances.

## **APPROACH**

The approach is analysis of a year-long set of near-bottom, time-series measurements of velocity, sound speed, temperature and conductivity, which were obtained between August 1996 and August 1997 as part of ONR's Coastal Mixing and Optics (CMO) program.

## **WORK COMPLETED**

A. J. Williams, a principal investigator on this project during the last funding period, had overall responsibility for obtaining the measurements. He supervised construction of the "SuperBASS" tripod, which supported a vertical array of seven BASS acoustic travel-time velocity sensors (Williams et al., 1987), a pressure sensor, a vertical array of thermistors, a horizontal array of three of Sontek's acoustic Doppler velocimeters (ADV), and two temperature-conductivity sensors. The bottom-most and top-most sensors were approximately 0.3 and 7.0 m above bottom, respectively. The BASS sensors were modified to measure absolute as well as differential acoustic travel time, so that they determined sound speed (a surrogate for temperature) and velocity in a single sample volume. The ADVs were all at the same height (approximately 0.3 m above bottom), and they were separated horizontally to permit a technique for removing contamination by surface waves from estimates of turbulent Reynolds stress by differencing measurements from

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spatially separated sensors (Trowbridge, 1998). The sensors were sampled rapidly (25 Hz for the ADVs and approximately 2 Hz for the other sensors) and the measurements were recorded by synchronized in-situ loggers. G. Voulgaris, a post-doctoral investigator, assisted with preparing the ADVs, and W. J. Shaw, a graduate research assistant, assisted with reducing the noise floor in the BASS measurements of sound speed to an acceptable level. Williams deployed the tripod at the central CMO site on the New England shelf, at a water depth of approximately 70 m, in August 1996. He recovered and redeployed the tripod, for the purpose of offloading data and changing batteries, in October 1996, January 1997, April 1997, and June 1997. The final recovery was in August 1997. Manuscripts describing the measurement program, the modification of the BASS sensors to produce low-noise measurements of sound speed, and preliminary analysis of the data were published in conference proceedings by Shaw et al. (1996), Trowbridge et al. (1996) and Voulgaris et al. (1997).

Analysis to date has focused on (1) obtaining direct covariance estimates of turbulent momentum and heat fluxes and indirect inertial-range estimates of turbulence dissipation rate for turbulent kinetic energy and scalar variance from ADV and BASS measurements; (2) using the estimates of fluxes and dissipation rates to test simplified budgets for turbulent kinetic energy and scalar variance; and (3) using the flux estimates and Reynolds averaged velocity and sound speed measurements to test flux-profile relationships (i.e., turbulence closure models) which have been developed in the atmospheric literature. This work appears in W. J. Shaw's PhD thesis and in Shaw and Trowbridge (submitted), Shaw, Trowbridge and Williams (submitted), and Shaw and Trowbridge (in preparation).

## RESULTS

The "SuperBASS" measurements obtained during CMO resolve the structure of Reynolds-averaged velocity, temperature and density between 0.3 and 7.0 m above bottom, in addition to providing high-frequency velocity and temperature measurements sufficient to estimate turbulent fluxes and dissipation rates. Examples of results are time series of estimates of (1) Reynolds stress (Figure 1a), (2) turbulent heat flux (Figure 1b), (3) the dominant terms in the turbulent kinetic energy balance (production, dissipation and buoyancy) (Figure 2a), and (4) the dominant terms in the budget for scalar (sound speed) variance (production and dissipation) (Figure 2b).

Important results to date include (1) demonstration that the simplest turbulent kinetic energy balance (production equals dissipation) holds throughout the bottom boundary layer; (2) demonstration that the flux Richardson number maintains a value of approximately 0.2 in the outer part of the boundary layer but maintains much smaller values nearer the bottom; (3) demonstration that the balance for sound speed variance is crudely a balance between production and dissipation, although departures from this balance occur with a systematic vertical structure likely produced by the divergence of the vertical flux of sound speed variance; and (4) demonstration that at small heights above bottom, relative to the boundary layer thickness, the relationships between turbulent heat and momentum fluxes and profiles of velocity and temperature are quantitatively consistent with the classical Monin-Obukhov scaling obtained in the atmospheric boundary layer; and (5) demonstration that at greater heights above bottom systematic departures from the Monin-Obukhov scalings occur.

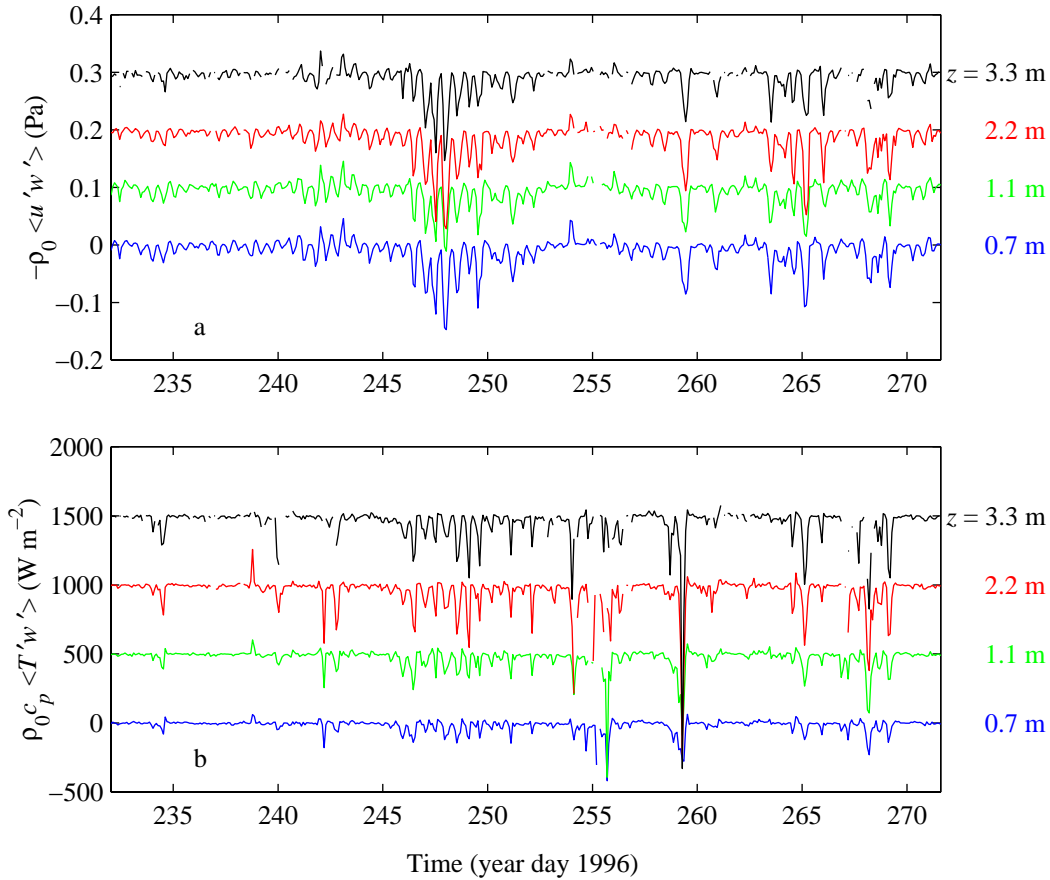


Figure 1: Time series of (a) the eastward component of Reynolds stress and (b) turbulent heat flux at heights of 0.7, 1.1, 2.2, and 3.3 m above the bottom (records from different heights are offset vertically by equal amounts).

## IMPACT/APPLICATIONS

This study has demonstrated successful measurement of turbulent fluxes and dissipation rates and their interpretation in the continental shelf bottom boundary layer. This work will lead ultimately to critical tests and improvements of turbulence closure models (such as the widely used Mellor-Yamada model).

## TRANSITIONS

The estimates of turbulence statistics obtained during this study are being used in companion studies of sediment transport and particle dynamics by P. S. Hill (of Dalhousie University), Y. C. Agrawal (Sequoia Scientific, Inc.), and P. Traykovski (Woods Hole Oceanographic Institution) (Hill et al., submitted, Traykovski and Agrawal, submitted).

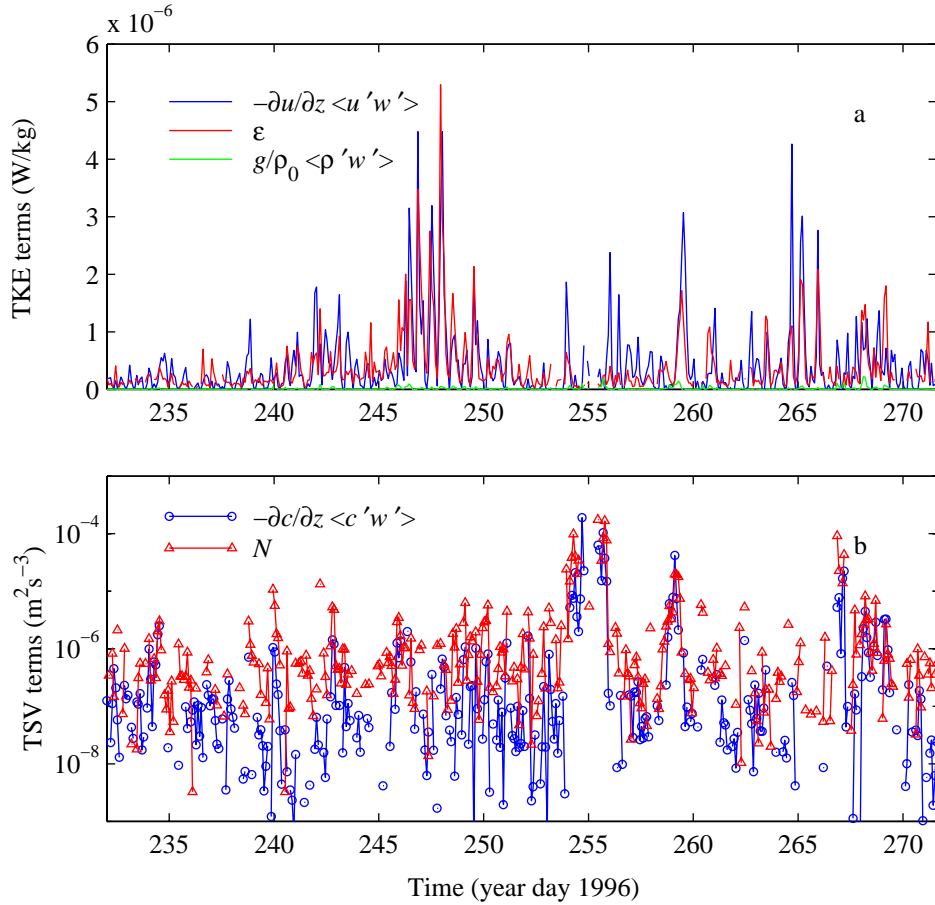


Figure 2: Time series of (a) production, dissipation and buoyancy flux terms in the turbulent kinetic energy budget and (b) production and dissipation terms in the turbulent scalar variance budget estimated at a height of 0.9 m above the bed.

## RELATED PROJECTS

Trowbridge's and Y. C. Agrawal's participation in the ONR program HYCODE will capitalize on the techniques for turbulence measurement and analysis that have been developed during this study.

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