Turbulence Measurement Surveys in the Convectively Driven Upper Mixed Layer and Close-Bottom Boundary Layer Over a Continental Shelf During a Storm Front

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LONG-TERM GOALS

The principal objective of this work is to contribute to the development of effective remote autonomous mine countermeasure operations by providing pertinent flow, heat flux and sediment transport characteristics in the benthic boundary layer to missions engaged in sea mine reconnaissance and hunting. These environmental characteristics govern acoustic and light propagation, chemical and biogenic activity in the bottom boundary layer, distribution of sediment over a buried mine and other physical processes, knowledge of which is critical to the effective performance of acoustical, chemical or other sensory-based methods for mine detection and MCM operations. To address these issues, comprehensive numerical models of the flow in a shallow water column are required. The aim is collect significant data to help parameterize sub-grid processes in such a numerical model and develop an associated accurate sub-grid scale model.

OBJECTIVES

The specific objectives of the proposed project are (a) To develop an internet accessible data bank of four dimensional measurement of turbulence in the shallow water column during the passage of a cold front, together with measurement of bubble distribution in the upper mixed layer and sediment distribution in the close-bottom boundary layer, for validating and formulating models of the dynamics of the water column during such a storm, (b) to examine the interrelationship between *in-situ* turbulence levels associated with breaking waves in the upper mixed layer and acoustic noise, sonar reverberations and acoustic propagation in a water column atmospherically forced by a cold front.

APPROACH

A program for making turbulence measurements in the benthic boundary layer, using the AUV-deployable turbulence platform developed at Florida Atlantic University, under different, simultaneously measured sea states, is proposed. The measurements will be supported by laboratory experiments to determine very near bed effects and numerical modeling to examine the coherence between the measured total velocity in the bottom boundary layer and the independent, simultaneous wave measurement.

<u>Task 1</u> <u>Planning the storm-front oceanographic experiment</u>, data collection and data analysis, and testing and development of dynamic models for convectively driven shallow water column.
It is proposed to use the OEX to carry out a turbulence survey of the upper mixed layer, measuring the three components of fluctuating velocity and microstructure temperature before, during and following a cold-air outbreak over the shallow water continental shelf off the coast of Florida. Further, a smaller AUV, currently being developed, will be used to perform simultaneous close-bottom surveys, to within 0.2m, of the benthic boundary layer in order to determine the relationship between episodic

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metrological forcing and sediment transport. Leading up to the proposed storm-front experiment, several missions (see Task 2) will be carried out in calmer conditions where the mixing layer is primarily driven by convection associated with drop in air temperature.

Meteorological forcing. Available weather data will be obtained from south Florida synoptic observation network as part of the coordinated experiment in order to determine a map of the metrological forcing field. However, since the network buoys are somewhat spread apart, we believe that it is also important to make local measurements of atmospheric conditions, both as a check on the interpolated data from the synoptic network and as a way of accounting for any localized variations, such as in precipitation and cloud cover, which are quiet common in south Florida. We therefore propose to The wind speed and direction, air temperature, relative humidity, short-wave (solar) radiation and long-wave (IR) radiation will be measured at the experimental site, so that the total heat and buoyancy flux into the ocean can be determined and the surface stress can be estimated from bulk formulae. This will be accomplished using a Met Station.

Bottom mounted instruments. An upward looking ADCP will be borrowed from Dr S Monismith of Stanford University and mounted rigidly to the bottom. This unit can unambiguously determine the vertical velocity and will provide profiles of the beam velocity variance. Thus the ADCP will provide estimates of TKE, its individual components and Reynolds stress, giving corroborative evidence of any turbulent flow features which may be apparent in the *in-situ* measurements.

AUV-based measurements. The AUVs will carry shear probes and a dynamic pressure probe for measuring all three components of fluctuating velocity as well as a thermistor for making microstructure temperature measurement. Continuous CTD profiles will be taken during the experiment to assess the changes in stratification and to detect horizontal intrusions. A box survey would be taken around the experimental site to assess the horizontal homogeneity. The OEX will be programmed to repeatedly follow a boxed pattern around the ADCP site while being in the upper mixed layer, as close to the surface as possible, measuring turbulence as well as detecting wave-breaking events ahead of the vehicle using the miniature scanning unit from Imagenex. The smaller AUV would perform a similar motion in the close-bottom region (see Task 5) at altitude ranging from a minimum of 0.2m to 1.5m and measuring turbulence and suspended sediment. This will allow determination of the variation of dissipation rate and Reynolds stress with altitude and allow an opportunity to test the validity of the classical "law of the wall".

The feasibility of the two AUVs operating simultaneously will be considered. This will allow measurement in the upper mixed layer and the bottom boundary to be taken simultaneously so that assumptions of stationarity are not required.

<u>Task 2</u>. <u>Test missions</u>.

Test missions, leading up to the coordinated storm-front experiment, will be carried out off the coast of Florida. These will be in the form of short missions primarily aimed at ensuring that the developed turbulence packages are operational and identifying the relevant parameters necessary in planning the storm-front experiment. The information gained from these missions will be immensely valuable. During each mission, turbulence data, in conjunction with the background information, will be collected. Measurements will be made during cold but calm metrological conditions in the shallow-water column. The tests will be planned to examine the influence of various physical factors, expected to arise during the final experiment. The data recorded during these test missions will be of immense scientific interest in their own right. They would be made readily available on the internet, for the researchers to test and develop relevant models for the physical processes. Twelve test missions are planned. These will include joint missions with USF in spring 1998 on the west coast of Florida.

Actual cost per mission will therefore vary. However, an average cost of $1600 per mission will be incurred.

Task 3. Self noise reduction and isolation measures on the OEX.
The following modifications will be made to a particular tail section which will have very low self noise characteristics and will be dedicated for turbulence measurements: (1) The tail section will have no gears and few moving parts, (2) the parts that move will have low inertia, (3) high quality bearings and shafts will be used, using as few bearings as possible (4) the shaft lengths will be made short, (5) a reduction in rpm will be achieved so that the noise due to any imbalance is reduced, and (6) tuned electronics will be used to minimize pole cogging with a modified driver wave form. It should be noted that rather than conflict with other design considerations, these suggestions enhance propeller efficiency, system efficiency, maintainability and simplicity.

Task 4. Further development of the dynamic pressure probe.
Work accomplished to date on the dynamic pressure probe development has established the frequency response of the probe as well as its accuracy through comparison of measurements in a jet ensuing into a tank with corresponding measurements obtained using shear probes(figure 5). Ocean tests using the pressure probe, however, have been setback by a problem with contamination by electrical oscillations when in the salt water. The internal arrangement needs modification to eliminate this problem and further tests need to be carried out. The required changes in the internal arrangement include shielding of the signal conductors, reevaluation of the preamplifier circuit and lowering the gain on the preamplifier. These issues will be resolved and subsequent testing will include wind tunnel comparisons with hot wire probes, turbulent jet tests with hot wire and shear probes, and finally utilizing it in *in-situ* tests at various depths. When ready, the probe will measure the mean and fluctuating streamwise component of the velocity. Together with the shear probe data, all three components of *in-situ* velocity will be provided.

Task 5. Development of close-bottom turbulence surveyor package.
The most interesting part of a bottom boundary layer is very near the bottom. This region can be well within a meter of the bottom and will place difficult performance requirements on the AUV. Bottom following within 0.2m of the bottom requires the use of a smaller vehicle and very accurate altimeter information and obstacle avoidance capability. The controller software for the mission will require tuning to allow a decent to near the bottom without the possibility of going aground. Two 12v altimeters from Tritech, with 0.1m minimum range and 6^0 beam($2,250/unit), will be used to achieve close-bottom following and forward-look capability. The turbulence package will consists of (i) y and z shear probes (see Lueck [13], for example) to measure cross-stream components of fluctuating velocity, (ii) the dynamic Pitot tube measurement system, mounted on the nose of the pressure case, allowing measurement of the axial component of mean and fluctuating velocity, (iii) a micro-structure temperature probe utilizing a FP-07 thermistor from Seabird electronics; (v) ICS model 3140 x, y and z accelerometers from IC Sensors. The turbulence package will utilize an on-board CTD package to obtain estimates of local salinity, temperature and depth. In close-bottom following, the ground speed can be determined from an ADCP which requires being at least 0.5m above the bottom. However, the vehicle rpm can be used to estimate the ground speed to within 2-3% error. The electronics conditioning for the shear probes is based on the design by Lueck[13] and consists of a two-channel high-impedance charge to voltage converter, an analog differentiator and a 6 pole Butterworth low-pass filter for anti-aliasing. The electronics and the computer will be housed in a pressure vessel located in the body of the vehicle. The pressure vessel will also contain a battery power supply for the computer.

WORK COMPLETED

The necessary work in readiness for the Fall experiment is going according to plan. The experiment is scheduled for December 14 - 23, 1998 (see http://www.oe.fau.edu/~manhar/awe for details). The necessary hardware has been purchased / ordered and the required shear and thermitor probes have been made. As described below, significant progress has been made in tasks 4 and 5; the pressure probe now has a more robust design while the bottom surveyor has been tested in the ocean and is being tuned at present. A significant measurement mission was carried out in Sargossa Sea, off Bermuda, with the turbulence package mounted on the nose of the Autosub, Southampton Oceanographic Center's AUV (see below). A good data set was obtained. Other missions are being carried out in Florida waters in preparation for the December experiment. Significant portion of the data analysis on the Gulf stream mission of 7/16/97 has been carried out and a journal paper for submission to JGR is in advanced stage of preparation. Analysis has also been carried out on ADCP and CTD data collected in Florida waters during December 1997; the data was collected during a cold front of the type expected in the December 98 experiment. A paper was submitted to UUVS '98 and a journal paper will be submitted to JOAT shortly.

RESULTS

<u>A. Miniaturization</u>: The size of the turbulence package has been reduce to less than 1/8 its original volume by using a PC104 data acquisition system. The system has an eight channel 16 bit differential A/D board, a power supply board, a CPU board and a 100 Mbyte solid state hard drive. This system lowers the power consumption to about 1.5 Watts which further reduces the system and battery size requirements. It can be powered from the host platform or from an inexpensive internal alkaline battery package which will last for up to 4 hours. The whole turbulence package is contained in a 14 inch long by 4.5 inch diameter piece of common aluminum pipe. It fits inside a universal isolation mount which eliminates nearly all the vibrations from the host platform. The isolation mount has been optimized to eliminate vibrations from the AUV. The system has been mounted to the Ocean Explorer AUV, the MADDOG AUV and the AUTOSUB AUV. Sample results using this package are given in section E below.

<u>B. Pressure probe</u>: A new approach using an air compensated pressure balance chamber on the negative port of the differential pressure transducer has been adopted. This design eliminates the contact with saltwater without the use of static pressure holes. The latter induce spatial correlation problems in which the separation distance between the static holes and the front pressure port on the Pitot tube amplifies turbulence scales at these wavelengths and their harmonics but attenuates at all other wavelengths. The new air compensated system uses a second Pitot tube for the cancellation of the hydrostatic and time averaged hydrodynamic pressures. The time averaging is accomplished within the tube connecting the compensation Pitot tube to the negative side of the differential pressure transducer. The tube is restricted at the ends by hypodermic needle tube and the volume of air in the bladder contained in the compensation Pitot tube. This assembly may be modeled as a resistor/inductor and may then be tuned to give the desired response. Measurements have been made in the laboratory which look very promising. The resulting system does have some degree of drift with depth due to the elasticity of the bladder but this does not introduce any error to the measurement of the time varying forward velocity component used for the calculation of the in-situ dissipation rate. Ocean tests are to begin in November, 98 and the instrument is to be used in the December 98 Adverse Weather Experiment.

<u>C. Signal conditioning board</u>: An analog signal conditioning board has been designed, built and tested for the turbulence package. By functionally replacing 3 separate circuit boards and their interconnects,

electrical noise is greatly reduced. It has a PC104 form factor and implements 3 accelerometer, 2 shear, 1 pressure, 1 pressure derivative and 1 fast response thermister channels. Each channel has the appropriate preamplifier followed by an 8 pole Butterworth low pass filter for anti-alliasing and a final amplifier stage. The board also contains its own power conditioning circuitry to suppress related electrical noise. The design is a multi-layer surface mount PCB which also reduces EMI. Results from tests in the Florida coastal waters has yielded dissipation measurements as low as 10-13. The resulting board was used with excellent results in the Bermuda experiments discussed in section E.

D. Close-bottom Surveyor, MADDOG (Task 5): A small AUV (Figure 1) has been built and tested specifically for turbulence measurements. The body is a long (~2 m) slender (~0.1 m diameter) piece of aluminum pipe. This shape was chosen to lower the frequency and amplitude of the rigid body motions. It uses a direct drive flooded motor with integral isolation mounts. The fin actuators are also direct drive with open loop stepper motors, resulting in a simple robust control system. Over 40 ocean missions have been accomplished with only one hardware failure in which the vehicle completed the mission, and no software crashes have occurred to date. The operations are simple and inexpensive requiring only a small support vessel and a single operator. The instrument package is designed to enable close bottom following for benthic boundary layer measurements.

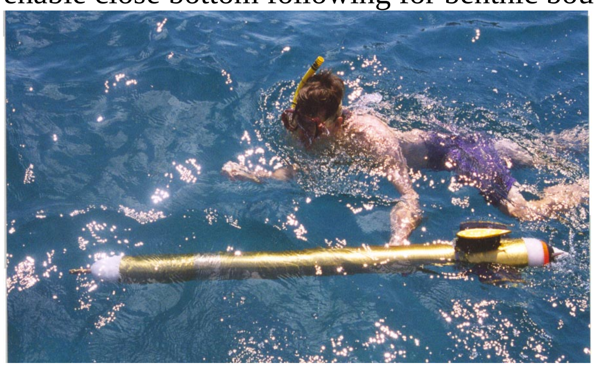


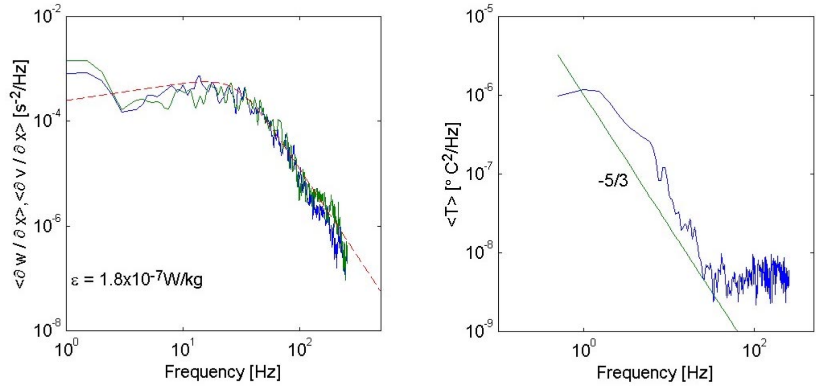
Figure 1. MADDOG: A close-bottom surveyor

Figure 2. Turbulence Measurement using the Autosub.

E. Bermuda Mission: Excellent small-scale turbulence data have been collected in the Sargossa Sea, south-east of Bermuda in August 1998 as part of NICOP related collaboration with Southampton Oceanographic Center (SOC). Three profiling missions, to depths up to 400m in over 800m deep waters were conducted successfully with our turbulence package mounted on SOC's Autosub (see Figure 2).

As a result we have obtained, once again, high quality two cross-stream shear and microstructure temperature data over a total of six hours (around 210Mbytes; see Figures 3 and 4 for samples of velocity and temperature spectra). Dissipation rates as low as *O*(1e-10 W/kg) were measured. The AUV also collected ADCP and CTD data which will be related to the variation in rate of dissipation measured by our sensors. The region near the time-series station Hydrostation S, Bermuda is well studied for its biogenic activities and involves determination of such quantities as sediment flux, fluorescence, dissolved oxygen and carbon dioxide and nitrate levels in the water column, the distribution of all of which is significantly influenced by the level of mixing induced by turbulence. The mixing rates reach their peak during hurricanes. Our profiling was carried out on three consecutive days prior to hurricane Bonnie reaching Bermudan latitudes. We observed increasing winds, from 0 to 15 knots during the three days with swells of up to 6ft and chops of up to 4ft. The following day 10ft swells were present and would have prevented boat activity. Thus, from an analysis of our data, collected over a 6km long region, to a depth of 400m using the versatility of the AUV, as well as those the from the moored instruments at Hydrostation S and the nearby BATS, we hope to make definitive statements about the rate at which turbulence levels increase at various depths, leading up to a storm.

Our large volume of micro-structure temperature measurements appear to be of high quality and will be of immense value in resolving the various discrepancies in the literature about heat flux measurements and determination of thermal diffusivity.



Figures 3 and 4. Spectra of cross-stream shear components and microstruture temperature at a depth of around 80m off Bermuda on 8/22/98. Shear spectra from two independent shear probes collapse onto the Nasmyth spectrum (---). The spectra suggest presence of a well mixed region.

IMPACT / APPLICATIONS

The close-bottom surveyor, with its small size, ease in handling and ability to survey bottom boundary layers to altitudes of 30 cm or higher clearly pushes the envelope of current autonomous measurement platform capabilities. The new pressure probe will be of significant interest to the oceanographic community.

TRANSITIONS

Collaboration with University of Miami, University of Victoria, Canada and Southampton Oceanographic Center are underway.

RELATED PROJECTS

The work is carried out in conjunction with other ONR-322OM/AOSN projects funded at Florida Atlantic University and with NICOP.

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(2) *Small Scale Turbulence Measurements in the Gulf Stream Using an AUV*. M Dhanak, K Holappa and R Lueck. AGU Meeting. December, 1998. Extended Abstract.

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