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One of the long-standing research interests in physical oceanography is the nature of finescale variability in the ocean and its relationships to turbulent dissipation and mixing. With the support of the present grant, a new moored instrument system capable of cycling vertically through the ocean and returning repeated profiles of the velocity, temperature and salinity structure, has been developed and field tested. First, scientific use of these instruments was in May-June 1998 as part of the Littoral Internal Wave Initiative. Three new Moored Profiler Instruments were deployed in a coherent array on the continental slope and synchronized to return vertical profiles every 1.5 hours. The vertical and horizontal information obtained from this coherent array will allow quantified tests of internal wave generation/reflection models. Improved understanding of the finescale velocity and density fields, and ultimately the mixing process in the littoral ocean, will result.

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Final Report

July 30, 1998

Grant No. N00014-97-1-1001

Title: A moored profiling instrument for observing finescale velocity, temperature and salinity variability in the coastal environment.

Principal Investigators: Raymond W. Schmitt and John M. Toole

Abstract

One of the long-standing research interests in physical oceanography is the nature of finescale variability in the ocean and its relationships to turbulent dissipation and mixing. With the support of the present grant, a new moored instrument system capable of cycling vertically through the ocean and returning repeated profiles of the velocity, temperature and salinity structure, has been developed and field tested. First scientific use of these instruments was in May-June 1998 as part of the Littoral Internal Wave Initiative. Three new Moored Profiler instruments were deployed in a coherent array on the continental slope and synchronized to return vertical profiles every 1.5 hours. The vertical and horizontal information obtained from this coherent array will allow quantified tests of internal wave generation/reflection models. Improved understanding of the finescale velocity and density fields, and ultimately the mixing processes in the littoral ocean, will result.

Technical summary

Ocean velocity, temperature and salinity finestructure, features having vertical scales of 10's to hundred's of meters and horizontal scales of 1 to 10 km appear intimately related to turbulent processes that occur on meter-to-centimeter scale. Developing understanding of finescale motions is thus key to learning about dispersion and mixing in the ocean. The WHOI Moored Profiler is a new instrument designed to investigate finescale motions in the ocean. The Profiler is designed to cycle vertically along a conventional plastic-jacketed mooring wire acquiring repeated high-resolution profiles of temperature, salinity and velocity, figure 1. The basic instrument platform integrated to a Conductivity-Temperature-Depth (CTD) sensor was developed with funding from the National Science Foundation over the past five years. Grant N00014-95-1-1001 from the Office of Naval Research supported the addition of a current measuring system to the device, mechanical, electrical, and software system changes to improve the instrument's performance, and field trials of the Profiler in the littoral ocean.

A technical description of the WHOI Moored Profiler and its performance in a variety of ocean environments is given by Doherty *et al.* (1998). In brief, the 0.8 X 0.4 m device utilizes a traction drive to propel itself along a standard jacketed-wire-rope mooring wire at a speed of ~0.3 ms^{-1}. The average power consumption at this profile speed is 1 - 2 W. At this rate, the battery capacity will support in excess of 10^6 m of profiling. Maximum depth is 5000 m and within this limit, maximum profiling range is set simply by the length of mooring wire used. Instrument actions are controlled by an on-board microprocessor allowing complex dive programs to be carried out. An acoustic transponder fitted to the Profiler allows the user aboard a support ship to monitor Profiler motion to verify its operation. Oceanographic and engineering data are recorded internally on a hard-disk interfaced to the microprocessor. The measurement suite thus far deployed consists of engineering sensors (pressure, electrical current to the drive motor, battery voltage), a CTD for deriving ocean temperature and salinity profiles, and an acoustic-phase current meter (ACM) that returns ocean velocity profile data.

The basic research program we initially envisioned called for the straightforward addition of a current meter to an existing Moored Profiler instrument design previously developed with NSF funding, and to test the instrument in the littoral ocean. Our first ocean trial was in January-February 1997 using a standard ACM manufactured by Falmouth Scientific, Inc. mounted horizontally at the front end of the Profiler. The trial revealed several shortcomings in the instrument design. In this heavy biofouling environment, material became lodged inside the cowling that surrounded the guide sheaves and drive wheel of the first prototype. Material also entered the bearing races of the guide sheaves. After about 10 days, the Profiler stopped moving vertically. While it was profiling, we observed the instrument to oscillate ("wag") by ±20 degrees at 5-10 s period when the incident horizontal flows were greater than about 20 cm/s. This motion introduced spurious signals into the measured horizontal currents that we were not fully successful in modeling and removing. These ocean data, supplemented by tow-tank test work, further documented a problem with the current measurements when the incident horizontal flow speed was comparable to the vertical profiling speed of the instrument. In these cases, wakes shed off the struts supporting the acoustic transponders of the ACM aligned with the acoustic paths of the instrument, causing noisy signals and flow underestimation.

Based on these findings, the design of the basic Profiler mechanical system and of the scientific instruments were modified. Foremost, the instrument cowling about the drive wheel and guide sheaves was eliminated to allow these moving parts to be more easily flushed. The guide sheaves were redesigned to be less prone to fouling and the clearance tolerances between the mooring wire and Profiler's retaining brackets were enlarged. The CTD which had been previously mounted on the instrument flank was moved to the front of the Profiler where it too is better flushed. Working with FSI, we designed a modified acoustic transducer mount for the ACM that is less sensitive to wake effects than their standard arrangement. Assuming the Profiler roughly aligns with the horizontal flow, the 4-axis "pyramid" arrangement presents three acoustic paths to incident flow clear of wakes, sufficient to estimate the 3-dimensional relative velocity. In addition, we devised a method to position the transducer mount remote from the current meter's electronics pressure case, figure 1. This arrangement, in addition to the cowling change, greatly reduced the horizontal drag forces on the Profiler body acting forward of the mooring wire. As a consequence, the modified instrument appears to align better with the horizontal flow and does not wag. The measured velocity data are thus much cleaner.

A modified prototype was again deployed for testing in October-November 1997. This time, the instrument cycled for the full length of the deployment, recovering 500 vertical profiles of temperature, salinity and horizontal velocity. The data quality was good and revealed interesting mesoscale and high-frequency motions. (A summary of these data is presented in Doherty *et al.*, submitted). Subsequent to this trial, the Profiler control program was modified to initiate vertical profiles on a fixed time schedule. (Previous instruments had been programmed with user-specified rest intervals between cycles. As each profile could take different amounts of time, the sampling was temporally uneven.) Moving the instruments to a fixed time schedule allowed the synchronization of three Profilers used in an experiment in May-June 1998 (see below). In addition, an acoustic transponder was fitted to the Moored Profilers to allow users to monitor the vertical motion of the instruments. This feature proved invaluable this Spring when loose set screws in the drive systems of two Profilers disabled the instruments. Upon detecting that the instruments were failing to profile, they were quickly recovered, repaired and redeployed, saving the experiment.

The prototype instrument developed under grant N00014-95-1-1001 plus two Moored Profilers constructed under a companion DURIP grant (N00014-97-1-0378) were first used within a scientific study in May-June 1998, investigating internal waves over the continental slope off Virginia. The instruments worked very well and returned exciting data: a subset of which is given in figure 2. On average, temperature and salinity at the experiment site decreased with depth below a warm-salty maximum at around 200 m. On long time scales, this maximum varied in intensity, probably the result of onshore-offshore advection of the shelf-break front. Mesoscale events were sampled by the mooring that vertically displaced isotherms and isohalines in the water column (the main event was centered on day 8 of the deployment, see figure 2). High frequency vertical displacements by the internal tide are also evident with a striking fortnightly modulation. The accompanying horizontal velocity data are equally rich in temporal variability. A surface-intensified flow to the northeast early in the deployment was replaced on day 4 by a southward flow having maximum intensity around 400 m. This southward alongshore flow lasted for around 4 days, with relatively weak low-frequency currents observed later. At higher frequency, tidal currents appear well resolved by the 1.5-hour sampling. In addition to a 2-5 cm s^{-1} peak-to-peak amplitude barotropic tide, the Profiler also documented highly-variable baroclinic structures. Individual profiles frequently show significant coherence between components and turning of the velocity vector with depth typical of low-frequency internal waves. Ongoing analysis will investigate relationships between the barotropic and baroclinic tides and other internal waves, and the nature of these baroclinic mesoscale flow features.

We anticipate numerous follow-on experiments utilizing these Moored Profilers that will explore the characteristics and dynamics of finescale motions. Operationally, the Profilers now in hand constitute a nascent shared-use facility at the Woods Hole Oceanographic Institution. Access to the instruments will be coordinated through J. Toole. Instrument life is expected to be comparable to that of conventional fixed-depth current meters, with routine replacement of mechanical components such as wheel bearings and batteries. Just as with conventional meters, these maintenance costs are expected to be borne by the individual research programs using the instruments. Costs are projected to be $5000-$10,000 per instrument per deployment, plus the expense of the associated mooring components. The Moored Profiler technology has been licensed to McLane Research Laboratories, Inc. of Falmouth, Ma. MRL is planning to have a prototype production version of the Moored Profiler ready for field testing by the end of 1998.

Doherty, K.W., D.E. Frye, S.P. Liberatore and J.M. Toole, A moored profiling instrument. J. Atmos. Oceanic Tech., submitted.

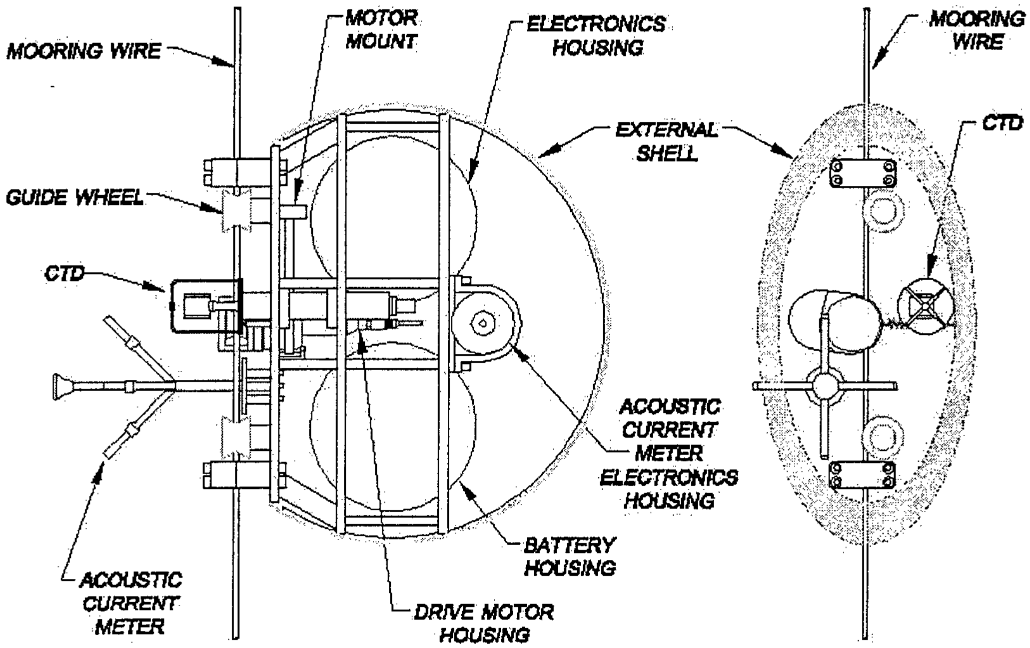

Figure 1. Schematic drawing of the WHOI Moored Profiler equipped with a Conductivity-Temperature-Depth (CTD) and an acoustic-travel-time 3-axis current meter. The overall dimensions of the oblate spheroidal instrument cowling are 0.8 X 0.4 m.

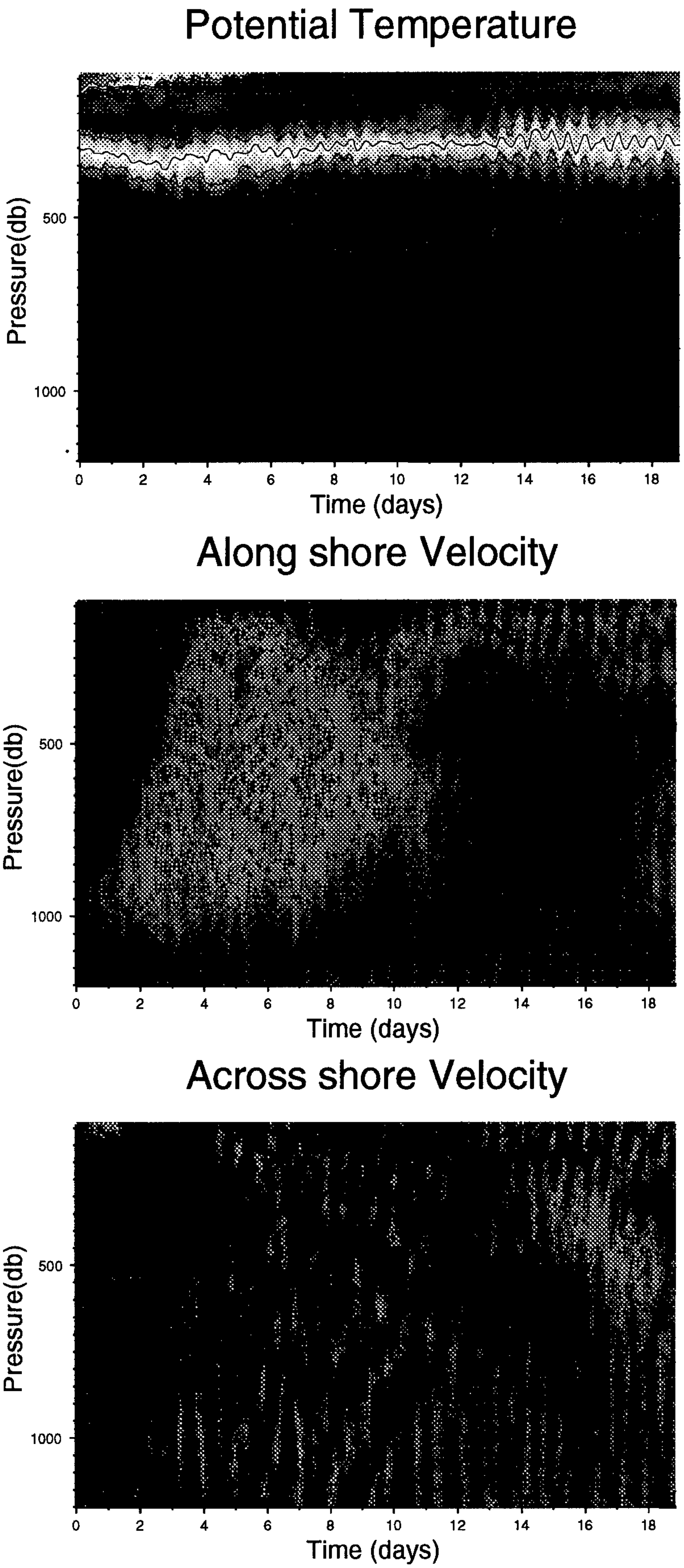

Figure 2. Contoured fields of potential temperature and velocity sampled by one of the Moored Profilers during the Turbulence and Waves above Irregular Sloping Topography experiment, a contribution to the Littoral Internal Wave Initiative. The contour interval for temperature is 1 degree and for velocity is 5 cm/s. Positive velocities are shown in blue, negative in yellow.