

Profiling Dissipation Measurements using χ Pods on Moored Profilers in Luzon Strait

James N. Moum

Jonathan D. Nash

College of Oceanic & Atmospheric Sciences

Oregon State University

Corvallis, OR 97331-5503

ph: (541) 737-2553 fx: (541) 737-2064 email: moum@coas.oregonstate.edu

<http://mixing.coas.oregonstate.edu/>

Award #: N00014-09-1-0280

LONG-TERM GOALS

The long-term goal of this program is to understand the physics of small-scale oceanic processes and how they affect the larger scales of ocean circulation. Ongoing studies within the **Ocean Mixing Group** at OSU emphasize observations, interaction with turbulence modelers and an aggressive program of sensor / instrumentation development and integration.

OBJECTIVES

The principal objectives of this project are to:

- quantify the energy losses to turbulence dissipation in the Luzon Strait in a systematic, comprehensive and extended way;
- quantify the spring-neap variation in these energy losses;
- obtain meaningful, long-term observations of the turbulent heat and momentum flux profiles in Luzon Strait, from which useful parameterizations can be derived;

APPROACH

To accomplish these objectives, we have:

1. modified 2 McLane Moored Profilers MPs for direct and extended measurements of turbulence, and
2. built, deployed and analyzed data from additional fixed-point turbulence measurements on IWISE moorings

WORK COMPLETED

We worked with engineers from the Applied Physics Lab at University of Washington to modify 2 MPs to house new pressure cases with analog electronics, fast thermistor sensors, analog-to-digital conversion electronics and batteries (Figure 1).

Initial engineering tests in December 2009 in Puget Sound prompted refinements which were incorporated into the unit deployed in Luzon Strait for the 2010 field campaign. Following this successful deployment, an additional MP was modified and 2 units deployed in Luzon Strait for the 2011 field campaign, yielding depictions that clearly show intense depth-dependent correspondence of turbulence with spring / neap tidal variations (Figure 1, right panel).

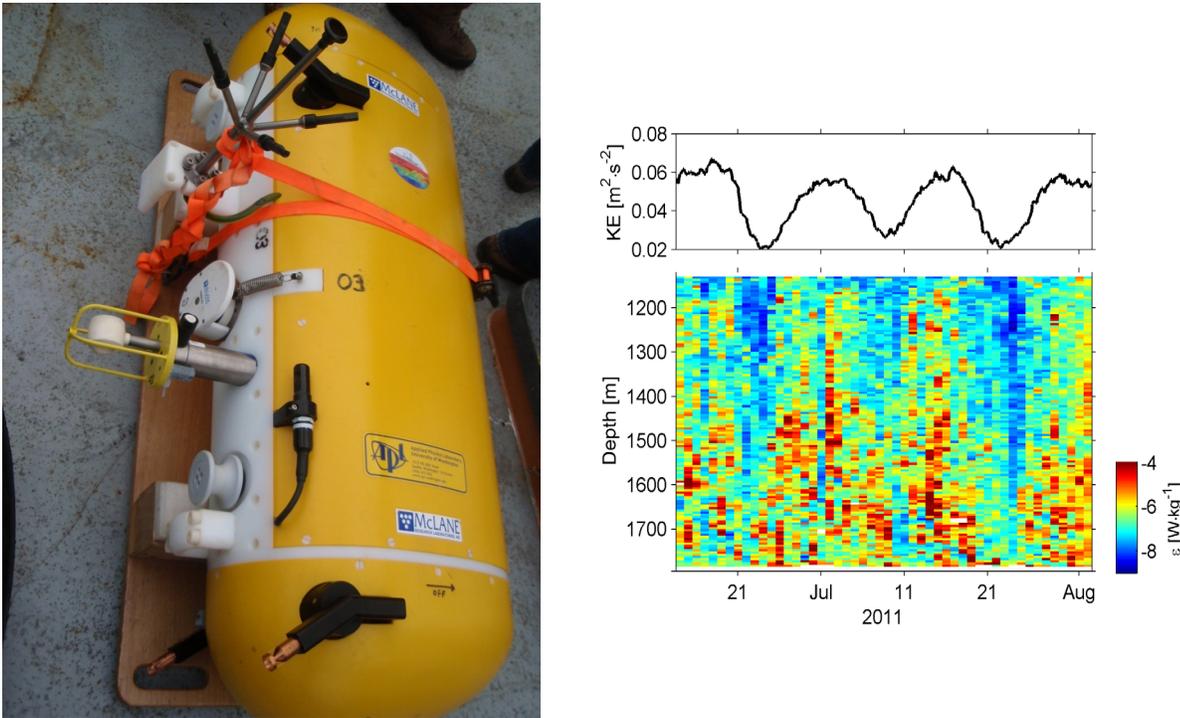


Figure 1 – turbulence-resolving xpod sensors (copper) on one (of 2) Moored Profilers deployed in Luzon Strait in summer 2011. Two chipods point UP on the upper part of the MP, two point DOWN on the lower part. The UP/DOWN concept permits a measurement of undisturbed flow when the MP profiles both UP and DOWN. Left panels show turbulence dissipation rate changes as tides change from spring (high KE) to neap (low KE).

An additional 5 individual moored chipods were deployed in the IWISE 2011 mooring array (A1, N1, N2). Two of these were deployed at 2000 m depth below the MP chipod units, a depth greater than all previous chipod measurements. These were equipped with a new pitot sensor designed to provide mean flow speeds (as well as turbulent velocity fluctuations) for incorporation into chipod temperature variance dissipation rate calculations.

RESULTS

Three significant results ensue from this work:

1) This is the first experiment in which several distributed and extended time series measurements of turbulence were successfully made (from moored profiles and chipods on moorings). These resolve critical time-varying signals that are difficult (or impossible) to detect otherwise. An outstanding example is the *observational demonstration that turbulence dissipation scales with cubed barotropic currents* (Fig. 2).

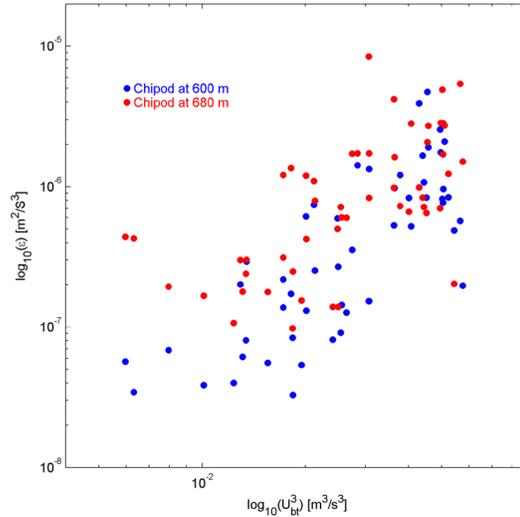


Figure 2 –Comparison of daily-averaged dissipation rates from Fig. 4 and cubed barotropic current velocity.

2) **Comprehensive comparisons of length scales critical to describing the energetics of the turbulence** (Fig. 3) are assessed from moored profiler measurements of turbulence. The Thorpe scale, L_T , represents a statistical descriptor of overturns caused by turbulence. In a rapidly-evolving, 3D flow such as found in Luzon Strait and with tremendously large overturns, it is not clear how quantitatively representative this scale is. In comparison to the dynamical scale, L_o , the range is considerably larger than found for well-defined and clearly-resolved thermocline patches (dots in Fig. 3; Moum, 1996). And there is a bias, only partly due to the unclear definition of stratification (N^2 ; Smyth et al., 2001). Estimation of ϵ depends on the squared length scale, further confounding quantitative estimation of turbulence from overturn scales.

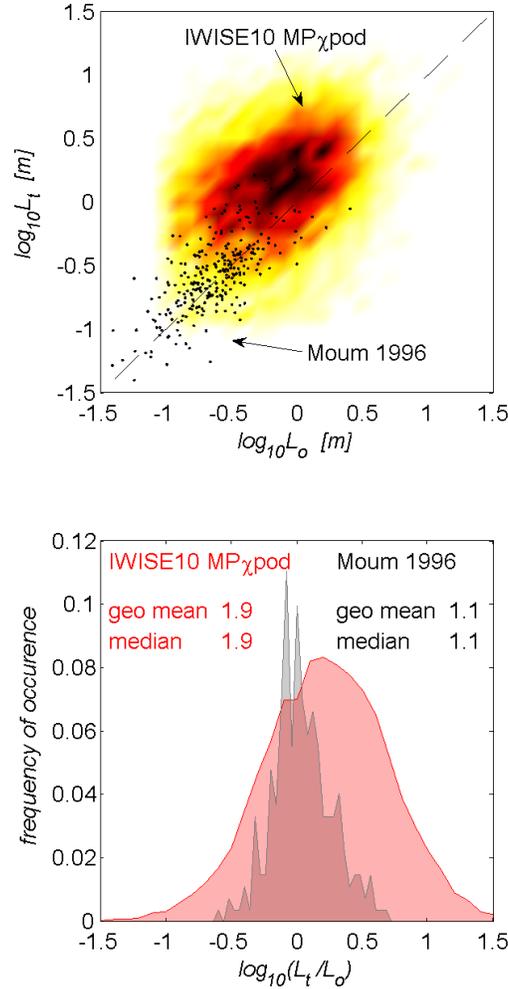


Figure 3 – Comparison of the large-eddy length scale statistic, L_T , and L_o , a large-eddy length scale defining the buoyancy limit of the turbulence.

3) **A new velocity measurement:** A fundamental requirement to compute χ_T and ε_χ from temperature gradient measurements is the flow speed past the sensor tip (Moum & Nash, 2009; Perlin & Moum, 2012). To address this issue, we have devoted considerable effort to develop a local measure of velocity using a differential pressure sensor – a pitot tube. The first deployment was on a mooring in Luzon Strait in summer 2011 at 2000 m depth (Fig. 4). The comparison of velocity from a nearby ADCP with large spatial and temporal averaging is very good (Fig. 5). Furthermore, the high-frequency part of the signal (sampled at 50 Hz) indicates the presence of an inertial subrange coincident with turbulence sensed by the temperature sensor on the χ pod. Comparisons of ε computed directly by scaling the inertial subrange of the velocity spectra to ε_χ derived indirectly from χ show statistical agreement on 5-minute spectral estimates within 20%. Another advantage of the complementary measurement of velocity fluctuations is evidenced just past 18:00 in Fig. 4 where the bottom boundary layer became well-mixed, reducing temperature stratification and thereby precluding any assessment of turbulence based on temperature gradient fluctuations alone. This has led to further deployments in Luzon Strait in 2011, in SE Alaska as part of NRL’s Breaking Waves Experiment, wind tunnel and tidal channel tests and implementation on all new chipods.

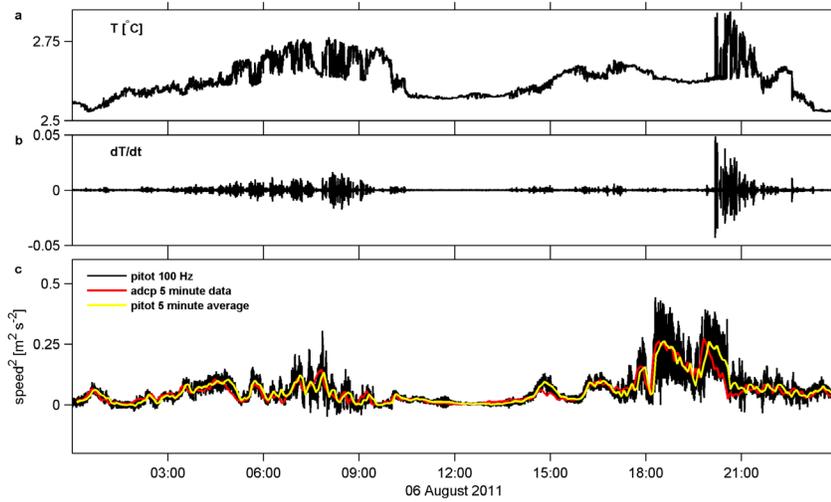


Figure 4 – A single day of a 2-month time series from a χ pod moored at 2000 m depth on mooring N1 in Luzon Strait. a) temperature; b) time derivative of temperature (dT/dt), from which χ_T is computed; c) velocity from a nearby ADCP (red) and from a pitot tube on the χ pod (black at 50 Hz, yellow averaged to match ADCP). The pitot velocity was derived from a static lab calibration of pressure and Bernoulli, $u = \sqrt{2p/\rho}$.

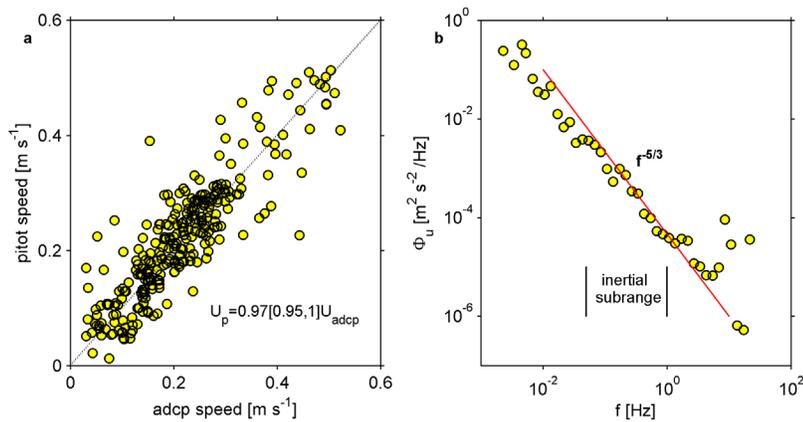


Figure 5 – Mean and turbulent velocities from a high-speed pitot tube on χ pod . a) direct comparison of ADCP and pitot velocities; b) velocity spectrum computed from 30 minutes of data from the pitot tube starting at 18:00. Estimates of ε derived from inertial subrange fits to the velocity spectrum agree statistically to within 20% of estimates of ε_χ from temperature gradient measurements on the same χ pod (3b).

IMPACT/APPLICATION

The development of a chipod for moored profilers offers a new way to obtain long time series of turbulence in the deep ocean. Development of a new, small, inexpensive, low power velocity sensor offers simultaneous measurements of both current speed and turbulence.

RELATED PROJECTS

The dissipation measurements derived from the chipods on moorings A1, N1 and N2 are being used to validate inferred estimates of turbulence from other platforms. Together, these are contributing to larger IWISE effort by providing a temporal and spatial assessment of dissipation and mixing in Luzon Strait. Some of the measurements are currently being used by Byungho Lim as part of his MS thesis project. This project has relied on the IWISE mooring project of Matthew Alford (APL/UW).

The development of our new velocity measurement of both mean+turbulence scales has led to additional deployments of two new chipods (plus 6 high-resolution pressure pods) in Cordova Channel off SE Alaska as part of a Naval Research Lab experiment on Breaking Wave Effects under High Winds (BWE; David Wang, Paul Hwang, Hemantha Wijesekera). This experiment builds on technical-scientific relationships established with NRL for the Mixing Over Rough Topography experiment in the Gulf of Mexico (MORT; Wijesekera et al., 2013).

REFERENCES

- Moum, J.N., 1996. Energy-containing scales of turbulence in the ocean thermocline, *J. Geophys. Res.*, **101**, 14,095–14,109.
- Smyth, W.D., J.N. Moum and D.R. Caldwell, 2001. The efficiency of mixing in turbulent patches: inferences from direct simulations and microstructure observations. *J. Phys. Oceanogr.* **31**, 1969 – 1992.
- Moum, J.N. and J.D. Nash, 2009. Mixing measurements on an equatorial ocean mooring, *J. Atmos. Oceanic Technol.* **26**, 317-336.
- Perlin, A. and J.N. Moum, 2012. Comparison of thermal dissipation rate estimates from moored and profiling instruments at the equator. *J. Atmos. Oceanic Technol.*, **29**, 1347-1362.

PUBLICATIONS

- Shroyer, E.L., J.D. Nash, K.J. Benoit-Bird and J.N. Moum, 2013. Stratification and mixing regimes in biological thin layers over the mid-Atlantic Bight. *Limnol. Oceanogr.* [submitted, refereed]
- Smyth, W.D. and J.N. Moum, 2012: Ocean Mixing by Kelvin-Helmholtz instability. *Oceanography*, **25**(2), 140-149. [published, refereed]
- Wijesekera, H.W., D.W. Wang, W.J. Teague, E. Jarosz, E. Rogers, D.B. Fribance and J.N. Moum, 2013. Surface wave effects on high-frequency currents over a shelf edge bank. *J. Phys. Oceanogr.*, **43**, 1627-1647. [published, refereed]