

The Role of Biologically-Generated Turbulence in the Upper Ocean

Eric Kunze, John Dower, Richard Dewey
School of Earth and Ocean Sciences
University of Victoria
PO Box 3055, STN CSC
Victoria, BC, V8W-3P6, Canada
Phone: 250-472-4482 Fax: 250-721-6200
e-mail: kunze@uvic.ca, dower@uvic.ca, rdewey@uvic.ca
<http://web.uvic.ca/eosc/people/kunze.htm>

Award #: N000140810700

LONGTERM GOALS

Our interests are in oceanic processes that contribute to stirring and mixing in order to understand their impact on larger scales so that better subgridscale parameterizations may be implemented. This includes phenomena ranging from the microscale (1 cm) up to the mesoscale (10-100 km).

OBJECTIVES

Work on ocean biosphere energetics suggests that schooling marine organisms might generate turbulent dissipation rates $\varepsilon \sim 10^{-5} \text{ W kg}^{-1}$ (Huntley and Zhou 2004) with as much as 1 TW available globally to generate ocean turbulence (Munk 1966; Dewar *et al.* 2006). Measurements in Saanich Inlet (Kunze *et al.* 2006) revealed intense ($10^{-5} - 10^{-4} \text{ W kg}^{-1}$) turbulent bursts coinciding with the dusk vertical migration of a dense krill swarm comprised of up to 10^4 individuals m^{-3} (0.1% by volume). Lasting only 10-15 minutes, this event was nevertheless of sufficient intensity to increase daily-average mixing by 2-3 orders of magnitude. This mechanism could be important for mixing nutrients and gases through the transition layer at the base of the surface mixed-layer. But turbulence dissipation does not always arise in association with migration of backscatter layers (Rippeth *et al.* 2007; Rousseau 2009) and mixing is not always associated with elevated dissipation (Gregg and Horne 2009). We seek to establish whether swimming marine organisms can contribute significantly to ocean mixing by determining (i) how frequently vertically migrating backscatter layers generate turbulence and turbulent mixing and (ii) under what conditions (season, cloud-cover, lunar cycle, backscatter intensity, backscatter migration speed, etc). We have also been asked to participate in the Lateral Mixing DRI where we will map dye spreading and characterize the internal wave and turbulence conditions.

APPROACH

Our approach has been to collect shipboard microstructure and acoustic profile time-series deliberately or on ships of opportunity. Work to date indicates that this sampling strategy will not be an effective means of accumulating adequate statistics. For this reason, we are collaborating with the VENUS observatory program to collect long term time-series. VENUS has received funding to add a profiling

Report Documentation Page				Form Approved OMB No. 0704-0188	
Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.					
1. REPORT DATE 2009		2. REPORT TYPE		3. DATES COVERED 00-00-2009 to 00-00-2009	
4. TITLE AND SUBTITLE The Role of Biologically-Generated Turbulence in the Upper Ocean				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) University of Victoria,School of Earth and Ocean Sciences,PO Box 3055, STN CSC,Victoria, BC, V8W-3P6, Canada,				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					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT Same as Report (SAR)	18. NUMBER OF PAGES 5	19a. NAME OF RESPONSIBLE PERSON
a. REPORT unclassified	b. ABSTRACT unclassified	c. THIS PAGE unclassified			

mooring to the Saanich Inlet observatory. We are considering which suite of sensors might best be used. One possibility would be to infer qualitative turbulence levels with a high-frequency acoustic sensor but this would likely be qualitative. An alternative would be to attempt to measure density overturns; because Saanich Inlet is salinity stratified, this would require temperature and conductivity sensors. We are also considering mounting a Rockland Scientific MicroRider onto either a seaglider or a profiling float but this option may be more expensive than our budget will allow. The acoustic backscatter layer is already being continuously monitored in the inlet. Ph.D. student Mei Sato is analyzing this time-series.

Our contribution to the Lateral Mixing DRI will be to tow-yo a horizontal fine- and microstructure profiler (Hammerhead) to characterize the internal wave and turbulence fields in dye streaks released as during the low-energy eddy field component which is likely to take place in the subtropical western North Atlantic during 2011.

WORK COMPLETED

For her Master's research, Shani Rousseau collected 11 additional dawn and dusk time-series in Saanich Inlet, 6 at Ocean Station P and 5 off Monterey Bay. She defended in July 2009 (Rousseau 2009) and a paper is being prepared from her results. New Ph.D. student Mei Sato has begun analyzing a year-long bioacoustic profile time-series in Saanich Inlet to characterize the properties of the vertically migrating layer and attempt to relate variations to environmental parameters.

In preparation for the dye-release experiment, we have participated in a field test in Saanich Inlet during May 2009 in collaboration with Drs. Jody Klymak (UVic) and Patrick Cummins (IOS BC). Two streaks of dye were injected on different density surfaces, nominally at 82 and 120-m depth. These were tracked as they spread over the course of the following week using 2 ships and 2 towed bodies. This work provided a test of our ability to find and survey dye streaks using a new log-scale Chelsea fluorescein sensor and a new tow-yo winch over an extended period.

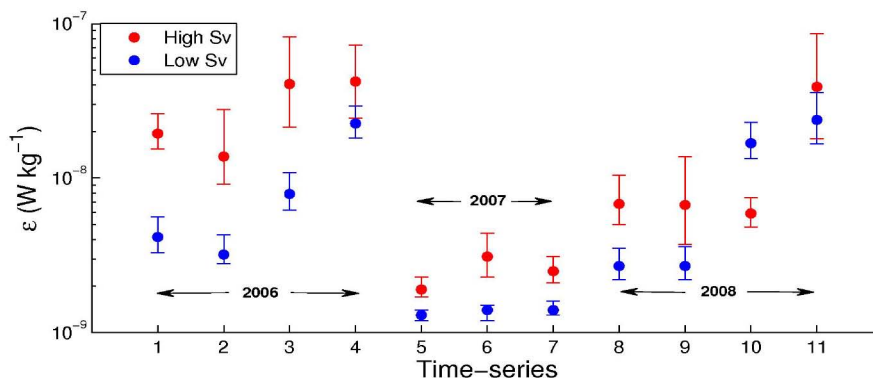


Figure 1: Average turbulent kinetic energy dissipation rates ϵ inside and outside layers of high acoustic backscatter signal S_v from 11 dawn and dusk time-series in Saanich Inlet, BC, each comprised of at least 10 microstructure profiles and continuous bioacoustic profiling. In 9 out of the 11 time-series, dissipation rates are significantly higher in high than low acoustic backscatter. On average, the dissipation rates are a factor of two higher in high acoustic backscatter.

RESULTS

No repeat of the dusk turbulent burst reported by Kunze *et al.* has been observed in Saanich Inlet. Further, no evidence for biological generation of turbulence was found at OSP where the turbulence could all be attributed to shear generation. Turbulence levels in layers of high acoustic backscatter were found to be a factor of two higher than in acoustically quiet waters, regardless of whether they were migrating or not (Fig. 1). The major scientific conclusion from this is that the efficiency of turbulence production by swimming marine organisms is low, implying that only a small fraction of the 1 TW marine organisms expend on swimming goes toward turbulence mixing, less than 8% based on our sampling. Further measurements are needed to constrain just how infrequently such events occur.

The dye streaks injected in the north end of Saanich Inlet were subsequently carried southward in a western boundary current, then northward along the eastern boundary in a hitherto unknown cyclonic circulation likely related to tidal rectification over sloping topography (Fig. 2). We also observed more horizontal stirring of the streaks than anticipated (Fig. 2), likely due to eddies spun off by the tidal currents interacting with headlands.

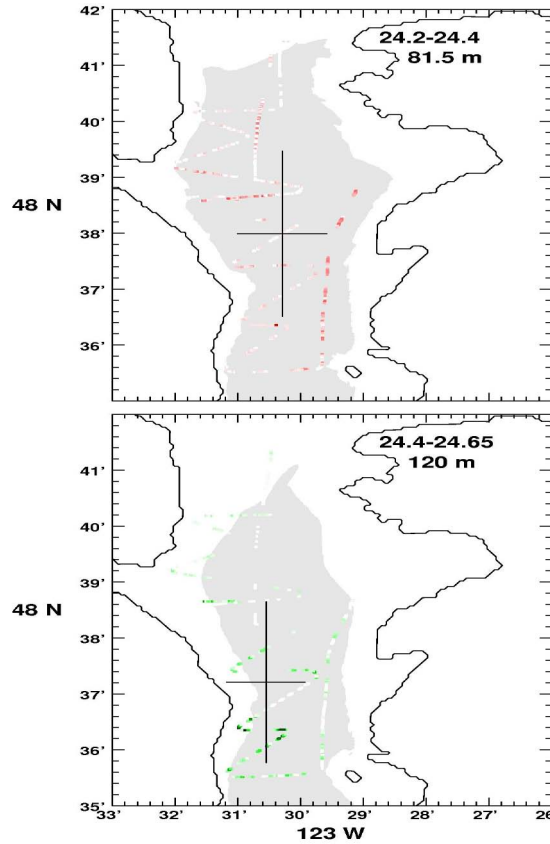


Figure 2: Maps of fluorescein distributions at 2 injection depths in Saanich Inlet, BC, 5 days after injection. Crosses indicate the centroid and standard deviations of the distribution. The dye was injected in 2 streaks near the north end of the inlet. It subsequently was carried along the western boundary in a cyclonic circulation, taking about a week to come around to the eastern boundary. It was also stirred along density surfaces by eddies likely generally by tide/headland interactions.

IMPACT/APPLICATION

Turbulent mixing associated with migrating krill swarms is proving controversial. Rippeth *et al.* (2007) found no evidence of elevated turbulence associated with the vertically-migrating acoustic backscatter layer in 11 time-series collected on the continental shelf west of the British Isles. Visser (2007) challenged the very notion that 1-cm krill could produce turbulence mixing because they inject shear too close to the Kolmogorov scale. This seemed to be supported by Gregg and Horne (2009) who found only weak temperature microstructure associated with intense turbulence in aggregations of small fish in Monterey Bay. However, our original Saanich Inlet time-series had coincident microscale shear, temperature-gradient, density overturns and a spectrum consistent with the Nasmyth spectrum. This contradiction with Visser's argument is suggested to be because the krill swarms generate turbulence from their aggregate behavior, not individually. Kakani and Dabiri (2009) recently invoked the Darwin mechanism in which viscous drag of fluid along with mobile organisms could contribute significant mixing without generating turbulence. They demonstrated this mechanism with dye and jellyfish. However, they did not account for molecular diffusivity of heat and solutes which would limit mixing for the smallest organisms that dominate the ocean's motile biomass.

RELATED PROJECTS

The PIs are co-PIs on a funded VENUS infrastructure proposal to the Canada Foundation for Innovation that will support part of the biological turbulence measurements in Saanich Inlet.

REFERENCES

- Dewar, W.K., R.J. Bingham, R.L. Iverson, D.P. Nowacek, L.C. St. Laurent and P.H. Wiebe, 2006: Does the marine biosphere mix the ocean? *J. Mar. Res.*, **64**, 541-561.
- Gregg, M.C., and J.K. Horne, 2009: Turbulence, acoustic backscatter and pelagic nekton in Monterey Bay. *J. Phys. Oceanogr.*, **39**, 1097-1114.
- Huntley, M.E., and M. Zhou, 2004: Influences of animals on turbulence in the sea. *Mar. Ecol. Prog. Ser.*, **273**, 65-79.
- Kakani, K., and J.O. Dabiri, 2009: A viscosity-enhanced mechanism for biogenic ocean mixing. *Nature*, **460**, 624-627.
- Kunze, E., J.F. Dower, I. Beveridge, R. Dewey and K.P. Bartlett, 2006: Observations of biologically-generated turbulence in a coastal inlet. *Science*, **313**, 1768-1770.
- Munk, W., 1966: Abyssal recipes. *Deep-Sea Res.*, **13**, 707-730.
- Rippeth, T.P., J.C. Gascoigne, J.A.M. Green, M.E. Inall, M.R. Palmer, J.H. Simpson and P.J. Wiles, 2007: Turbulent dissipation of coastal seas. *Science Online*, **313**, (<http://www.sciencemag.org/cgi.eletters/313/5794/1786?ck=nck>)
- Rousseau, S., 2009: Influence of swimming marine organisms on turbulence on the ocean from in-situ measurements. M.Sc. thesis, SEOS, U of Victoria, Victoria, BC, 103 pp.
- Visser, A.W., 2007: Biomixing of the oceans? *Science*, **316**, 838-839.

PUBLICATIONS

N/A