Proceedings of the 17th Physics of Estuaries and Coastal Seas (PECS) conference,
Porto de Galinhas, Pernambuco, Brazil, 19-24 October 2014

Turbulence over the Sill of Saanich Inlet, BC, Canada

CAROLINA CAMARGO[1] , EMMA MUROWINSKI[2] , ROLF LUECK[2] , FABIAN WOLK[2]

[1]Department of Oceanography, Universidade Federal do Rio Grande, Rio Grande, Brazil
Email: caromlcamargo@gmail.com

[2]Rockland Scientific Inc., Victoria, BC, Canada
Email: fabian@rocklandscientific.com

Keywords: dissipation, turbulence, Saanich Inlet, vertical mixing, fjord-estuary.

SUMMARY
Saanich Inlet is a physically quiet fjord-estuary, with anoxic deep waters and restricted circulation with the adjacent basins. Despite the limiting conditions, the inlet presents high levels of primary production. Previous works have tried to describe how this primary production is sustained, but no conclusions were made. Vertical mixing could be the mechanism resupplying nutrients from the deep, nutrient-rich waters into the euphotic zone, thus sustaining primary production. We hypothesize that tidal action at the mouth of Saanich Inlet has enough energy to vertically mix the water column. Using a turbulence profiler (VMP-250) we collected microstructure temperature, conductivity and shear data in the water column. The shear data was used to calculate dissipation rates. Our observations show that there is significant turbulence in the inlet, supporting our hypothesis.

1. INTRODUCTION

Vertical mixing is an essential process affecting the dynamics of estuaries [1]. The flow of geophysical fluids is driven by density gradients, which can exist both in the vertical and horizontal dimensions. Density gradients can be 'broken' by mixing, a consequence of turbulence processes. The generation of turbulence is an expression of vorticity and eddy production [2]. Turbulent eddies control the exchange of oxygen and nutrients between the surface layer and the deep water, and are recognized as an important factor to the functioning of the marine food web. Primary producers require both light and nutrients for growth, and when light is not the limiting factor, phytoplankton populations will grow until the euphotic zone becomes nutrient depleted. Usually deep waters are a reservoir of inorganic nutrients, thus turbulent mixing at the base of the surface mixed layer can be a method of resupplying nutrients to the euphotic zone and promoting primary production. Measurements and characterization of turbulent fluxes is crucial for understanding the process(es) and rate at which nutrient refuels [3].

When compared with a typical coastal inlet of British Columbia, Saanich Inlet, located in southeastern Vancouver Island, has a larger than expected primary production [4]. Saanich Inlet (Figure 1) is described as a physically quiet environment: a fjord-estuary with weak wind and tidal forces, and dominant freshwater supply from outside the inlet mouth [5]. During the summer the waters of the Fraser River affect Saanich Inlet, entering the system through Satellite Channel. During the winter, the major source of freshwater is the Cowichan River, which enters the inlet through Cowichan Bay. The shallow sill at the mouth of the inlet, approximately 70m deep, makes deep water renewal infrequent. During the fall, oxygenated waters intrude the inlet and replace the anoxic deep layer [6]. Because the source of freshwater is not at the head of the estuary, as in most cases, Saanich Inlet presents a reverse estuarine circulation, which is associated with downwelling processes. With such conditions, low primary productivity is expected.

Assuming low rates of turbulent nutrient resupply, previous researchers looked for other explanations for the surprisingly high primary production, and it was suggested that pressure gradients generated by strong tidal mixing outside the inlet could be the mechanism resupplying nutrients. The only current and dissipation rate measurements were in Patricia Bay, an embayment inside Saanich Inlet. The dissipation rates there were insufficient to explain the nutrient resupply [7]. Higher dissipation rates, expected at the mouth of the inlet, can potentially supply nutrients to the euphotic zone and sustain high primary productivity in the inlet.

The presence of one or more underwater sills is a basic characteristic of fjord-estuaries [8]. There are many processes of water exchange between a coastal fjord and the adjacent basins, however the underwater sill restricts the circulation and limits the exchange of waters [9]. Barotropic effects, especially tides, meteorological forcing, and direct shelf processes are some of the mechanisms that force exchange over sills [2]. The circulation pattern of a fjord will reflect the dominance of one or more of these mechanisms over others [10]. Knight Inlet is a well-studied fjord of British Columbia, with a sill at the mouth and strong tidal action. The processes occurring in Knight Inlet are not representative of all fjords, but do provide illustrative circulation examples and is a good comparison for Saanich Inlet, despite the tidal forcing being stronger. It was observed that the tidal flow over the sill of Knight Inlet generates an internal lee wave; the breaking of the lee-wave is a possible source of vertical mixing [9].

Saanich Inlet is connected to the waters of the Strait of Georgia through the Satellite Channel (Figure 1). Across the channel the waters are turbulent and well mixed [11]. It has been considered that when these waters reach the inlet, their energy would already have been dissipated. However, we hypothesized that spring tides would be strong enough to move the turbulent waters into the inlet, generating dissipation at the entrance of the inlet. The upstream turbulence would be responsible for the nutrient resupply over the inlet. The objective of this work was to measure the dissipation rates at the sill in order to determine if there is overturning brought in by tides.

2. METHODS

In order to test our hypothesis, we measured the dissipation rates at the southern side of the sill of Saanich Inlet (Figure 1). We used a Vertical Microstructure Profiler (VMP-250, Rockland Scientific Inc.), which measures the microstructure of temperature, conductivity and shear. The VMP-250 was equipped with standard oceanographic conductivity and temperature sensors (CT, JFE Advantech) and a fluorometer (JFE Advantech).

To examine the turbulence generated by the tidal movement, time series data were collected between the low and high tide, registering about 7 hours of flood into the inlet. To have a spatial view of how the tides affect the inlet, we collected data over a cross-section parallel to the mouth of the inlet, moving from east to west. The fieldwork took place on two days of a spring tide. On the first day we only collected data over the cross section, moving from station A to F (Figure 1). The first cross-section occurred at low tide, and the second one at flood tide. On the second day we collected data over the cross-section at low tide, and held location at station C ('star' station in Figure 1) during the flood tide. The time series recorded data from the low tide, at 13:40 PDT, until the high tide, at 20:30 PDT, with two rest breaks.

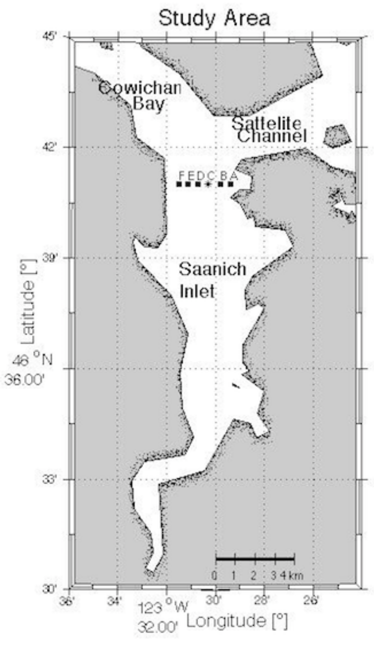

Figure 1:Map of Saanich Inlet with the research stations

3. RESULTS

The data from the first-day cross-section measurements show that the shallower parts of the section (stations A, B and F) present high dissipation data, probably because of the bathymetry, while the central and deeper areas (C, D, and E) are more influenced by the Satellite Channel waters. The spatial survey showed that the best location to collect the time series was Station C, which is above the deepest part of the sill, 85m deep, and very influenced by the tidal movement.

The time series (Figure 2) allowed us to see what levels of dissipation the tides generate, and how they vary with the depth and time. As the inlet started to flood the dissipation levels started to increase, and as the tide got stronger the dissipation level reached their peak. This turbulence was bottom-related, generated at 50m. The vertically averaged dissipation (Figure 2a, blue solid line) was highest when the water level (Figure 2a, red dashed line) increased most rapidly, around 18:00 PDT. As the tide reached the slack, the averaged dissipation showed a more constant behavior. The turbulent events had a long duration, about 30 min long. The estimated flow for this tide was 20.5 cm/s.

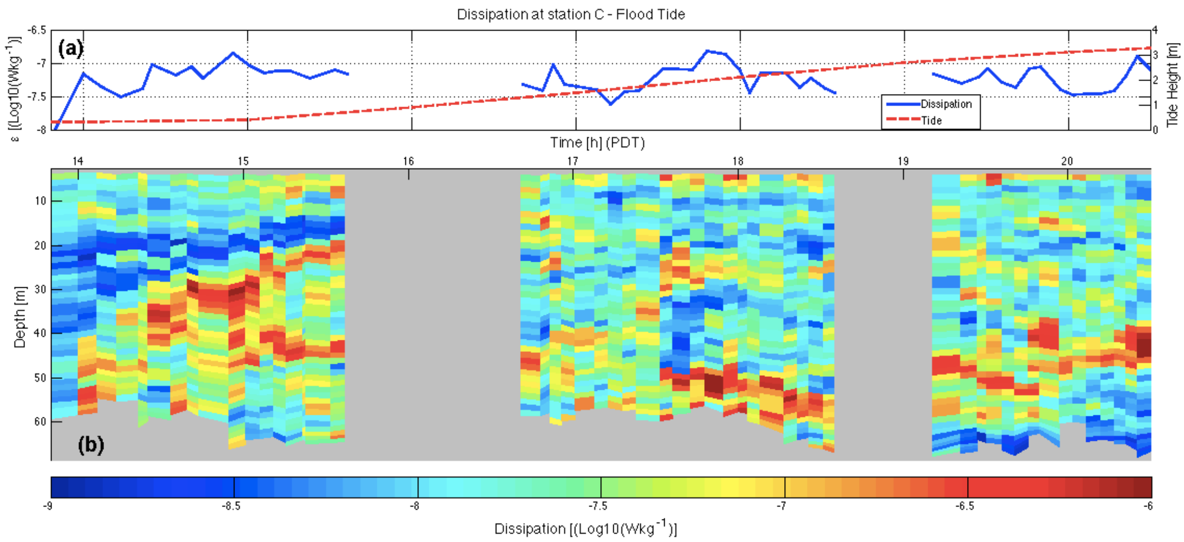

Figure 2: Time series of the dissipation rates at Station C. a: Dissipation averaged through depth (blue solid line) and tidal height (red dashed line) varying with time. b: Dissipation varying with time and depth. Darker red means high dissipation, and darker blue low dissipation (color bar). Gray gaps between the data represent the breaks during the data collection. Gray space at the bottom is not necessarily the topography, but the depth of the deployment. The real depth of Station C is 85m. The variations of the depth between the profiles are due the movement of the boat (a fixed length of rope was used for all the profiles).

4. DISCUSSION

Saanich Inlet is considered to be a physically quiet environment; however, our observations show that there are significant levels of dissipation occurring near the sill of Saanich Inlet. The increase of dissipation with the flood tide supports our hypothesis, and is evidence that the tidal action might be energetic enough to bring the turbulent waters of Satellite Channel into Saanich Inlet before the energy is completely exhausted.

For our hypothesis to be correct, the generation of dissipation should be minimum during the slack tide. Our data show that the dissipation events were long and energetic. It is possible that the strong turbulence generated at 18:00 PDT took a couple of hours to dissipate all its energy. The high dissipation rates recorded at the end of the time-series have moved up in the water column, supporting the idea that it was the energy remaining from previous mixing.

The observed dissipation may be a result of the tides bringing the well-mixed and turbulent waters of Satellite Channel into the inlet. The vertical mixing caused by the tide can be one of the sources of the nutrient resupply into the euphotic zone, and may explain the high primary productivity in the inlet. The results of this research are based on a limited data set, and motivate further studies in the Saanich Inlet. Longer time series, that include the entire tidal cycle, could confirm our results and provide better understanding of the dynamics of the estuary. Our observations illustrate the importance of using an instrument that profiles rapidly enough to provide data that are densely spaced.

5. REFERENCES

[1] Geyer, W. R., Scully, M. E., and Ralston, D. K. (2008). Quantifying vertical mixing in estuaries. *Evironmen Fluid Mech , vol 8*, pp. 495-509

[2] Farmer, D. M., and Freeland, H. J. (1983). The physical oceanography of fjords. *Prog Oceanog , vol 12*, pp. 147-220.

[3] Gargett, A. E. (1996). "Theories " and techniques for observing turbulence in the ocean euphotic zone. *Scientia Marina ,vol 61*, pp. 25-45.

[4] Timothy, D. A., and Soon, M. Y. (2001). Primary production and deep-water oxygen content of two british columbia fjords. *Marine Chemistry* , pp. 37-51.

[5] Gargett, A., Stucchi, D., and Whitney, F. (2003). Physical processes associated with high primary production in Saanich Inlet, British Columbia. *Estuarine, Coastal and Shelf Science , vol 56*, pp. 1141-1156.

[6] Anderson, J. J., and Devol, A. H. (1973). Deep water renewal in Saanich Inlet, an intermittently anoxic basin. *Estuarine and Coastal Marine Science ,vol 1*, pp. 1-10.

[7] Sato, M. (2013). Variability in Diel Vertical Migration of Zooplankton and Physical Properties in Saanich Inlet, British Columbia. *PhD thesis, School of Earth and Ocean Sciences, University of Victoria*.

[8] Valle-Levinson, A. (2010). Contemporary Issues in Estuarine Physics. *Cambrigde.*

[9] Kylmak, J. M., and Gregg, M. C. (2003). The Role of Usptream Waves and a Downstream Density Pool in the Growth of Lee Waves: Stratified Flow over the Kinght Inlet Sill. *Journal of Physical Oceanography , vol 33*, pp. 1446-1461.

[10] Vlasenko, V., Stshchuk, N., and Hutter, K. (2002). Water exchange in fjords induced by tidally generated internal lee waves. *Dynamics of atmospheres and oceans* , pp. 63-89.

[11] Grundle, D. S., Timothy, D. A., Varela, D. E. (2009).Variation of phytoplankton productivity and biomass over an annual cycle in Saanich Inlet, a British Columbia fjord. *Continental Shelf Research, vol 29*, pp. 2257-2269.