

SCAR-COMNAP Fellowship Report 2012-13

Candidate: Jenson V. George, National Centre for Antarctic and Ocean Research, Goa, India

Host: Dr. Marcus Dengler, GEOMAR | Helmholtz Centre for Ocean Research Kiel, Germany

Duration of Visit: 20th March -10th July 2013

Title: Influence of small scale mixing on the primary productivity and water mass formation in the Southern Ocean

Objectives

One of the major objectives was investigation of small scale mixing in the Southern Ocean. For this the micro scale turbulence observations carried out using microstructure profiler has to be processed, analyzed and interpreted. It was also aimed to estimate the diapycnal fluxes of nutrients, heat and salt to infer the influence of small scale mixing on the primary productivity and water mass formation in the Southern ocean.

Work carried out

The MSS90L microstructure profiler (Prandke and Stips, 1998) data collected during 5th Indian expedition to Southern Ocean (SO) is processed and analyzed. Vertical/horizontal microstructure velocity measurement is used to infer the small scale mixing rates (Osborn 1980, Maum et al. 1995). Airfoil shear probes are one of the most-used methods to measure the microstructure velocity. Because of the finite size of the shear probe and noise associated with its vibrations, rigorous processing of microstructure velocity data is required to get reasonable estimates of dissipation rates. The inferred dissipation rates from the microstructure profiler data were further used to calculate the eddy diffusivity. Nitrate flux in the subtropical front of Indian sector of SO was estimated using the calculated eddy diffusivity. An effort was made to compare the dissipation rates inferred from microstructure profiler data and CTD/XCTD data using Thorpe length method. However due to the lower dissipation rates and inherent noise present in the CTD/XCTD data, we could not achieve a robust conclusion.

Results

MSS90L microstructure data processing

Based on the Reynolds averaged turbulence kinetic energy equation, the turbulent kinetic energy dissipation rate is given by

$$\epsilon = \overline{\nu \frac{\partial u_i}{\partial x_j} \left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} \right)} \quad (1)$$

ν is the kinematic viscosity, as a function of temperature and salinity, u is the turbulence velocity fluctuations, x represents the spatial coordinate system with standard tensor notations and the over bar represent the ensemble average. In isotropic turbulence, equation (1) is reduced as

$$\epsilon \approx 7.5 \nu \overline{\left(\frac{\partial u}{\partial z} \right)^2} \quad (2) \quad \text{Here } \frac{\partial u}{\partial z} \text{ is the vertical}$$

gradient of the horizontal current shear fluctuations (Moum et al. 1995).

The airfoil of PNS06 has 6mm and 10mm diameter and length respectively. Finite size of the probe limit the measure of eddies comparable to the size of probe and results in spatial averaging. Spatial averaging increases at higher wave numbers and cause under estimation of variance, resulting in dissipation rates biased low. Again lower limit of dissipation rate is limited by vibration associated with profiler itself. Because of the inherent noise in the measured shear spectrum, it is compared with the universal shear spectrum, the Nasmyth spectrum. This spectrum is used to estimate variance. To correct the underestimated variance due to spatial averaging the shear spectrum has to be boosted with a single pole transfer function of the form $1 + (k\lambda_c)^2$ Oakey (1982). For PNS06 shear probe λ_c is set as 0.25 based on the probe shape. From the corrected shear spectrum the epsilon is calculated as

$$\epsilon = 7.5\nu \int_{k_{\min}}^{k_{\max}} \Phi_{\text{shear}} dk \quad \text{----(12), where } k_{\min} \text{ is the lowest possible wave number}$$

and k_{\max} highest possible wave number. Figure 1a shows the power spectral density computed from 3s vertical velocity shear characterized by different dissipation rates and corresponding corrected Nasmyth spectrum fit. Inverted triangles indicate minimum and maximum integration limit of the corresponding spectrum used for the dissipation rate estimation. The measured spectra agree well with the universal spectrum in the minimum and maximum integration limit computed from the iterative procedure similar to Maum et al (1995). The filled circles represent the respective Kolmogorov number associated with the shear spectrum. Figure 1b shows the shear spectra (dashed line) averaged at different dissipation rates along with the corresponding averaged Nasmyth spectra (continuous line). For averaging purpose data is taken from temperature range 12°C to 18°C and sinking velocity from 0.7m/s to 0.9m/s. It is noted that at dissipation rates of the order 10^{-8} and above there is a good agreement with the observed shear spectra and universal Nasmyth spectra especially at lower wave numbers. However at dissipation rates of order of 10^{-9} and less the spectra deviates from its universal form (Figure 1b). On the basis of departure of observed spectra from its universal Nasmyth spectra, the lower detection limit is of the order of 1×10^{-9} W/kg.

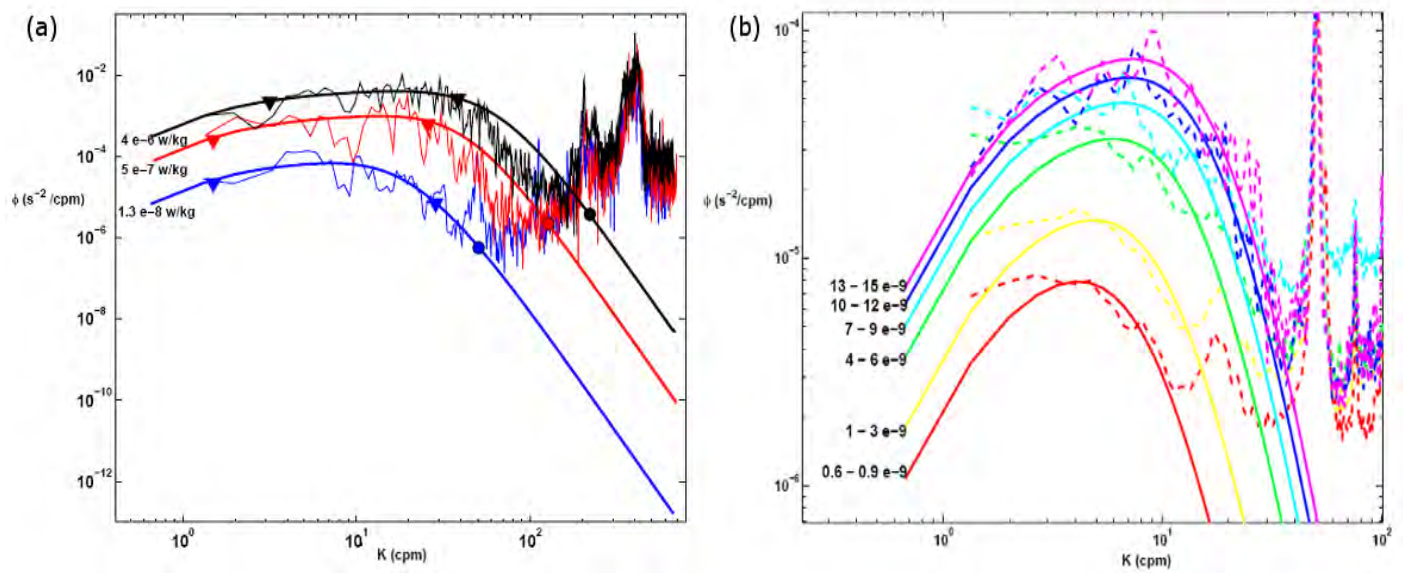


Figure 1 (a). The vertical shear spectra and their corresponding Nasmyth spectra at different dissipation rates. The inverted triangles represent corresponding minimum and maximum integration limits used for the estimation of dissipation rates. Filled circles represent the respective Kolmogorov wave number. **(b)** The shear spectra (dashed line) averaged at different dissipation rates along with the corresponding averaged Nasmyth spectra (continuous line). For averaging purpose data is taken from temperature range 12°C to 18°C and sinking velocity from 0.7m/s to 0.9m/s.

Dissipation rates and Nutrient Flux at the Time series Location in the Indian sector of Southern Ocean

Time series data collected during Indian Ocean expedition to southern Ocean 2012 at 40°S, 58°30'E is shown in Figure2. The temperature (~19°C) and Salinity (35.6) values at the surface show that the time series location was at the Sub Tropical Front (STF) (Anilkumar et al. 2006). The vertical distribution of potential density and Brunt Vaisala Frequency indicate a strong stratification at the time series location. The very low Nitrate values at surface and presence of DCM at thermocline region suggest nitrate limitation. One of the major source of nutrients from thermocline waters to surface is via diapycnal mixing. However the dissipation rate inferred from the microstructure data show very low values close to the noise level of the instrument, in the thermocline region. To estimate the nitrate flux from thermocline waters to the nitrate limited upper waters the high gradient nitrate region is chosen. The vertical nitrate flux by turbulent mixing is calculated as the product of eddy diffusivity and vertical nitrate concentration gradient. $Flux = K_{\rho} \frac{dNo_3}{dz}$, where eddy diffusivity $K_{\rho} \approx \Gamma \frac{\epsilon}{N^2}$, N is the Brunt visala frequency. The mixing efficiency Γ is chosen as 0.2 following Shih et al (2005). The average nitrate flux from thermocline waters to the nitrate limited upper waters was estimated as $1.6e-2 \mu M m^{-2}s^{-1}$.

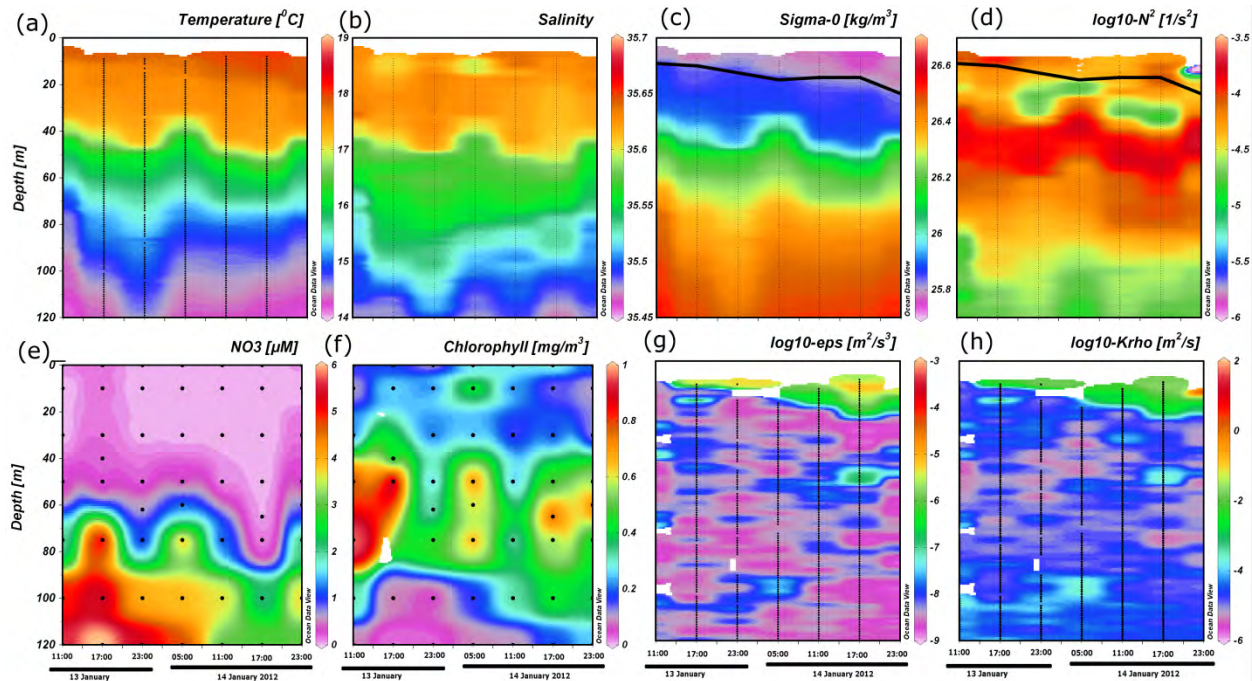


Figure 2. Time series of The vertical distribution of (a) Temperature (b) Salinity (c) potential density (d) Bruntvisala frequency (e) Nitrate (f) chlorophyll (g) dissipation rates and (h) eddy diffusivity at 40S, 58.5E. The thick black line indicates the mixed layer depth.

Future Work

Skills developed during the fellowship will be utilized in developing sustained measurement programs of oceanic turbulence with an aim to understand the spatial variability of small scale mixing processes and micro scale turbulence's role in the vertical transport of heat, salt, nutrients. There is also plan for research papers in collaboration with IFM GEOMAR.

Acknowledgement

This study was supported by the combined fellowship grant by Scientific Committee on Antarctic research and Council of Managers of National Antarctic Program. The fellowship work was made possible by the generous hosting of Dr Marcus Dengler, GEOMAR | Helmholtz Centre for Ocean Research Kiel, Germany. The continued support and encouragement by the director NCAOR, Shri. Rasik Ravindra is greatly acknowledged. I also acknowledge Dr. N Anilkumar, my guide for all the support rendered.

References

Anilkumar N., Luis A.J., Somayajulu YK., Ramesh Babu V., Dash MK. , Pednekar SM., Babu KN., Sudhakar M., Pandey P.C., 2006, Fronts, Water Masses and Heat Content Variability in the Western Indian Sector of Southern Ocean during Austral Summer 2004. *Journal of Marine Systems* 63, 20-34.

Moum, J. N., M. C. Gregg, R. C. Lien, M. E. Carr, 1995, Comparison of Turbulence Kinetic Energy Dissipation Rate Estimates from Two Ocean Microstructure Profilers. *J. Atmos. Oceanic Technol.*, **12**, 346–366.

Oakey. N. S., 1982, Determination of the rate of dissipation of turbulent kinetic energy from simultaneous temperature and velocity shear microstructure measurements. *Journal of Physical Oceanography*, 12, 256–271

Osborn, T. R., 1980, Estimates of the Local Rate of Vertical Diffusion from Dissipation Measurements. *J. Phys. Oceanogr.*, **10**, 83–89.

Prandke, H., & Stips, A., 1998, Test measurements with an operational microstructure-turbulence profiler: Detection limit of dissipation rates. *Aquatic Sciences*, 60(3), 191-209.

Shih, L. H., J. R. Koseff, G. N. Ivey, and J. H. Ferziger, 2005, Parameterization of turbulent fluxes and scales using homogenous sheared stably stratified turbulence simulations, *J. Fluid Mech.*, 525, 193–214.

Fund Allocation

A total of \$9200 was allotted for this study. \$3,400 was used for travelling between India and Germany, \$2000 was used for housing in Kiel. Rest of the money was spent for internal travel and living in Kiel for ~4 month.