Observed Ocean Turbulence Spectra from ARGO Profiling Floats

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Abstract

The spectral characteristics of turbulence and eddies in the ocean are examined using ARGO profiling float data. Many theories predict the spectral slopes associated with the statistics of ocean macro-turbulence, but there are few observations at depth to guide these discussions. Here, a method developed for estimating the structure function of atmospheric macro-turbulence using rawinsondes is adapted to estimate the structure function and corresponding spectral slope of oceanic macro-turbulence using data collected by ARGO profiling floats. Horizontal structure functions over a range of depths and latitude bands, as well as in eddy-rich and eddy-poor regions will be shown. The structure function evaluated at pressure levels differs from that evaluated along potential density surfaces, consistent with the internal wave spectrum. In pressure coordinates below 45m at scales larger than 100km, results follow the Batchelor (1959) theory and smaller scales follow a steeper slope. The potential density coordinates results are consistent with the Batchelor theory for passive tracers at large scales over all depths. The spectral slope's dependence on latitude, depth, and the presence of eddies will also be discussed.

Structure Function and Spectral Slope

The second-order structure function estimates the difference in potential temperature, velocity, or salinity between two locations a distance, *s*, apart:

$$D(s) = \overline{(\theta(x) - \theta(x+s))^2}$$

The structure function is related to the temperature variance, kinetic energy, or salinity variance spectrum, respectively, by a simple change of variables, from the structure function, $D(s) \propto \alpha_D s^{\gamma_D}$, to the temperature variance spectrum, $B(k) \propto \alpha_B k^{\gamma_B}$. The relationship between the spectral slope and the structure function slope is, therefore

$$\gamma_D = -\gamma_B - 1.$$

The primary goal of this project is to estimate γ_D from ARGO data over length scales where an inertial range is apparent, and compare to theories that predict γ_D.

Reference	Theory	Scales	γ_B	γ_D
Kolmogorov (1941)	3D Energy Cascade	All	-5/3	**2/3**
Kraichnan (1967)	2D Enstrophy Cascade	Small	-1	**0**
Charney (1971)	QG Enstrophy Cascade	Small	-1	**0**
Kraichnan (1967)	2D Inverse Energy Cascade	Large	1/3	-4/3
Charney (1971)	QG Energy Cascade	Large	1/3	-4/3
Blumen (1978)	SQG Inverse Energy Cascade	Large	-1	**0**
Blumen (1978)	SQG Temperature Cascade	Small	-5/3	**2/3**
Vallis (2006)	**Passive Tracer Spectrum**	**All**	**-1**	**0**
Obukov, Corrsin (1949, 1951)	**Passive Tracer Spectrum**	**"All"**	**-5/3**	**2/3**

Argo Global Distribution

Though the average distance between Argo Profiling Floats is 300km, the coincidental distance between floats is much smaller, allowing smaller scale (equivalent to large wavenumber) features to be identified. The sampling error will, however, increase, resulting in the larger confidence intervals seen on the structure function plots at small scales.

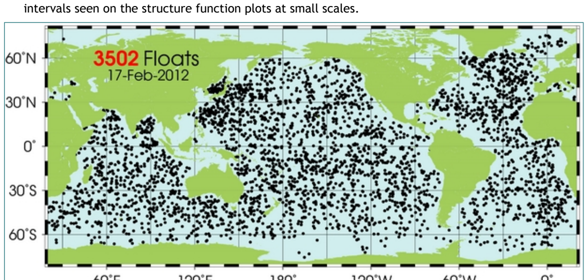


Figure 1: Locations of the 3502 operating ARGO floats in the world's oceans as of February 7, 2012.

Temperature Perturbation Maps

$$T'^2 = (T_{C\,\mathrm{lim}} - T_{Obs})^2$$

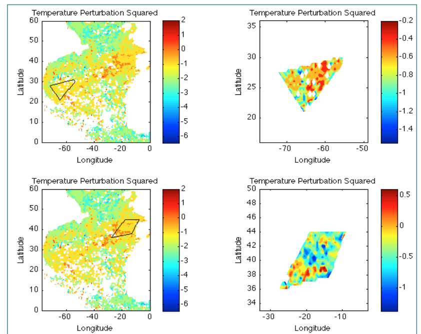


Figure 2: Maps of temperature perturbation squared in the North Atlantic at a depth of 27.8 kg/m³. Plots on right show the perturbations squared in the chosen "uniform variance" regions where structure functions will be calculated and compared.

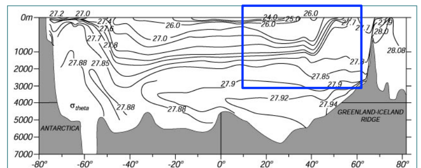
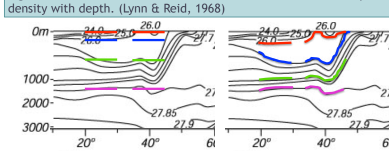


Figure 5: A section in the west-central Atlantic Ocean of potential density with depth. (Lynn & Reid, 1968)



Conclusions and Future Work

The most immediate and meaningful result is that it IS possible to use Argo data to calculate structure functions, and infer about the temperature (or salinity) variance spectra. The structure functions are most clear for the pressure-coordinate plots, with discernable small-scale slopes near to 2/3, and large-scale slopes near 0.

The results for the density coordinates show a slope of 0 for all scales. This could be described by the very large scalar temperature forcing by climate, but with small-scale eddies stirring. It is an important result that there is so little change in structure function power with depth, when it is known that the temperature variance changes with depth.

In immediate future work, normalizing perturbation regions will allow a comparison for all regions of variance.

In the future, an interesting problem will be to use other sources of data, like surfaces drifters, which provide velocity measurements, to calculate horizontal velocity structure functions (to be used to infer kinetic energy spectra), or moored TOGA-TAO buoys to calculate vertical structure functions for temperature. Higher-order structure functions may also illuminate more details as to the dominating forces in observed ocean turbulence.

Structure Function Results

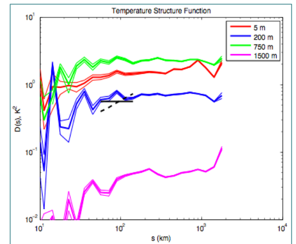


Figure 3: Structure function in south central Atlantic for 5, 200, 750, and 1500m. Also included are two black lines showing spectral slopes of 2/3 (dashed) and 0 (solid).

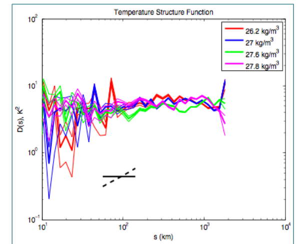


Figure 4: Structure function in the south central Atlantic for 26.2, 27, 27.6 and 27.8 kg/m³. Also included are two black lines showing spectral slopes of 2/3 (dashed) and 0 (solid).

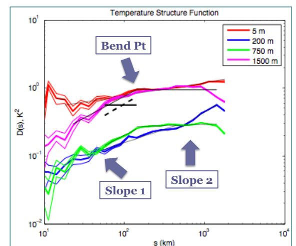


Figure 6: Structure function in the eastern North Atlantic for 5, 200, 750, and 1500m. Also included are two black lines showing spectral slopes of 2/3 (dashed) and 0 (solid).

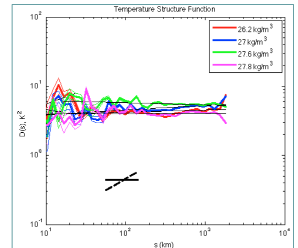


Figure 7: Structure function in the eastern North Atlantic for 26.2, 27, 27.6 and 27.8 kg/m³. Also included are two black lines showing spectral slopes of 2/3 (dashed) and 0 (solid).

Depth	Bend Pt	Slope 1	Slope 2
5m	N/A	N/A	0.19
200m	450	0.4	0.72
750m	140	**0.6**	**0**
1500m	140	**0.6**	**0**

Depth	Bend Pt	Slope 1	Slope 2
26.2 kg/m³	N/A	N/A	**0**
27 kg/m³	N/A	N/A	**0**
27.6 kg/m³	N/A	N/A	**0**
27.8 kg/m³	N/A	N/A	**0**

Acknowledgements

Thank you to Gael Forget at the Massachusetts Institute of Technology for providing the quality-controlled ARGO data, as well as the basic structure function and spectral slope MATLAB files. Thanks also to Rod Frehlich and Chris Fairall for their guidance and input. This project is funded by the NOAA-ESRL/CIRES Graduate Student Fellowship.

References

Batchelor, G. K. 1959 Small-scale variation of convected quantities like temperature in turbulent fluid .1. General discussion and the case of small conductivity. Journal of Fluid Mechanics 5 (1), 113-133.

Blumen, W. 1978 Uniform potential vorticity flow .1. Theory of wave interactions and 2-dimensional turbulence. *Journal of the Atmospheric Sciences* **35** (5), 774-783.

Charney, J.G. 1971 Geostrophic turbulence. *Journal of Atmospheric Sciences* **28,** 1087-1095.

Kolmogorov, A.N. 1941 The local structure of turbulence in incompressible viscous fluid for very large Reynolds number. *Dokl Akad Nauk. SSSR* **30,** 9-13.

Kraichnan, R.H. 1967 Inertial ranges in two-dimensional turbulence. *Physics of Fluids* **16,** 1417-1423.

Lynn, R. and Reid, J. 1968 Characteristics and circulation of deep and abyssal waters. *Deep Sea Res.* **15** (5), 577-598.