Interpreting Geostrophic Turbulence from Eddy Vertical Structure and Variability

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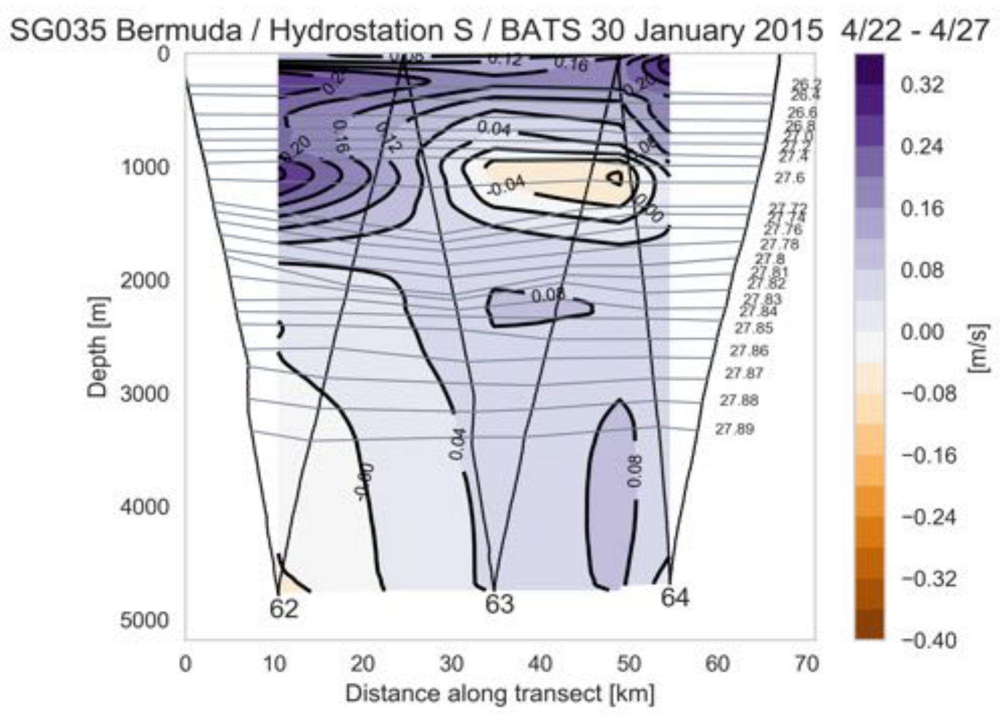
1. Goal

Using Deepglider AUVs, we seek an improved understanding of the vertical structure of time dependent geostrophic motions, the vertical partitioning of total mechanical energy, and the processes by which energy transfers across scales.

Turbulent energy transfer across spatial scales of 10's to 100's of km's where quasi-geostrophic motions dominate, termed geostrophic turbulence, has been broadly theorized but narrowly observed.

2. Methods

Gliders were deployed at multiple locations to collect near daily full-depth profiles for many months. Vehicles were piloted to maintain constant heading for multiple dives-climb cycles allowing the estimation of along-track density gradients at all. We then calculate the vertical shear of cross-track geostrophic velocity using thermal wind, and reference this to the glider estimated depth-average current.



We consider full-depth density and absolute geostrophic velocity profiles. Velocity (U) and vertical isopycnal displacement (ξ) profiles are then used to esimate depth-averaged kinetic (KE) and potential energy (PE).

3. Vertical Structure

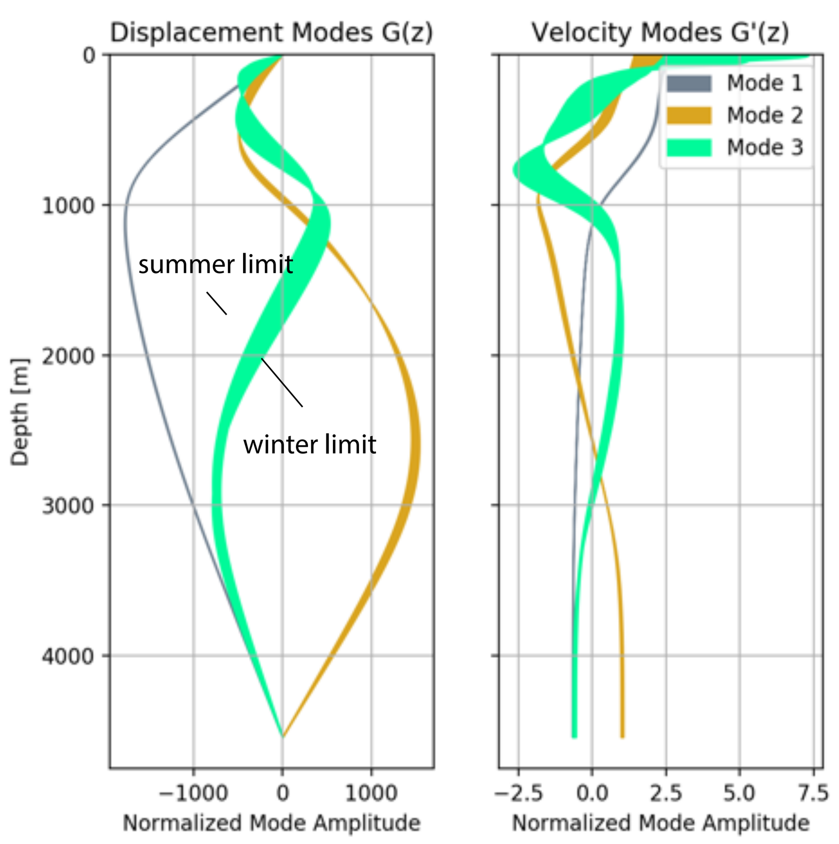
Orthonormal vertical modes, $G_n(z)$ and $G'_n(z)$, derived from the quasi-geostrophic potential vorticity equation are projected onto ξ_i and U_i profiles to find n mode amplitudes β(x,y,t), α(x,y,t) for each profile..

$$\xi_i = \sum_n \beta_n G_n(z)$$

$$U_i = \sum_n \alpha_n G'_n(z)$$

$$G''_n(z) + \frac{N^2(z)}{c_n^2} G_n(z) = 0$$

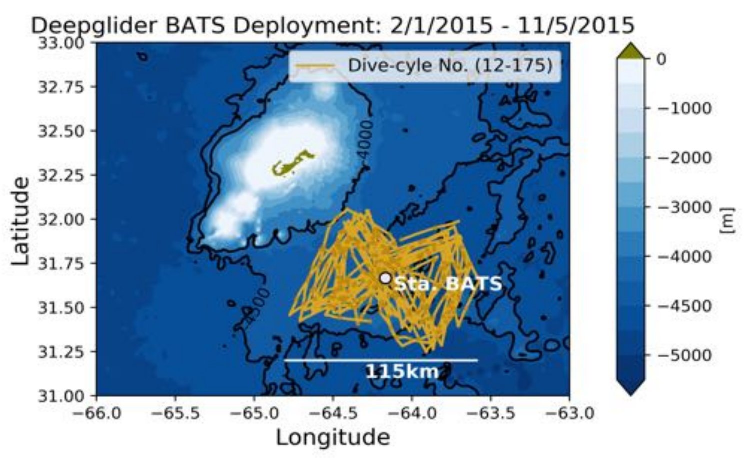
Solutions for eigenfunctions G(z) and eigenvalues c_n are solved for numerically using free-surface and flat bottom boundary conditions. Modes are normalized per unit energy.



$$KE = \frac{1}{h}\int_{-h}^{0} \langle U^2(x,y,z,t)\rangle dz = \frac{1}{h}\int_{-h}^{0} \left\langle \left(\sum_n \alpha_n(x,y,t) G'_n(z) \right)^2 \right\rangle dz$$

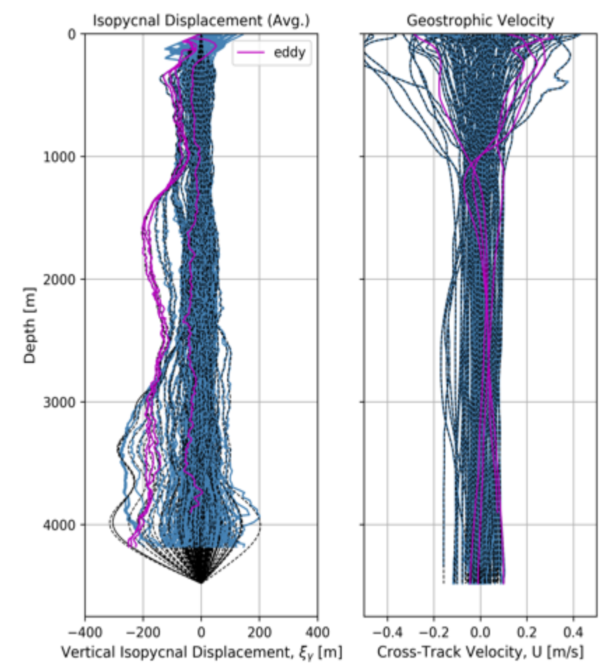
$$PE = \frac{1}{2h}\int_{-h}^{0} \langle N^2(z)\xi^2(x,y,z,t)\rangle dz = \frac{1}{2h}\int_{-h}^{0} \left\langle \left(\sum_n \beta_n(x,y,t) N(z) G_n(z) \right)^2 \right\rangle dz$$

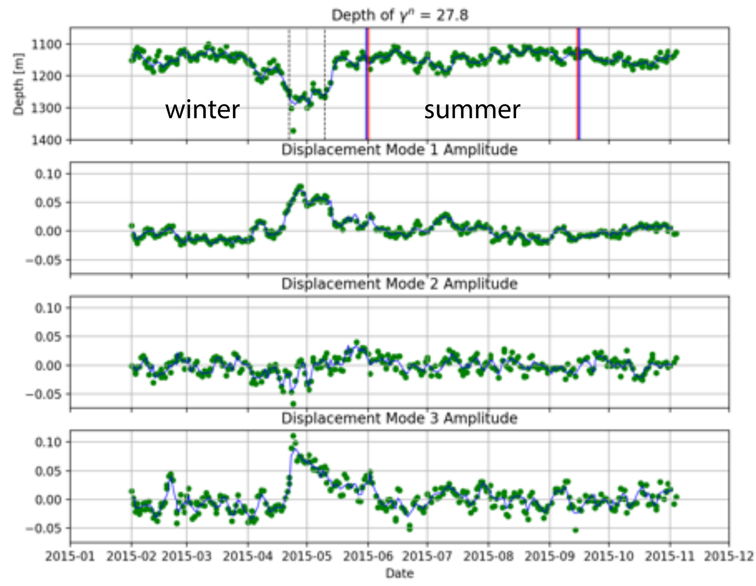
4. Deployment at Station BATS (64.2˚W, 31.6˚N)



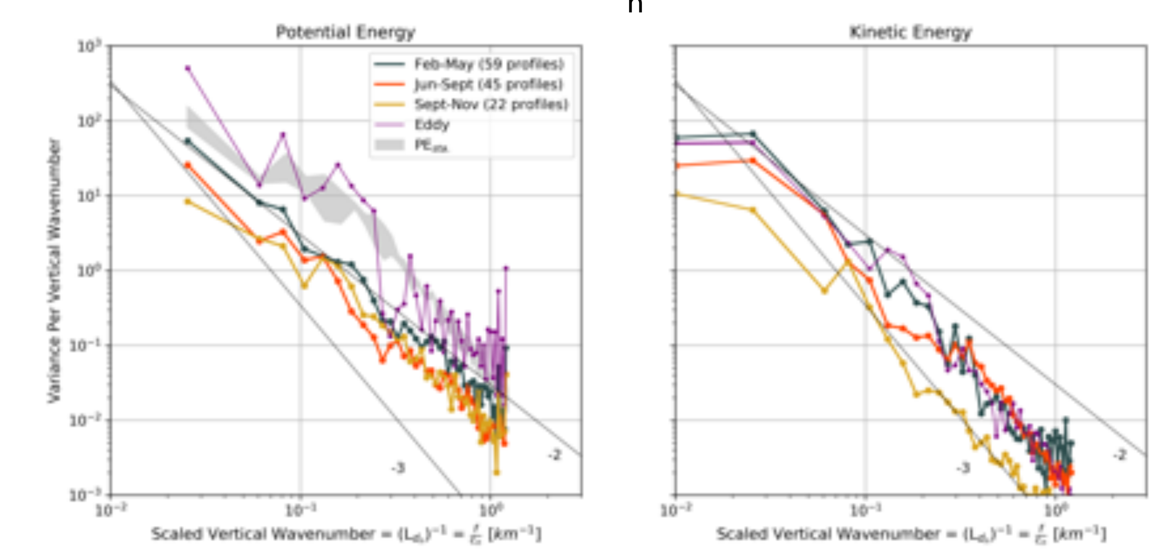
A Deepglider flew a bowtie pattern centered on the BATS site for 9 months collecting over 300 profiles.

Below: time series of a density surface and the first three baroclinic mode amplitudes.



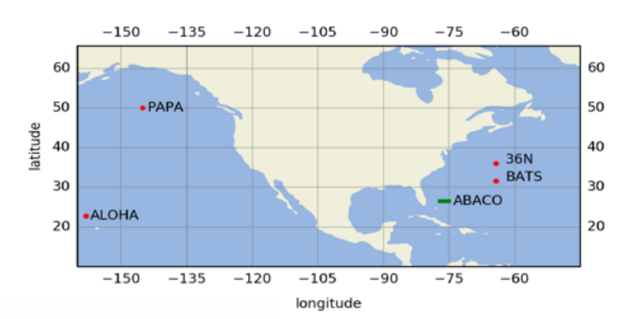


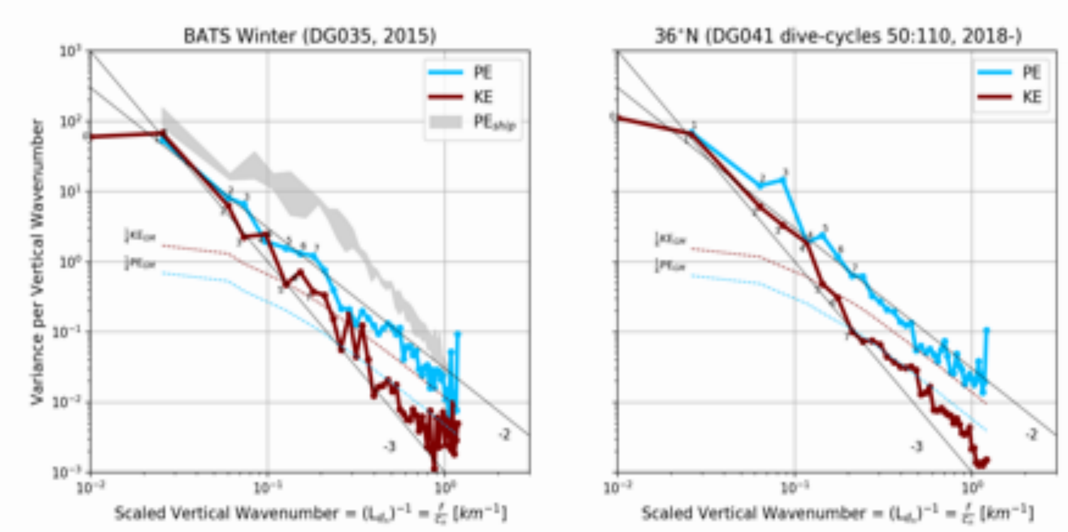
After projecting profiles onto vertical modes, depth-averaged PE and KE is expressed as a function of vertical mode number. (a scaled vertical wavenumber f/c_n and inverse deformation radius)



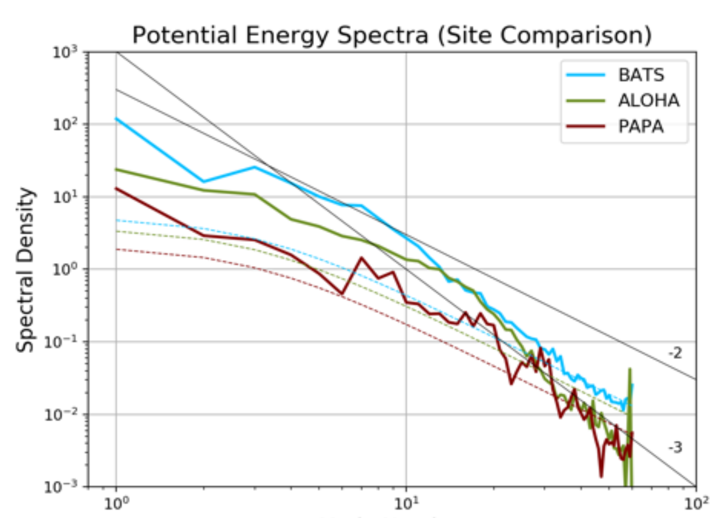
5. Geographic Variability

Additional Deepglider deployments at 36°N and along 26.5°N in the N. Atlantic allow geographic variabilty to explored.





Wintertime potential and kinetic energy spectra at BATS and 36°N.



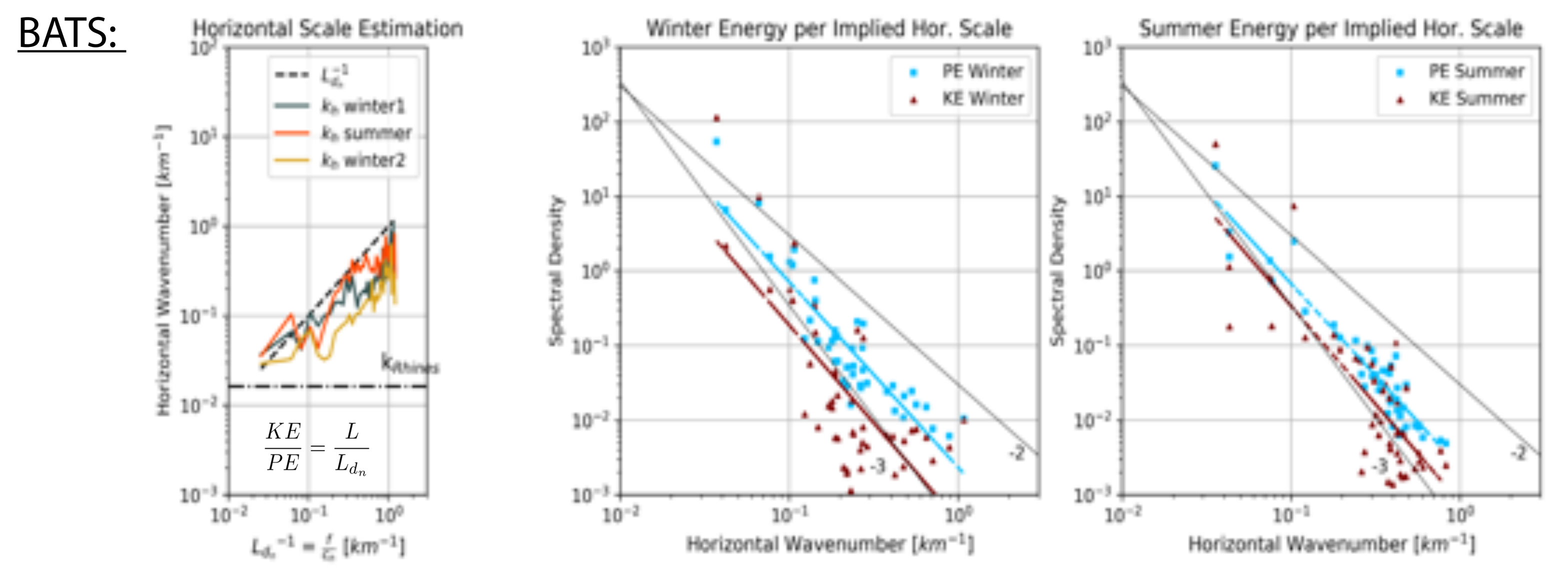
Potential energy at hydrographic stations: BATS, ALOHA, PAPA

Dashed lines are the Garrett-Munk (GM79) internal wave spectrum at each location. Station PAPA is least energetic with a spectrum similar the GM prediction.

6. Conclusions

- There is approximate equipartition between KE and PE in the first baroclinic mode at all locations. PE dominates at higher modes.
- The partition of energy across mode number varies by geographic location.
- Stratification distorts mode shapes and alters the transfer of energy across modes.
- Seasonal changes in energy partitioning across modes appear linked to changes in stratification.

BATS:

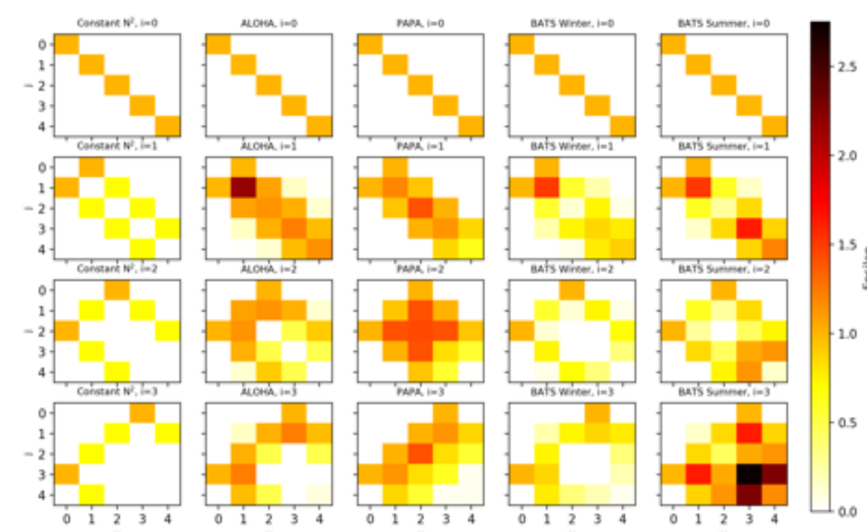


Geography of Mesoscale Energy

- In energetic regions near the Gulf Stream (BATS), energy is elevated above GM predictions. Geostrophic turbulence predictions of the spectral slope (k^{-3}) are consistent with observations.
- In less energetic regions (NE Pacific), the potential energy spectrum is flatter at low modes and less discernable from the GM spectrum.
- As deformation radii change with latitude, the wavenumber range within which geostrophic turbulence is prevalent widens/narrows.

Importance of Stratification

- Stratitfication controls the vertical stretching of mode shapes at modes n > 2. This alters the projection of modes onto displacement and velocity profiles. Enhanced surface stratification shifts maxima and minima in mode amplitudes towards the surface.
- Stratification relatively inhibits or enhances mode interactions and the transfer of energy across scales. This results in preferential collection at certain scales. Triple interaction coefficients show geographic and seasonal mode interaction variability.



$$\epsilon_{mij} = \int_{-H}^{0} G'_m G'_i G'_j dz$$

This term describes the strength of non-linear mode triplet interactions and the tendency for energy to remain at a given mode .

Seasonality

- In the presence of increased surface stratification, self-interactions between higher modes (n > 2) are enhanced. This results in relatively more energy at these scales and a flatter spectrum.
- In the absence of increased surface stratification, energy collects in the first baroclinic where it can barotropize.

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