Frequency-Domain Analysis of Energy Transfer in an Idealized, Eddy-Resolving Ocean-Atmosphere Model

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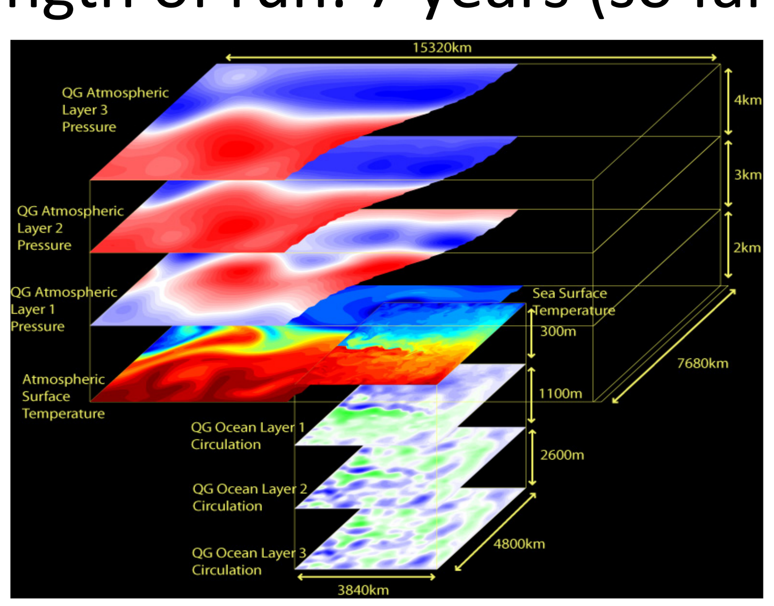
Motivation

- What are the key processes responsible for driving ocean and atmosphere variability?
- What are the sources and sinks of energy in the ocean and in the atmosphere?
- What are the relative contributions of each of these energetic processes across a range of timescales?

Model Setup

The Quasi-Geostrophic Coupled Model

- 3-layer coupled, QG ocean-atmosphere model
- Tuned for the North Atlantic
- Mixed layers in both ocean and atmosphere
- Leap-frog timestepping
- Arakawa C-grid: p and T points
- No seasonality
- Ocean resolution: 5 km
- Atmosphere resolution: 80 km
- Length of run: 7 years (so far)



(Hogg et al., 2006)

Frequency-domain diagnostic: energy transfer equations

Advection of Kinetic Energy

$$T_{KE,k}(x,y,\omega) = \frac{H_k}{f_0^3 H_{tot}} Re[\widehat{p}_k^* \widehat{J}(\nabla^2 p_k, p_k)]$$

Advection of Potential Energy

$$T_{PE,i}(x,y,\omega) = \frac{1}{f_0 g_i' H_{tot}} Re[\widehat{(p_{i+1} - p_i)}^* \widehat{J}(p_i, p_{i+1})]$$

→ With layer k=1,2,3 and interface i = 1,2

Windstress

$$T_{windstress}(x,y,\omega) = \frac{1}{H_{tot}} Re[\widehat{p}_1^* \widehat{w_{ek}}]$$

Buoyancy

$$T_{buoyancy}(x,y,\omega) = \frac{1}{H_{tot}} Re[\widehat{(p_2 - p_1)}^* \widehat{e}]$$

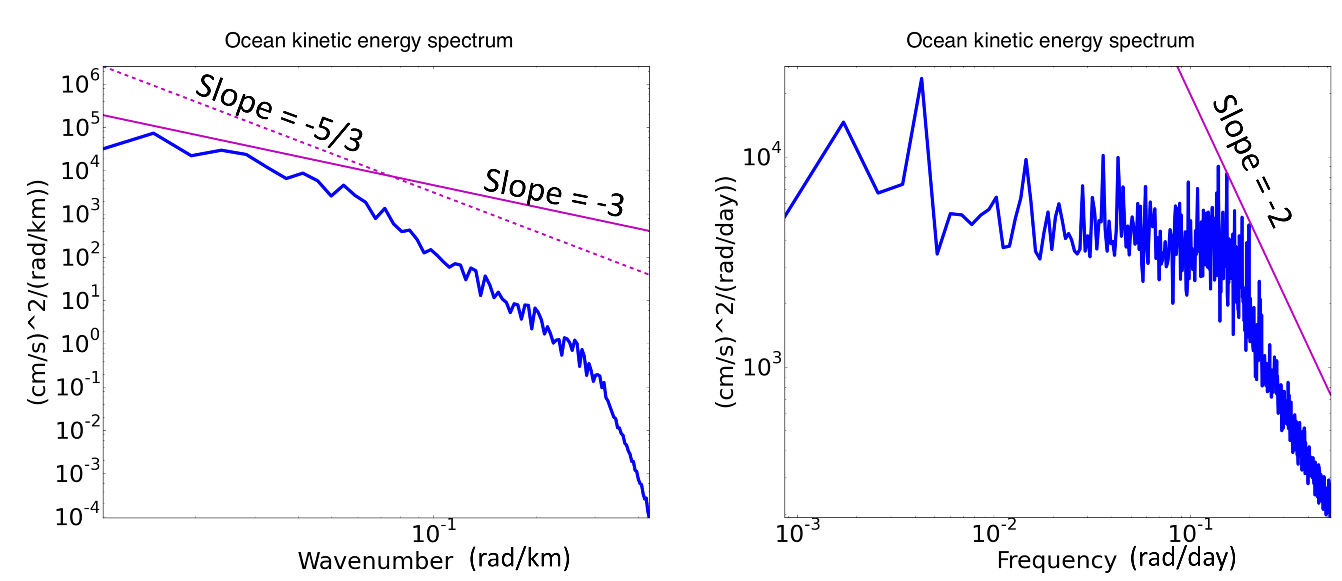
Bottom Drag

$$T_{bottomdrag}(x,y,\omega) = \frac{\delta_{ek}}{2 H_{tot} f_0} Re[\widehat{p}_3^* \widehat{\nabla^2 p_3}]$$

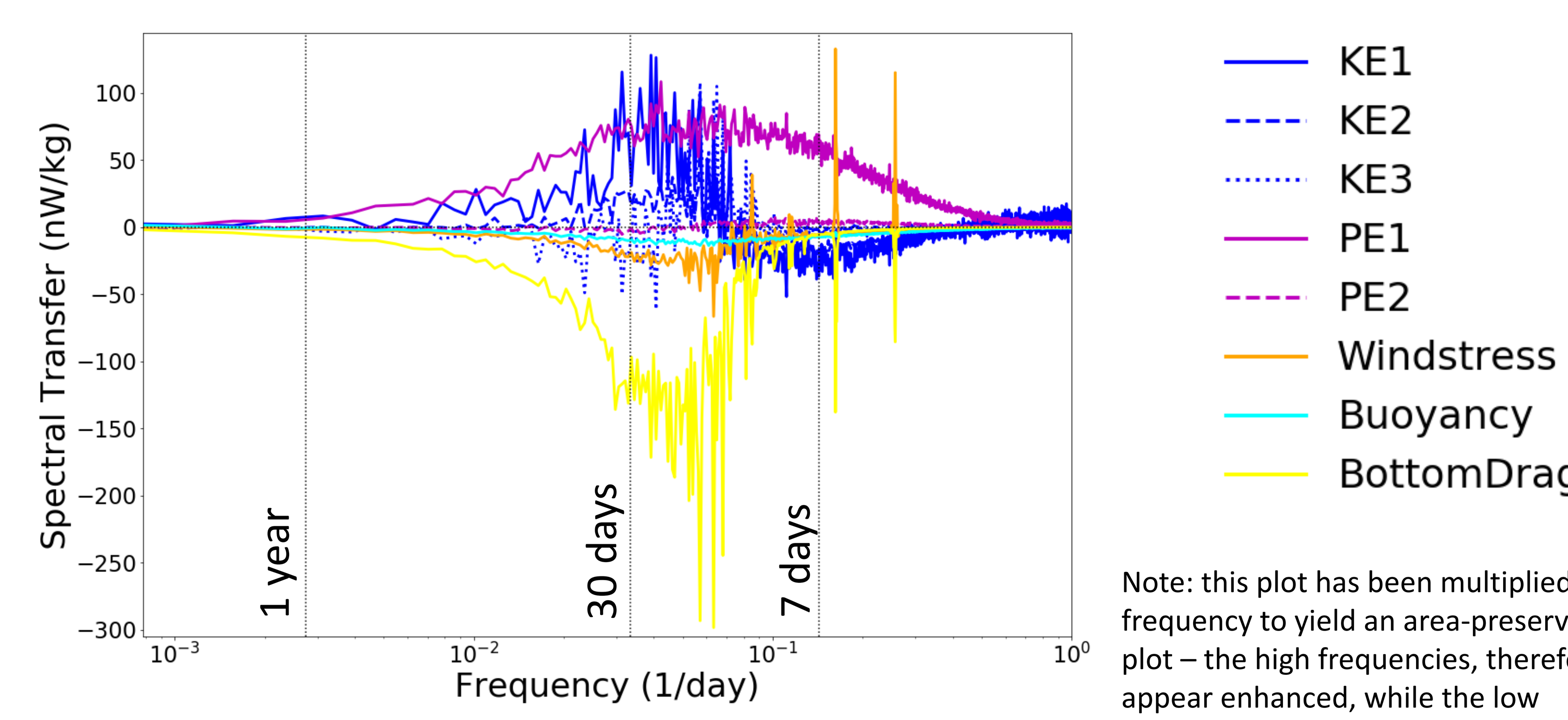
→ Spectral transfers reveal the relative contributions of each term to the overall energy budget. Positive (negative) values indicate that energy is being added to (extracted from) the system.

Results so far

Energy spectra in wavenumber (left) and frequency space (right)
→ 2-d turbulent regime



Ocean: Spectral Energy Transfers (7 years)



Note: this plot has been multiplied by the frequency to yield an area-preserving plot – the high frequencies, therefore, appear enhanced, while the low frequency behavior appears reduced

Preliminary Observations

- KE removes energy at high frequencies and adds energy at low frequencies.
- Wind stress appears to remove energy in the ocean - consistent with other findings (O'Rourke et al., 2017 and von Storch et al., 2007): the mean wind adds energy to the system at all frequencies, whereas the perturbation wind component removes energy at most frequencies. Since we take a Fourier Transform in the analysis, the mean components have been removed, and we are left with the behavior of the anomalous wind field only.
- The two large spikes in both the windstress and bottom drag terms correspond to the time it takes a wave to cross the atmospheric domain of the model.

Future work

- Plot spectral energy transfers for 100+ years to look at low-frequency behavior
- Perform spectral energy analysis on partially coupled, and ocean-only/atmosphere-only QGCM runs
- Do full frequency-wavenumber energy transfer analysis with higher atmosphere resolution → look at effect of ocean eddies on atmosphere
- Perform frequency-domain analysis on temperature budgets in the ocean and atmosphere mixed layers

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References: Arbic et al., J. Phys. Oceanogr., 2014
O'Rourke et al., J. Climate, 2017
von Storch et al., J. Phys. Oceanogr., 2007
Hogg et al., J. Climate, 2006

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