Impact of bottom friction on multi-layer quasigeostrophic turbulence with surface boundary effects (2987)

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Introduction

The quasigeostrophic (QG) equations arise as a simplification of the three-dimensional equations of oceanic motion in the small Rossby number limit for scales on the order of the deformation radius. These assumptions remove gravity waves and sound waves from the system, and thus allow a description of large-scale oceanic motion. In two-layer QG turbulence without surface dynamics or bottom friction, the system undergoes a “cascade” of energy to larger scales. The inclusion of bottom (Ekman) friction arrests this cascade. This indicates that friction is an important parameter in the formation of oceanic eddies and their characteristics [1,2].

Research Objectives

Study the effects of bottom (Ekman) friction in forced-dissipated multi-layer QG with surface dynamics. In particular:

• Determine the direction(s) of the energy cascade and arresting factors given a localized forcing, e.g., cascade inequality
• Quantify the effect of bottom friction on the cascade

This work is intended to generalize the analysis of Arbic and Flierl (2004) and Arbic, Flierl, and Scott (2007) to a multi-layer system with surface boundary effects.

For this poster we focus on some inequalities relating the forcing scale to the energy centroid and the numerical model setup.

Methodology

In QG without boundary dynamics, the cascade of energy is due to the conservation of energy and enstrophy. Analogously, in the general case, an inequality between forcing scale and energy scales can be obtained using the steady state energy and enstrophy transfers of the QG equation. In particular, our strategy is to:

1. Combine the forcing terms in the transfers by assuming a localized forcing: \( Q = -\kappa F \Psi \)
2. Bound the centroid of the energy, from above, with other conserved quantities: \( \kappa^2 E_k \; dk \geq \kappa^2 E_k \; dk \)

Preliminary Results

In the case without surface effects, if the friction acts only on the bottom layer, then following the methodology outlined above one can obtain the result

\[ \kappa_{n+1}^2 \geq \frac{1}{\kappa_n} \left( 1 - \frac{\kappa_{n+1}^2}{\kappa_n^2} \right) \]

\( \kappa_n \) is the centroid of the kinetic energy of the \( n \)th layer. The inequality shows that for certain values of the kinetic energy, there is a strict cascade in the bottom layer. This inequality is similar to that in Arbic, Flierl, and Scott (2007).

In the case with boundaries, if the friction is \( B = |B|\gamma \) (nearly uniform) for some constant \( \gamma \), then we easily obtain

\[ \kappa_n^2 \geq \kappa_{n+1}^2 \]

\( \gamma \) is a positive constant

\( \kappa_n \) is the centroid of the total energy

Further work is required to obtain an inequality in the general multi-layer QG. As mentioned in [2], we expect the bottom friction to arrest the cascade.

Numerical Setup

• Selected representative locations for mean flow profiles using the MyOcean database averaged over many decades
• MyOcean data was supplemented for depths greater than 500m with HYCOM profiles
• Numerical runs are still ongoing

Key Ideas

• Bottom friction can arrest the cascade of energy
• Numerical simulations will be required to assess bottom friction and mean flow sensitivity

Future Work

• Extend inequality to apply for the centroid of the total energy, kinetic energy, and/or potential energy
• Supplement analytical work with numerical simulations of spectral transfers and eddy statistics while varying bottom friction and damping values

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