Potential vorticity homogenization in an idealized model of the Southern Ocean

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Motivation/questions

What determines the equilibrium slope of buoyancy surfaces in the interior of the Southern Ocean?

How sensitive is the interior buoyancy structure to surface wind stress?

Theory

Buoyancy decomposition:

\[ b = \tilde{b}(z) + b'(x, y, z, t) \]

Quasi-geostrophic potential vorticity gradient:

\[ \partial_y q = \beta + \partial_z (f_0 N^{-2} \partial_y b') \]  (1)

Slope of buoyancy surfaces:

\[ N^{-2} \partial_y b' = M^2 / N^2 = \partial_y b / \partial_z \tilde{b} = -s_b \]

So equation (1) can be written (zonal and depth mean):

\[ \overline{\partial_y q} = \beta - f_0 \overline{\partial_z s_b} = \beta \left( 1 - \frac{\partial_z s_b}{\beta / f_0} \right) = \beta (1 - r) \]

PV homogenization metric:

\[ r(y, t) \equiv \frac{\partial_z s_b}{\beta / f_0} \]

Under homogenous PV (r=1):

\[ \frac{\partial s_b}{\partial z} \bigg|_{f_0} = \frac{2 \Omega a^{-1} \cos(\phi_0)}{2 \Omega \sin(\phi_0)} = a^{-1} \cot(\phi_0) \]

The large-scale slope structure is constrained by planetary-geometric parameters

Results: steady state

Fig. 1. Horizontal stratification versus vertical stratification in an idealized Southern Ocean model. Each point is calculated from a particular longitude/depth across the channel.

The large-scale slope structure is constrained by planetary-geometric parameters

Results: variability

Fig. 3. Mean value of \( r \) (the PV homogenization metric) in the circumpolar channel for the control (black, solid) and strong wind (blue, dashed) cases.

Fig. 4. Hovmöller diagrams (left column) and long-term zonal mean (right column) of \( r \) for both the weak wind (top row) and strong wind (bottom row) cases.

Model setup

The domain has 42 vertical levels and an eddy-permitting wind forcing (middle), and surface temperature profile (right). The domain has 42 vertical levels and an eddy-permitting horizontal resolution (1/6' x 1/6').

Acknowledgements:
The authors are thankful for support from the National Aeronautics and Space Administration (NASA), grant NNX08AL72G, and the National Oceanic and Atmospheric Administration (NOAA), grant NA08OAR4320893. The NASA Advanced Supercomputing division (NAS) provided computing and data storage resources.

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