Effects of eddy representation on vertical structure and energetics

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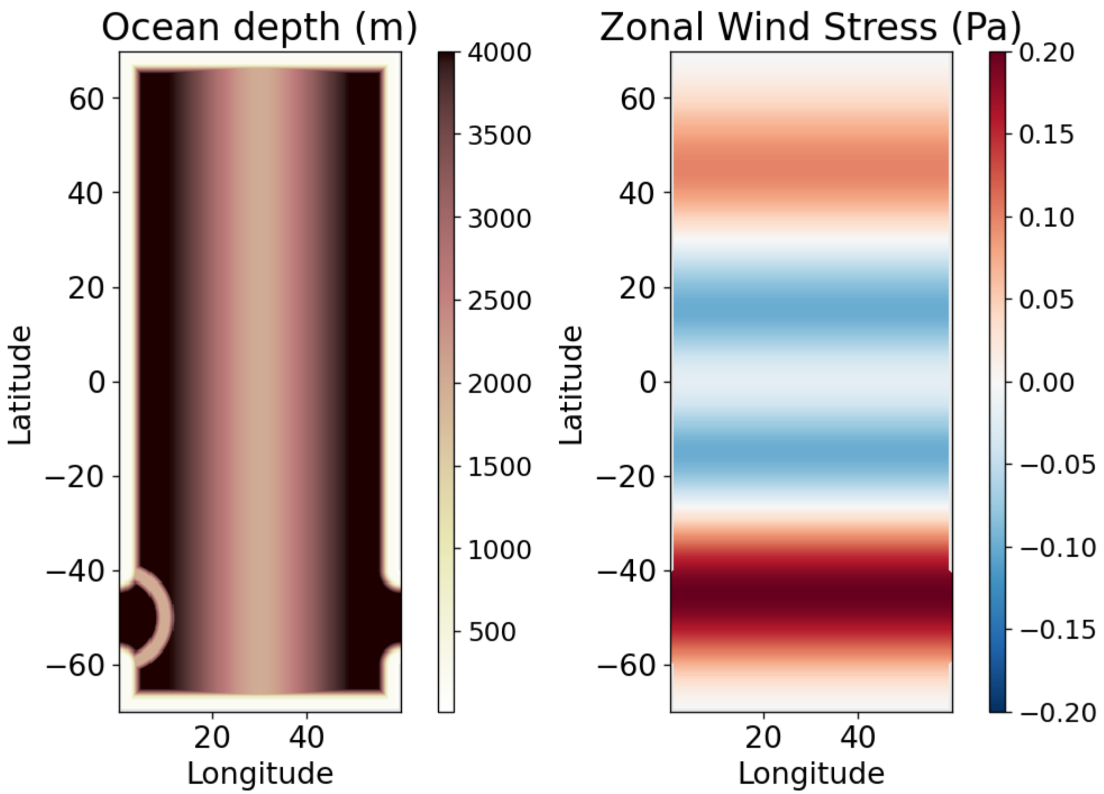
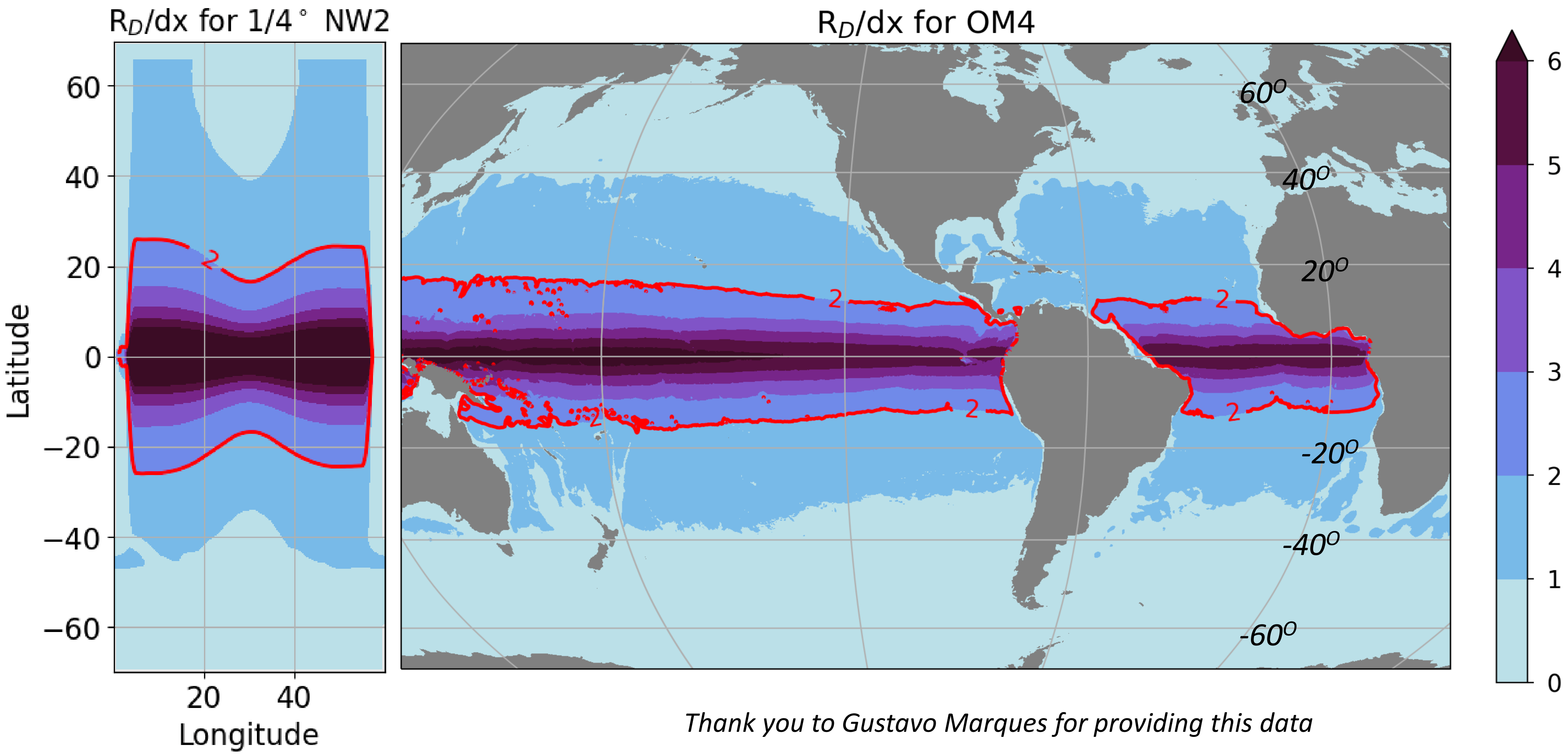


Outline

- Consider an idealized, one-basin setup within MOM6 (NeverWorld2):
  - 1/4°, 1/8°, 1/16°, and 1/32° resolutions
  - Comparing momentum, buoyancy, and energetic properties
- Specific questions we will address:
  - **How do the NW2 experiments compare in resolving eddies?**
  - **How does the zonally-averaged isopycnal structure vary?**
  - **To what extent does eddy resolution affect properties of the kinetic energy?**
    - **Barotropic vs. baroclinic**
    - **Eddy vs. mean**
- Next steps: considering APE and energy budgets

Comparing R_D/dx ratio at 1/4 degree

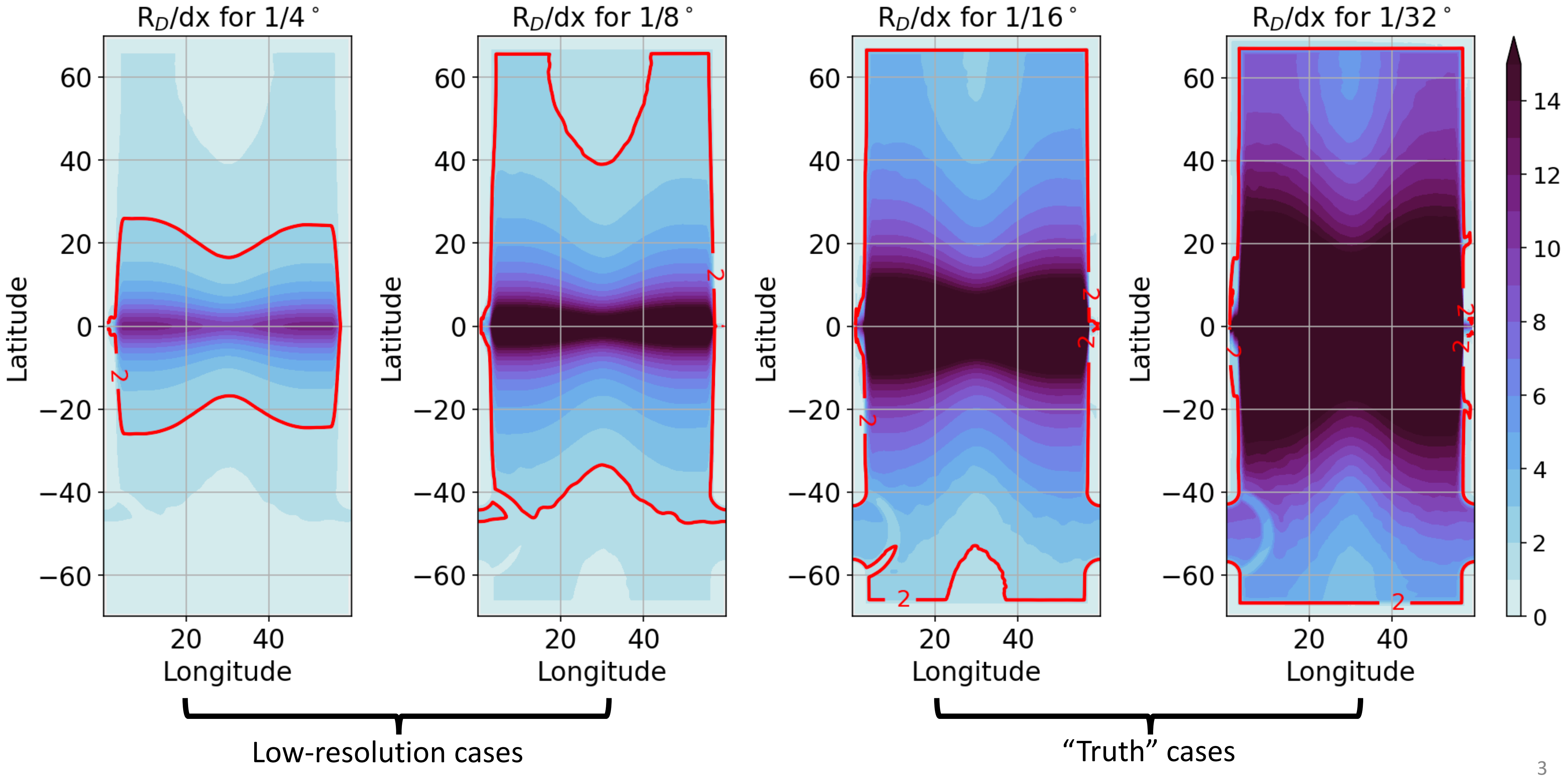
- $R_D/dx = \left(\frac{NH}{\pi f}\right)/dx$
- Higher values→ increased eddy resolution
- We consider $\frac{R_D}{dx} = 2$ as a rough cutoff between eddy resolving/not resolving.
- Idealized NW2 is broadly consistent with more realistic OM4



Thank you to Gustavo Marques for providing this data

This is a conservative estimate – using QG linear stability analysis shows fastest growing modes are 2-4x smaller than R_D

Comparing R_D/dx across NW2 resolutions



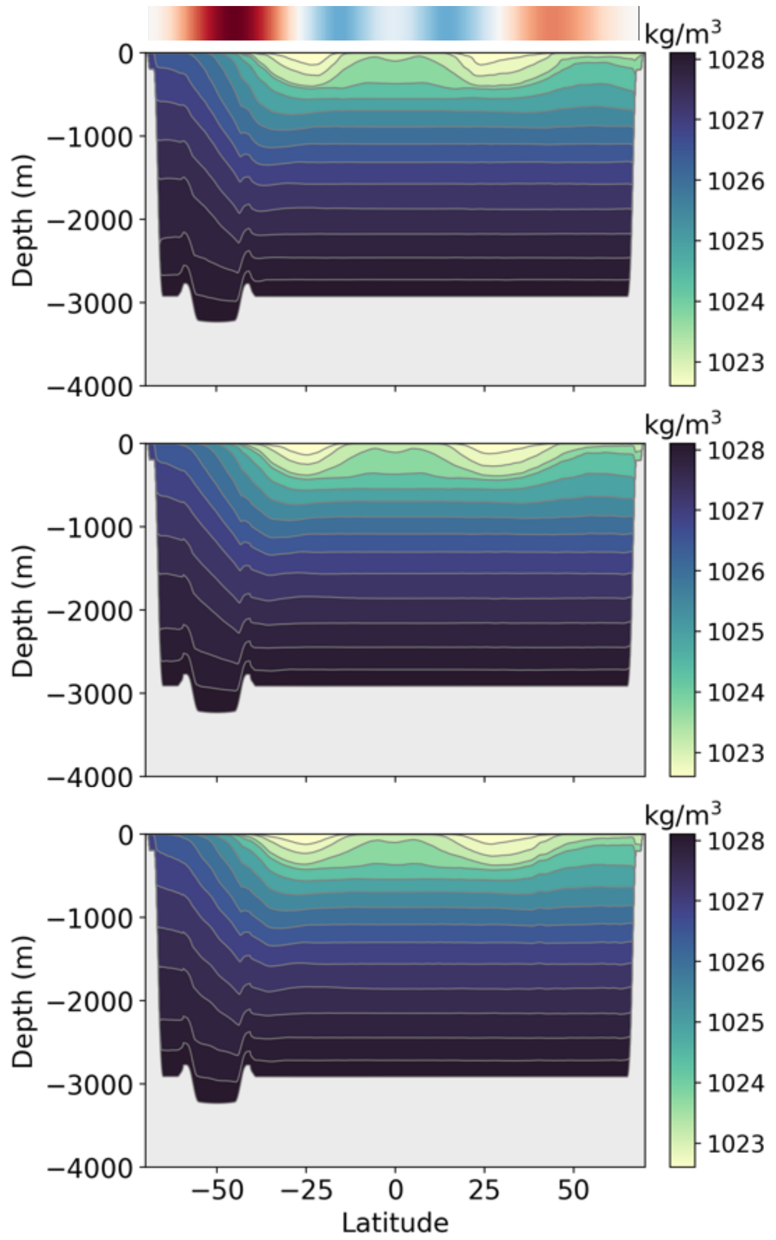
500-day zonal average:

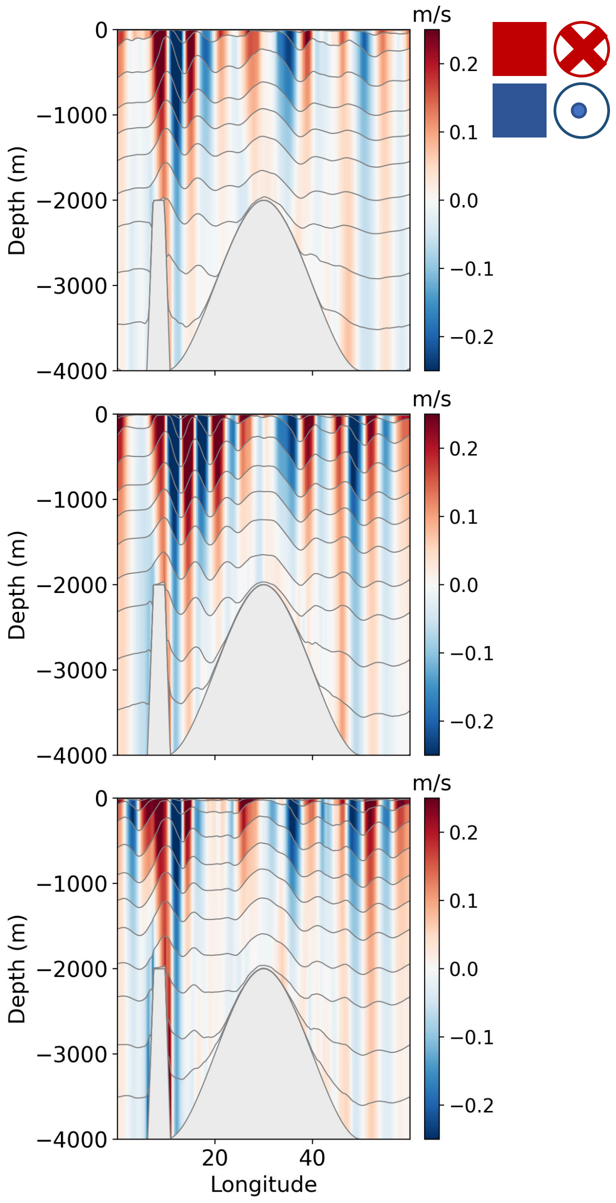
500-day ACC transect, v-velocity:

1/4 Degree

1/8 Degree

1/16 Degree



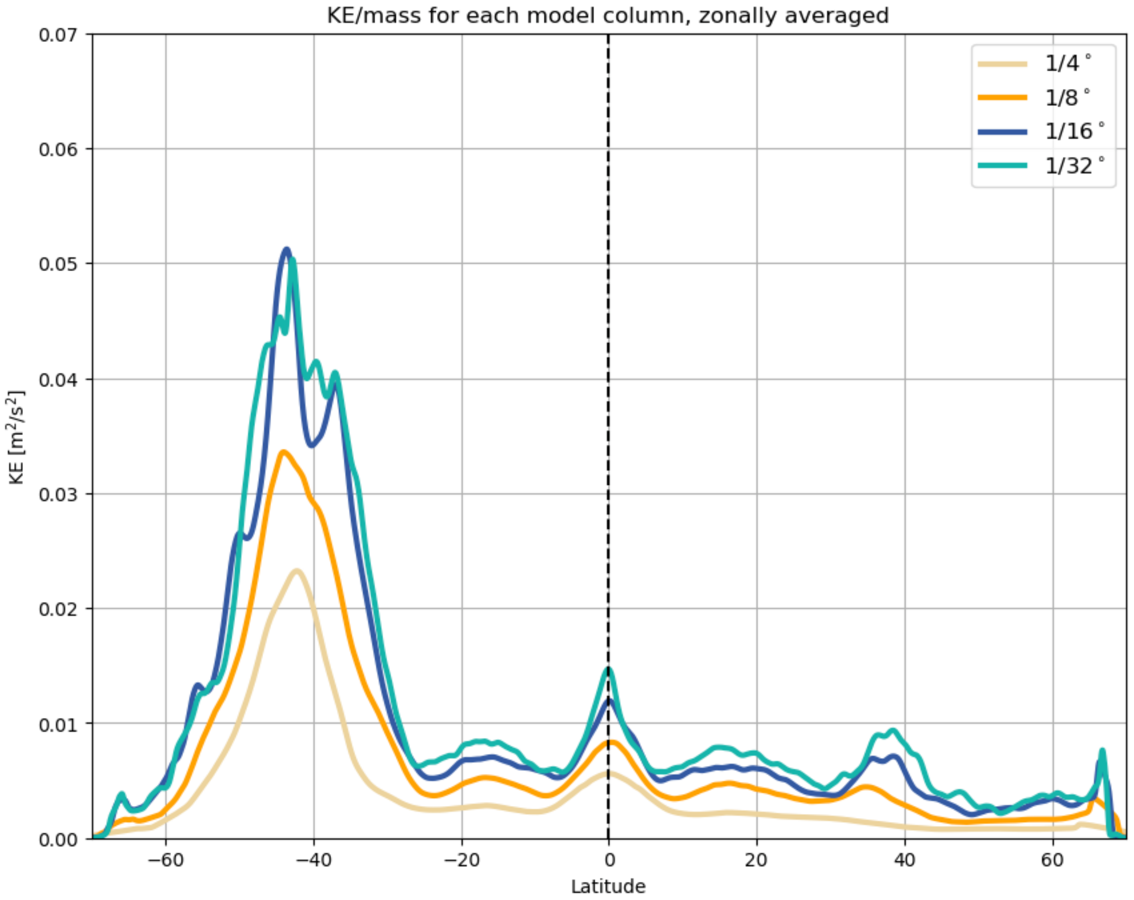


Notable features:

- ACC region has smoother and less steep isopycnals with increasing resolution.
- Midlatitude gyres have shallower downwelling and less steep isopycnals with increasing resolution.
- Prominent standing meanders in ACC at all resolutions.
- Evidence of increased barotropization (stronger velocities at depth) with increasing resolution.

Total KE increases with resolution

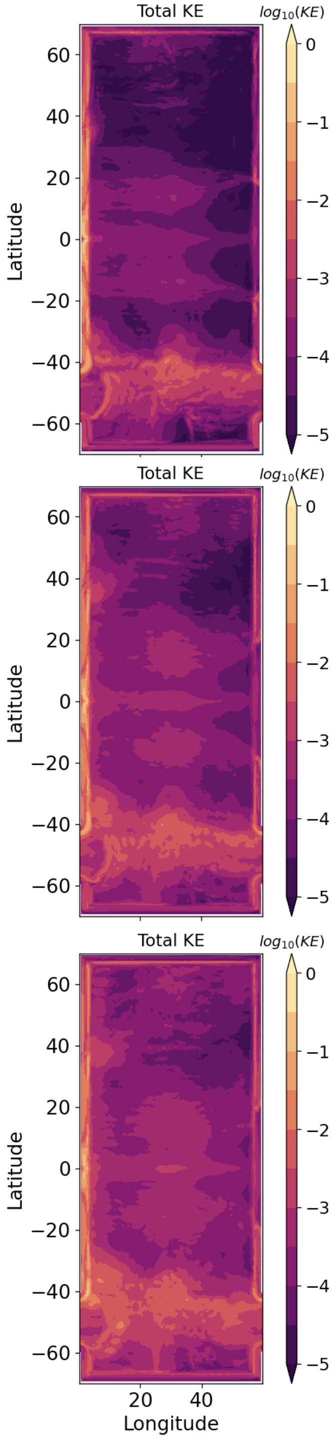
$$KE(i,j) = \left[\sum_{l=1:N} \frac{\rho_l h_l}{2\rho_0 D(i,j)}(u_l^2 + v_l^2)\right]$$



1/4 Degree

1/8 Degree

1/16 Degree

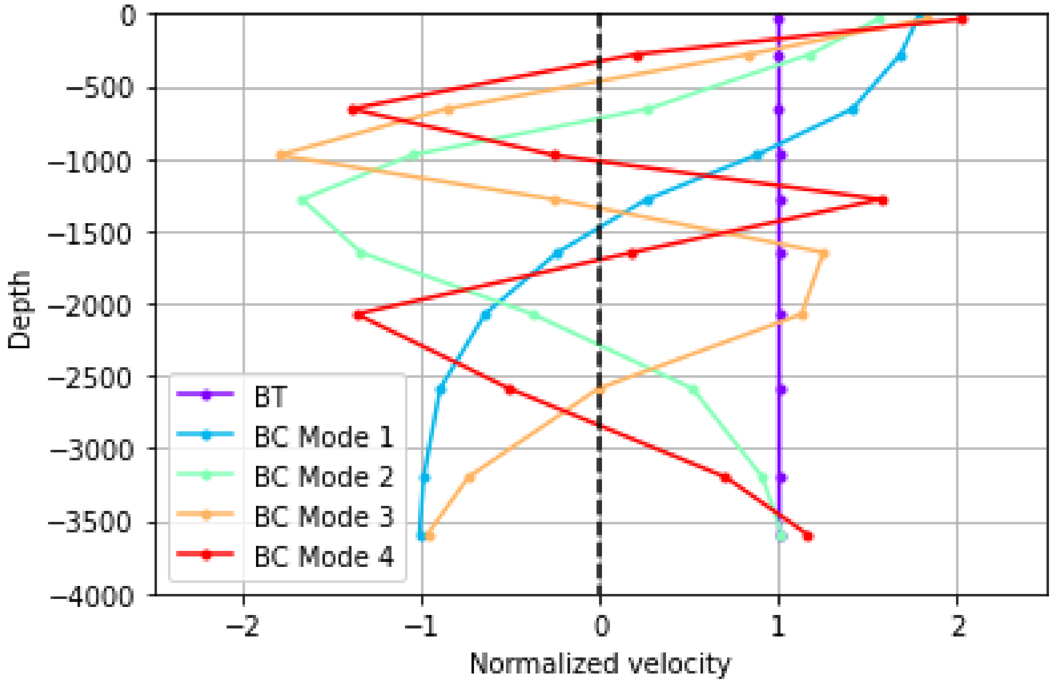


Applying QG modal decomposition to constrain vertical structure

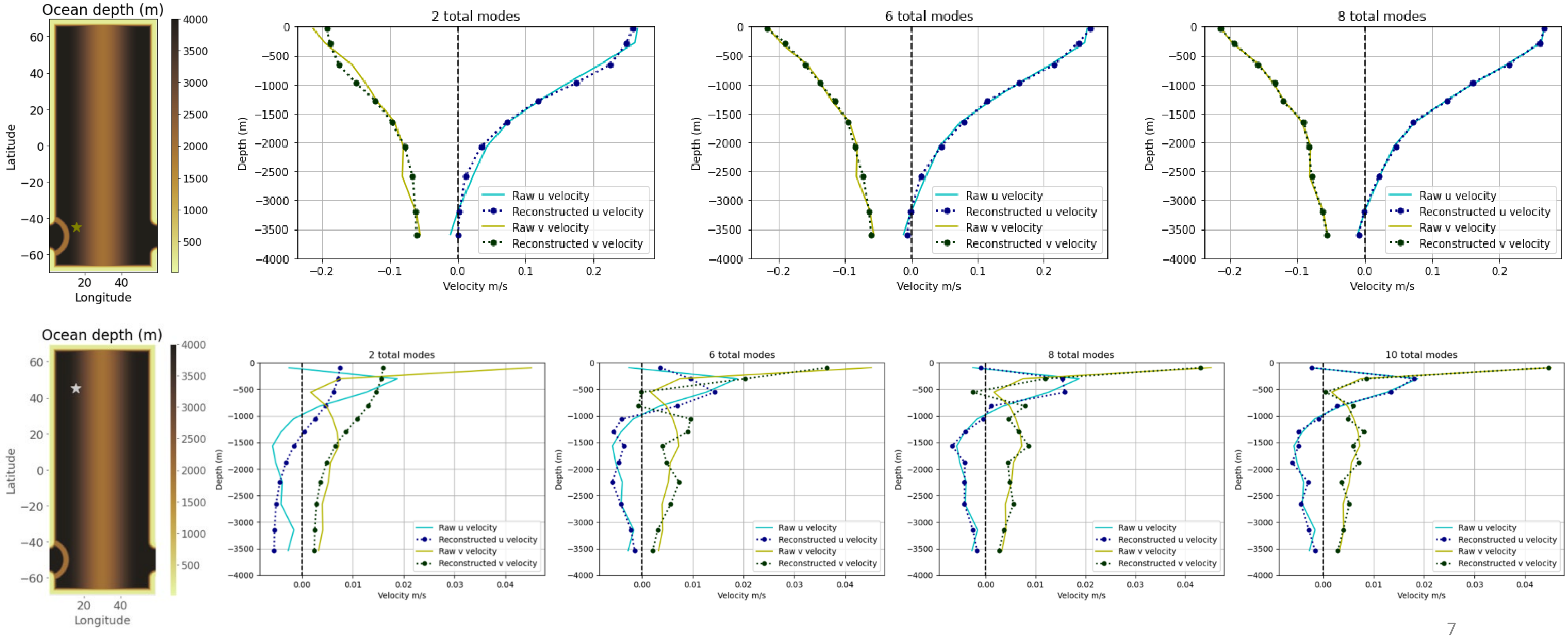
Thank you to Jake Steinberg for sharing code & discussions

Assuming flat bottom (w=0), free surface

Step 1: Solve for QG modes based on N^2, layer positions at each point.



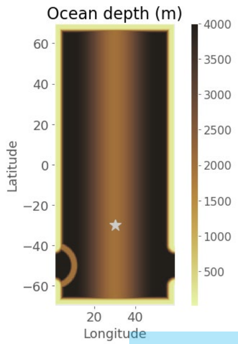
Step 2: Reconstruct the flow as a sum of QG modes of varying amplitudes at a given location.



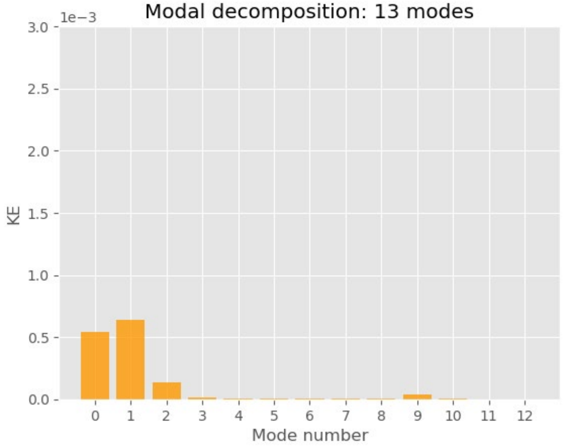
Step 3: Solve for KE corresponding to each mode using velocity amplitudes. Consider time averaged structure or time series. Allows decomposition into BT (0^{th} mode) and BC (1^{st} :Nth modes)

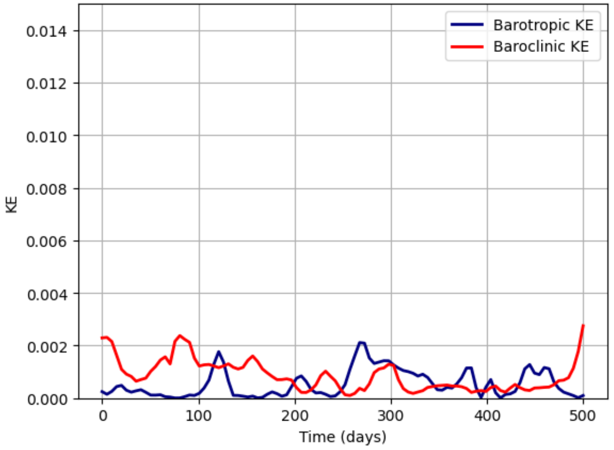
Southern gyre:

- Increase in KE with resolution
- Strong temporal variability
- Strong barotropization between 1/4 and 1/8 degree

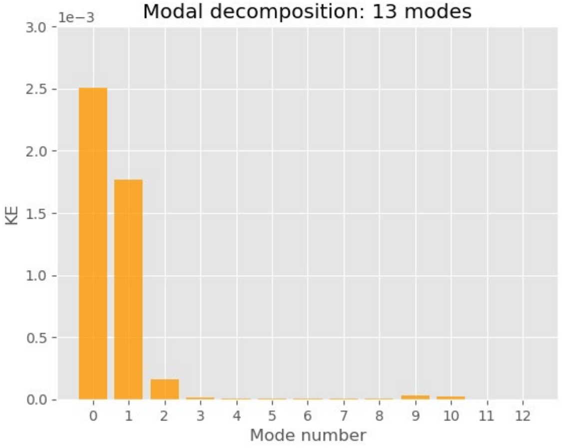


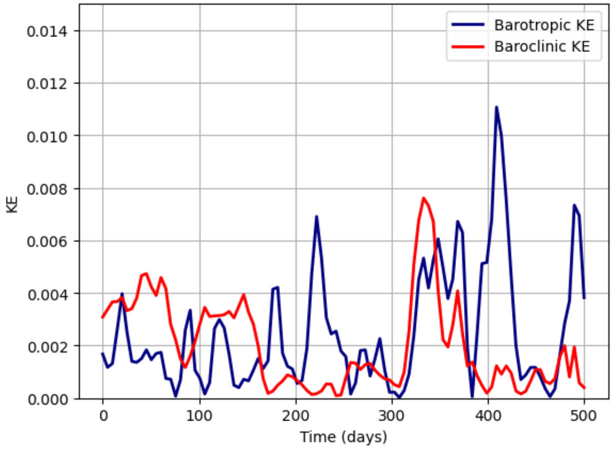
1/4 Degree, $\frac{R_D}{dx} = 1$



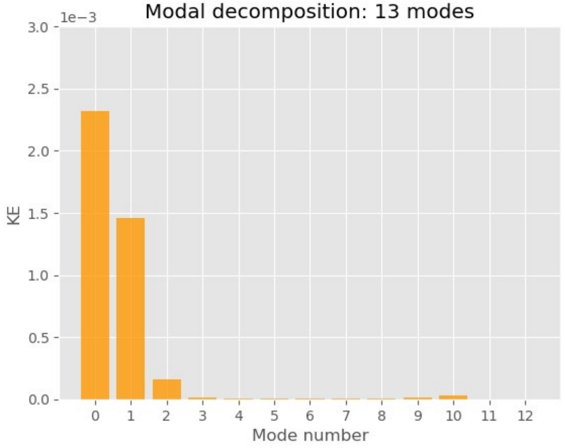


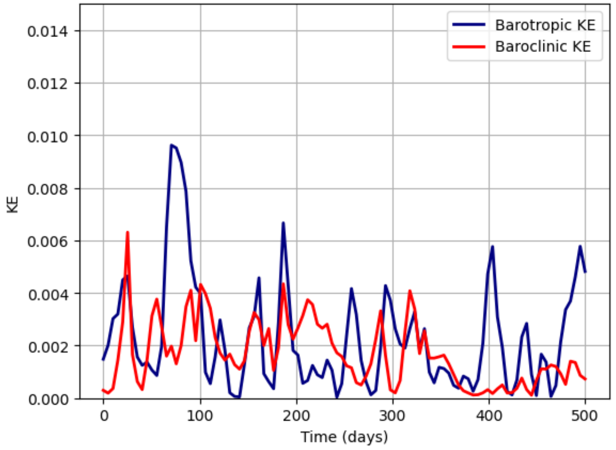
1/8 Degree, $\frac{R_D}{dx} = 2$



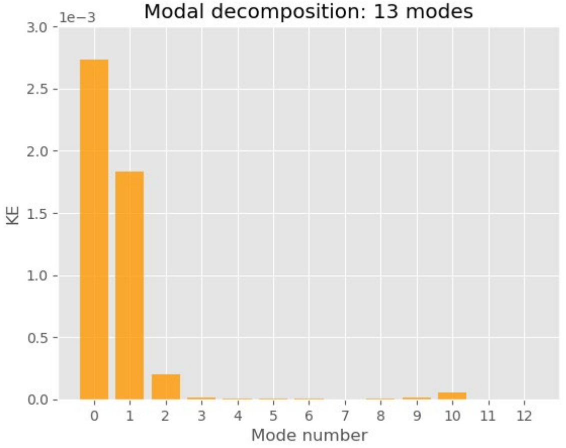


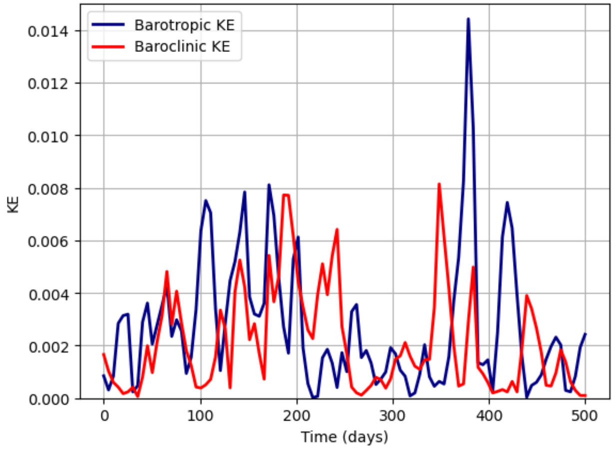
1/16 Degree, $\frac{R_D}{dx} = 4$

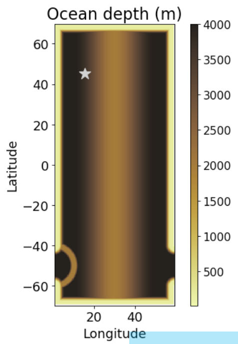




1/32 Degree, $\frac{R_D}{dx} = 10$



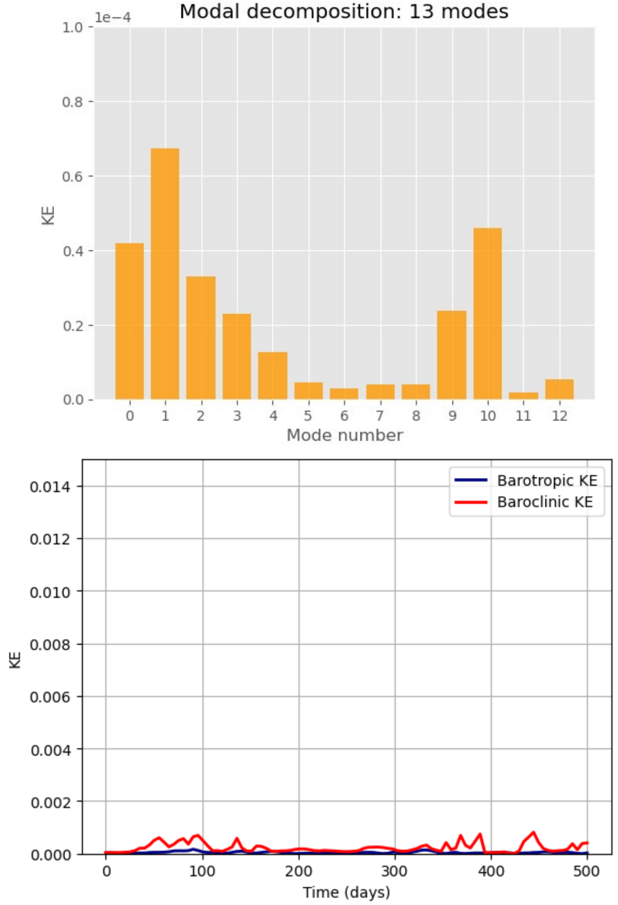




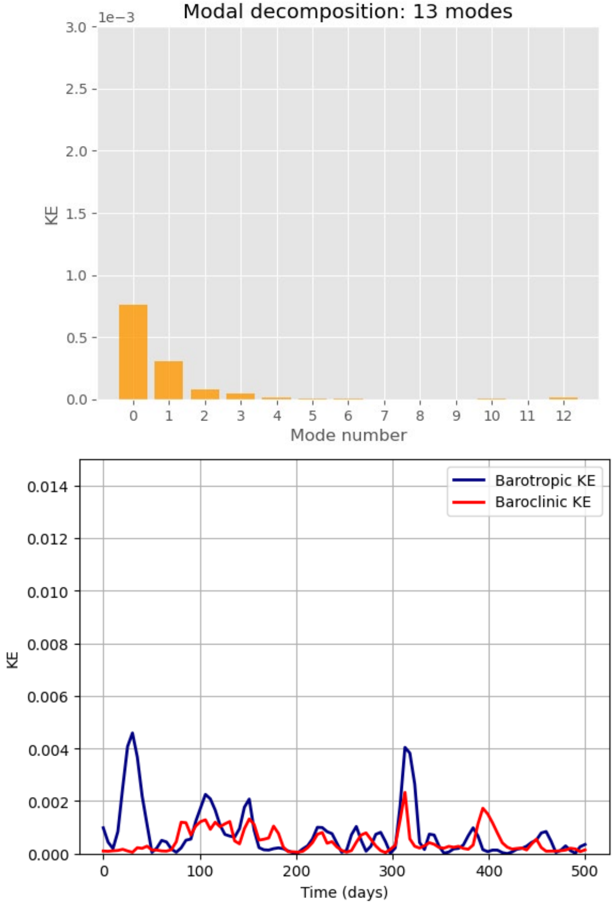
Northwest part of the domain:

- Weak mean flow, strong eddy signature
- Strong evidence of barotropization with resolution
- At low resolutions: energy trapped in higher BC modes

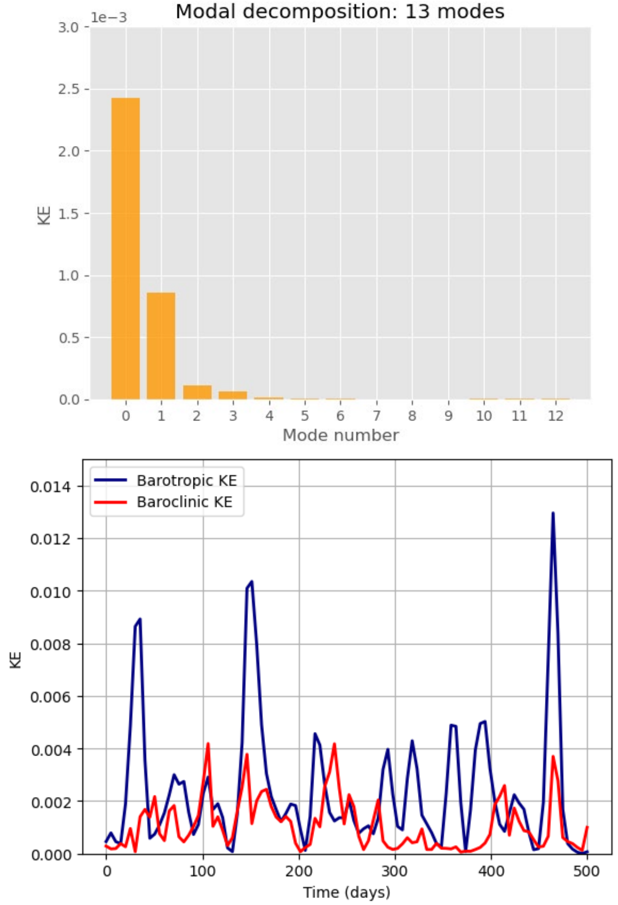
1/4 Degree, $\frac{R_D}{dx} = 1$



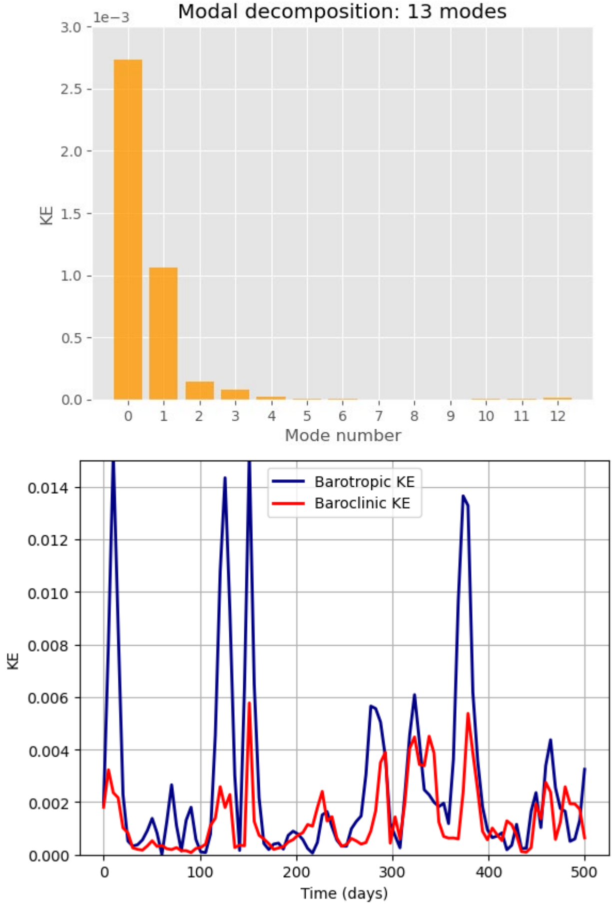
1/8 Degree, $\frac{R_D}{dx} = 2$

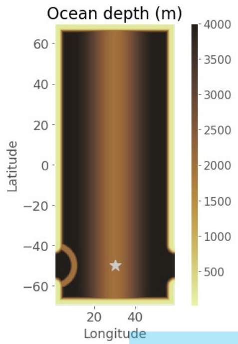


1/16 Degree, $\frac{R_D}{dx} = 4$



1/32 Degree, $\frac{R_D}{dx} = 9$

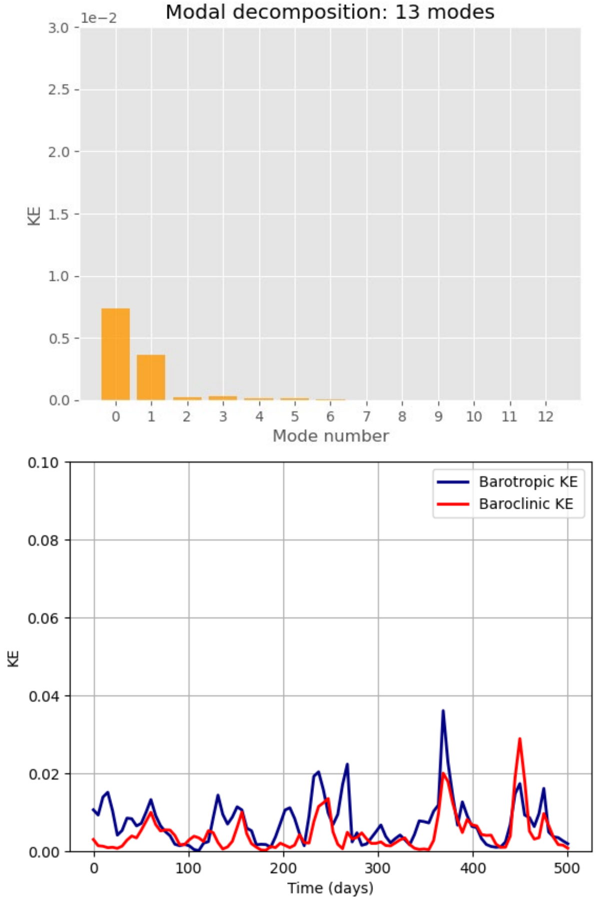


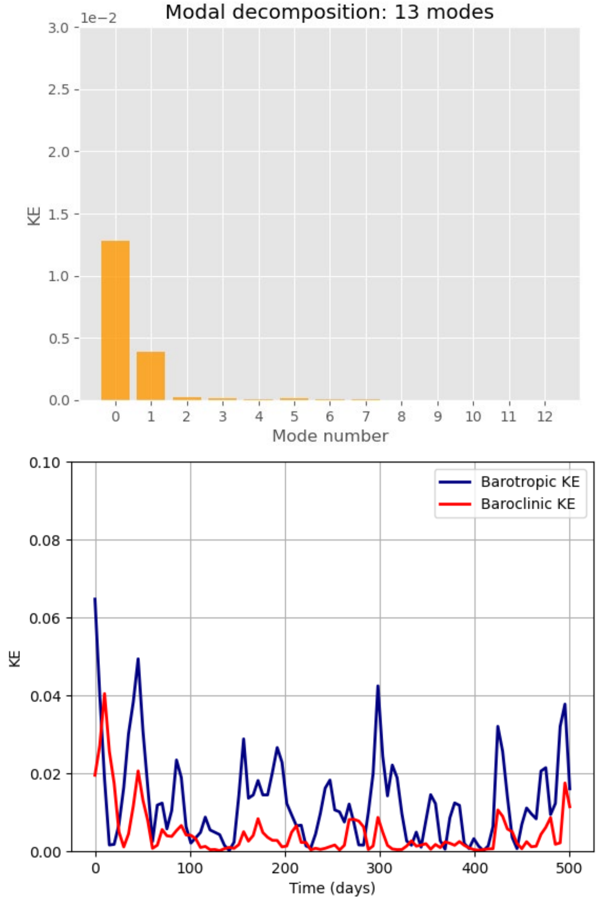


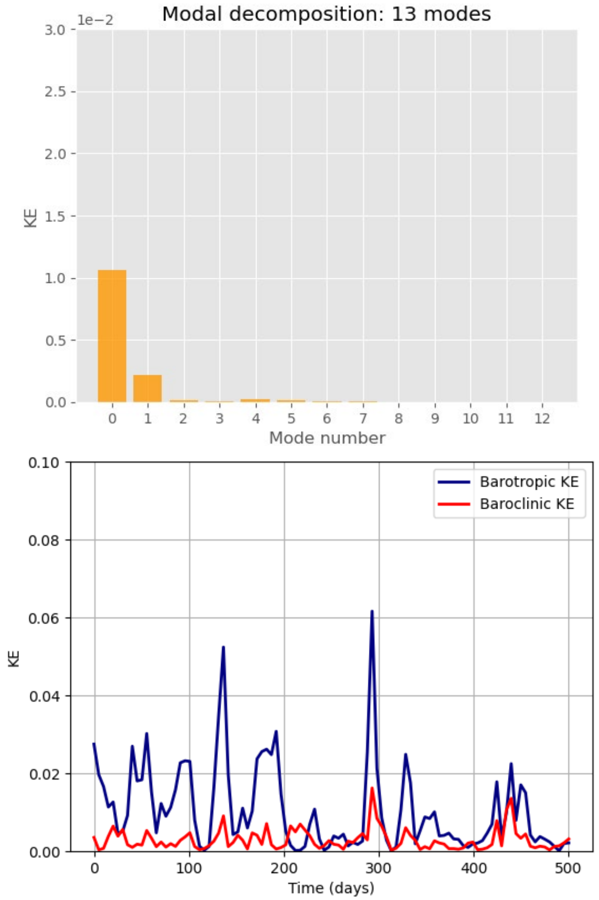
ACC Region:

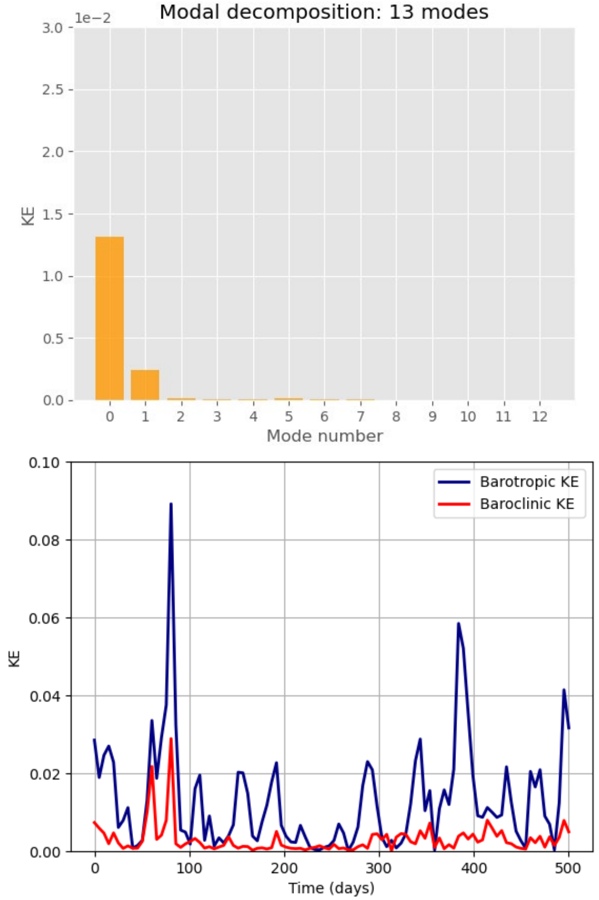
- Strong mean flow
- Modest increase in $\frac{R_D}{dx}$ with resolution
- Barotropization and increase in KE, but less than other regions

1/4 Degree, $\frac{R_D}{dx} < 1$	1/8 Degree, $\frac{R_D}{dx} = 1$	1/16 Degree, $\frac{R_D}{dx} = 2$	1/32 Degree, $\frac{R_D}{dx} = 4$



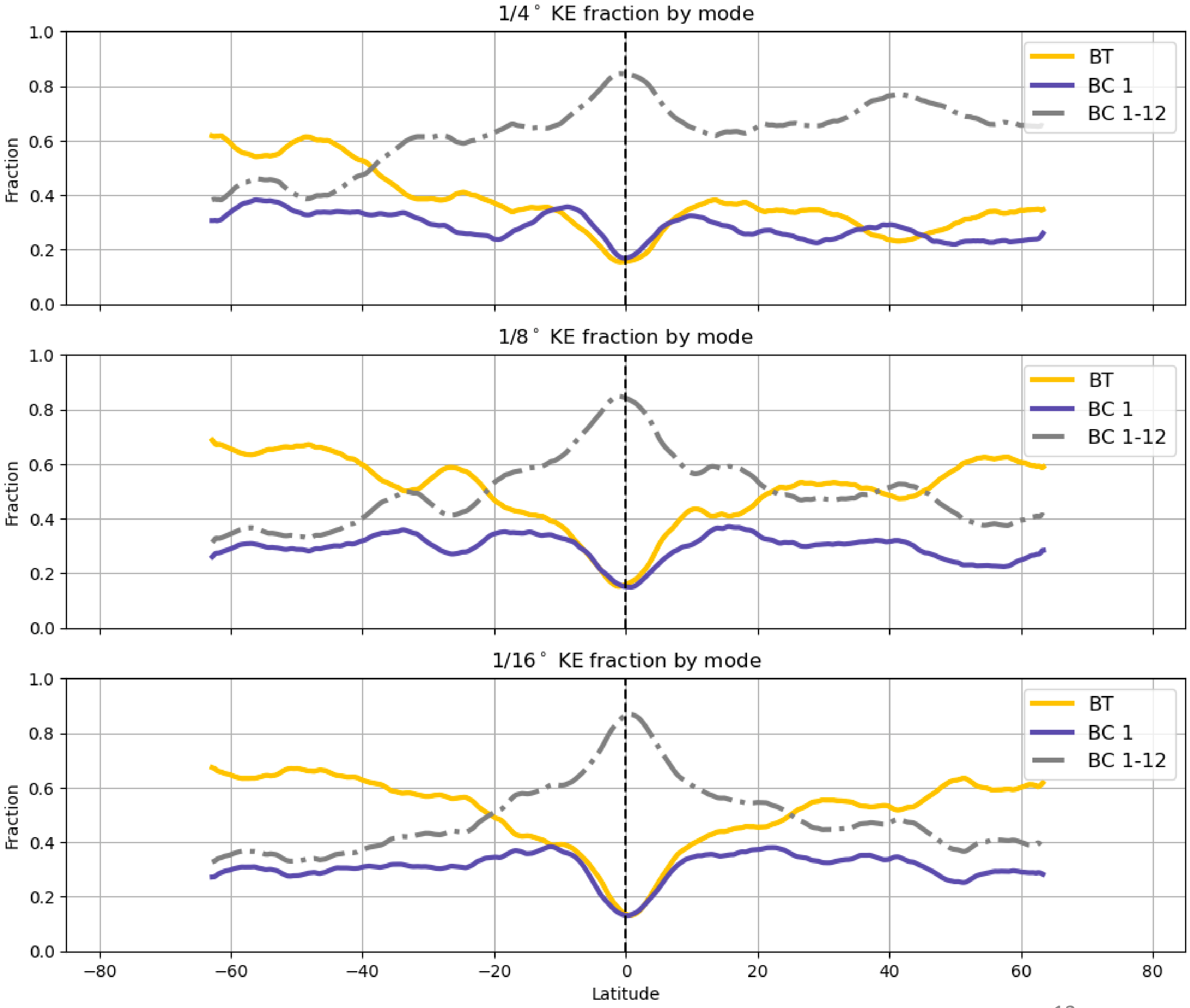




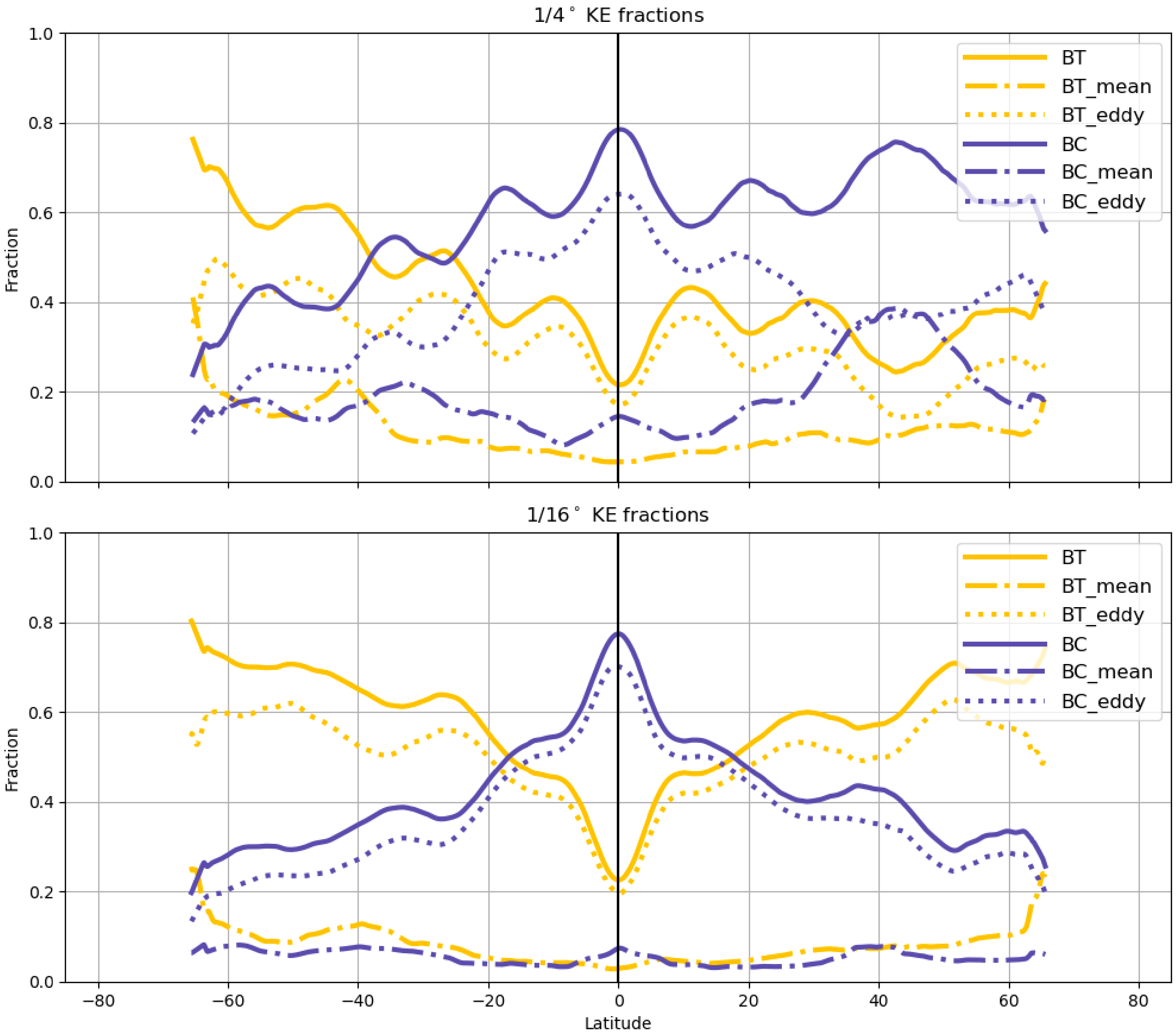


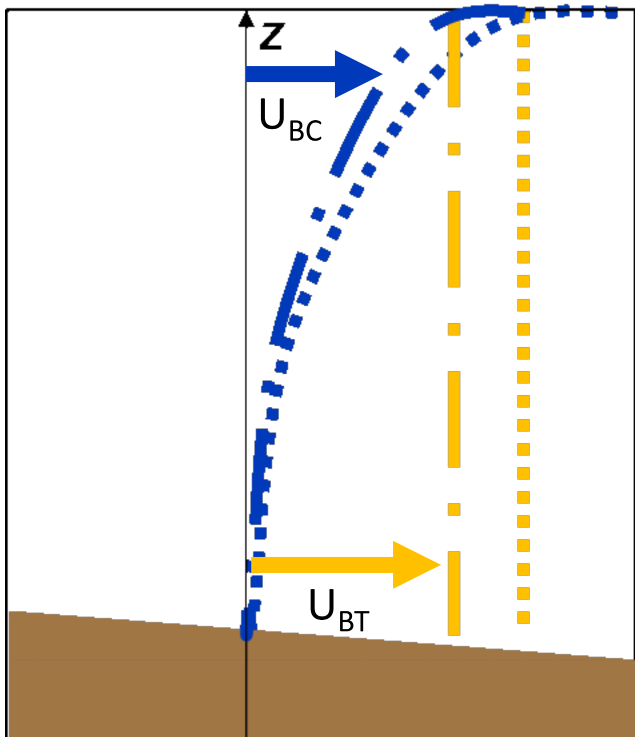
Zonally-averaged BT/BC decomposition

- Evidence of increasing barotropization with increasing model resolution
- As eddies are resolved, more momentum is transferred downwards creating a more uniform flow with depth



Eddy/Mean BT/BC decomposition





As resolution increases:

Flow becomes dominated by the BT eddy component.

Contributions & next objectives

- Dominant trend in vertical structure: as eddy representation increases, increasing KE goes into the BT mode, particularly the BT-eddy component.

- We attribute this to the inaccurate representation of BC energy transfers in the low-resolution models which leads to buildup of BC energy and lack of barotropization.

- Next steps:
  - **Consider APE, budgets to constrain energy transfers**
  - **Apply insights to developing scale-aware, energetically-consistent mesoscale eddy parameterizations**

Thanks for your attention!

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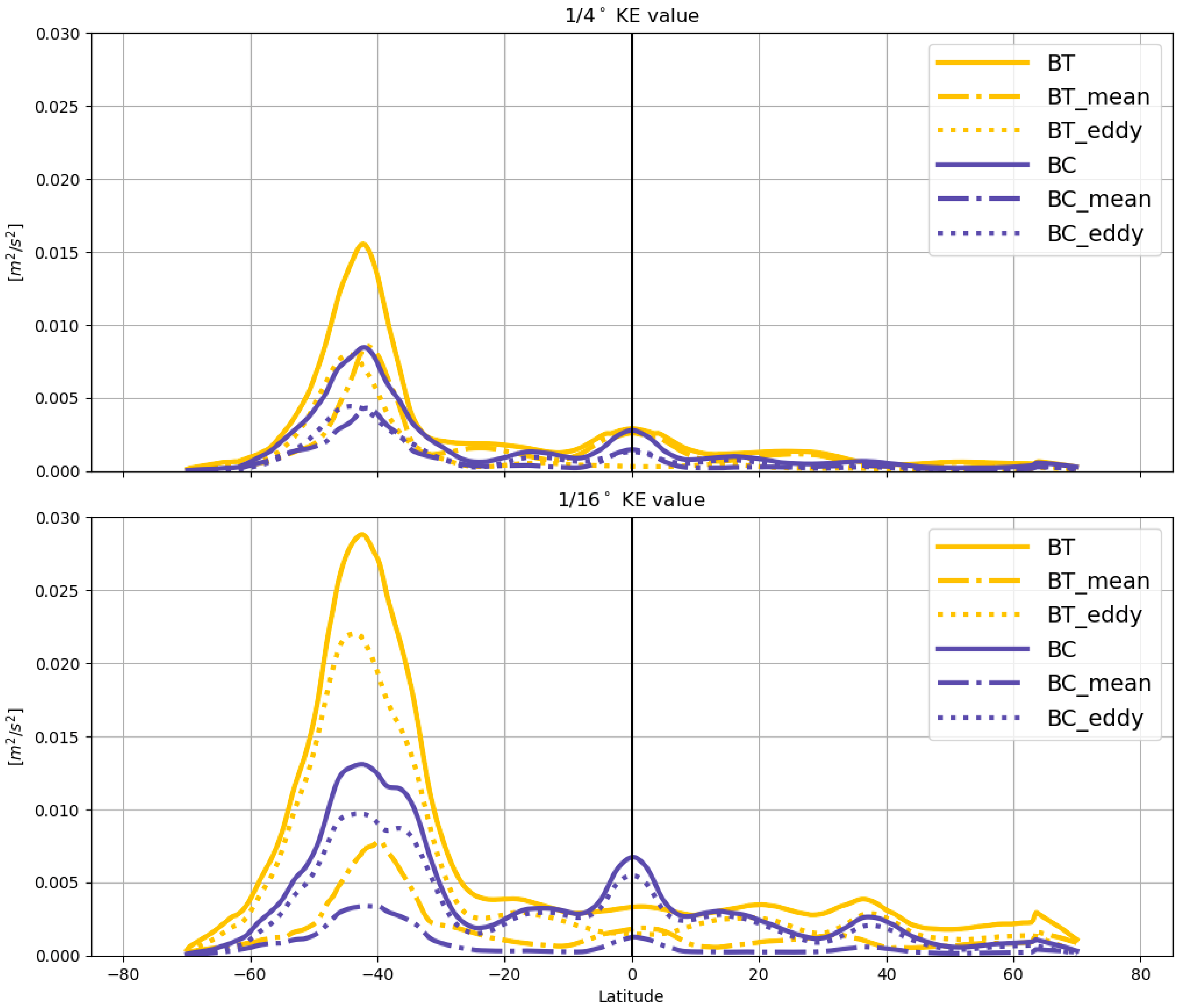
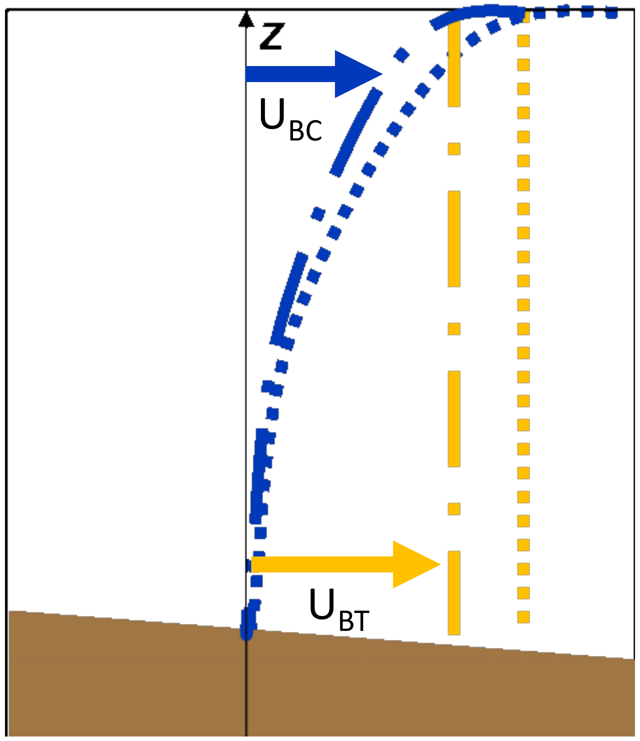
Extra slides

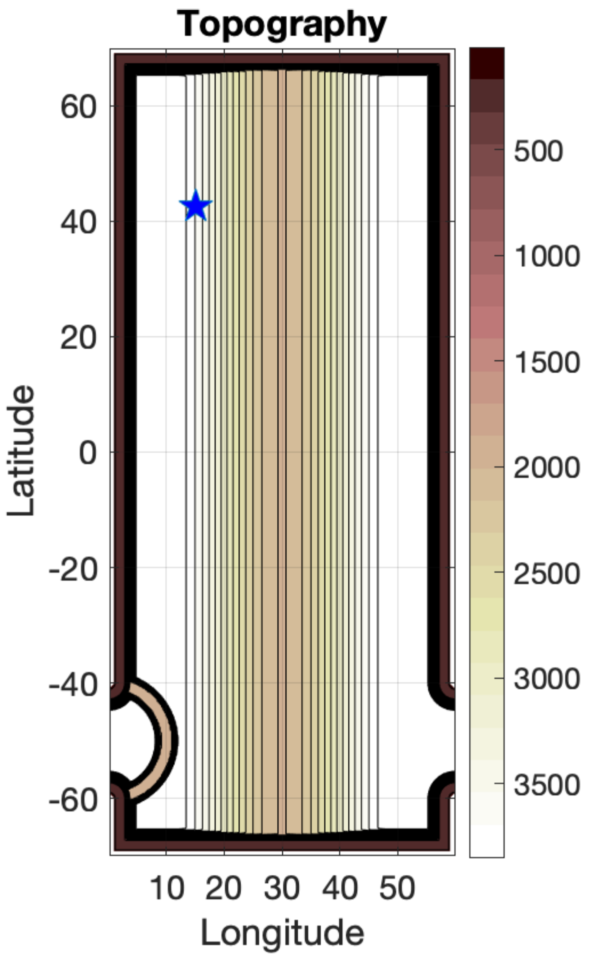
Eddy/Mean BT/BC decomposition

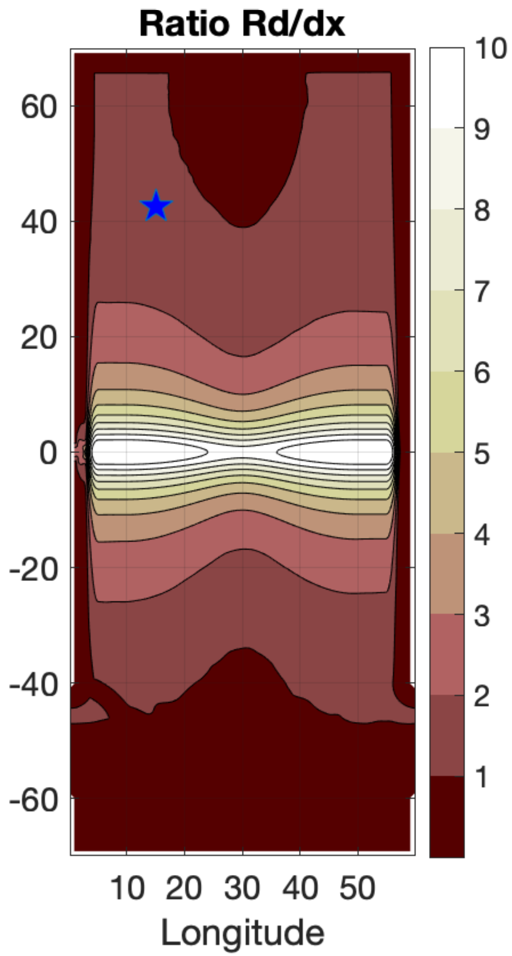


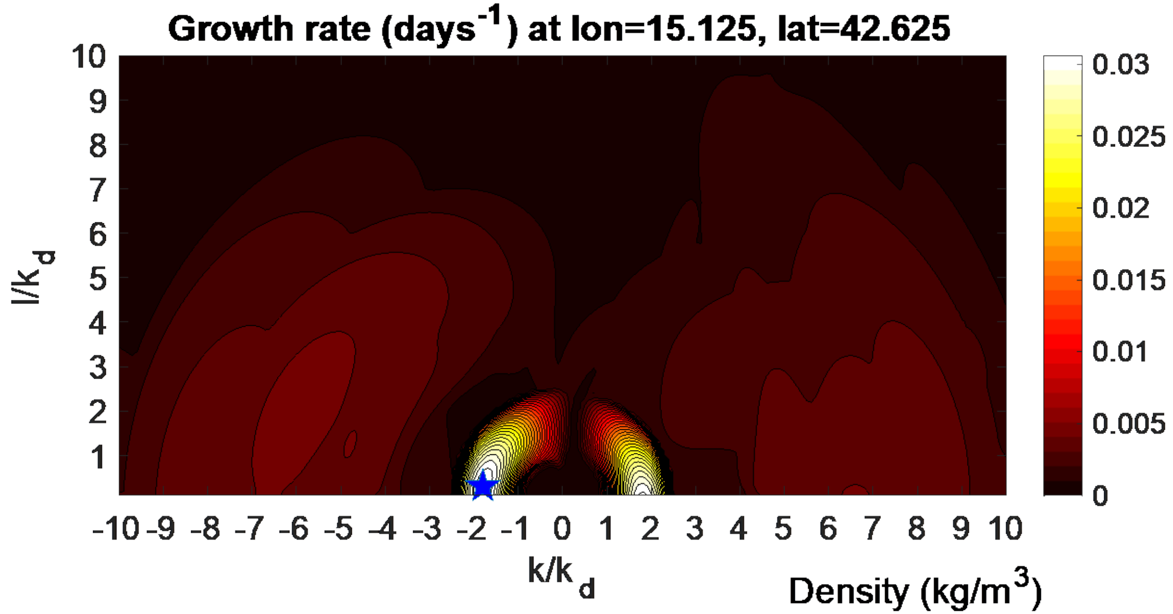


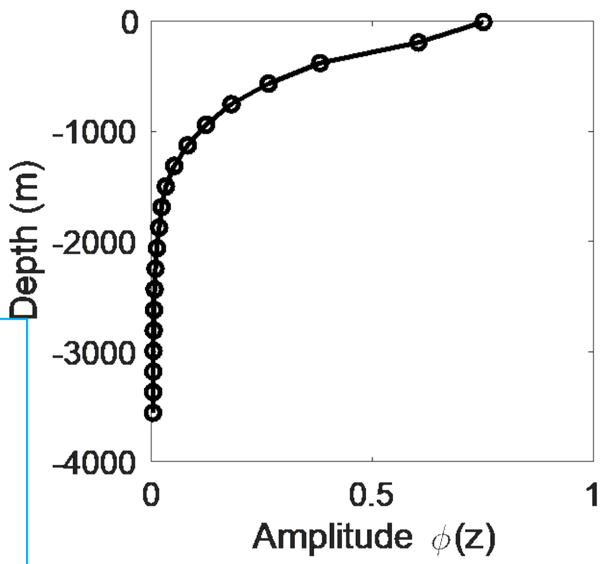
As resolution increases:

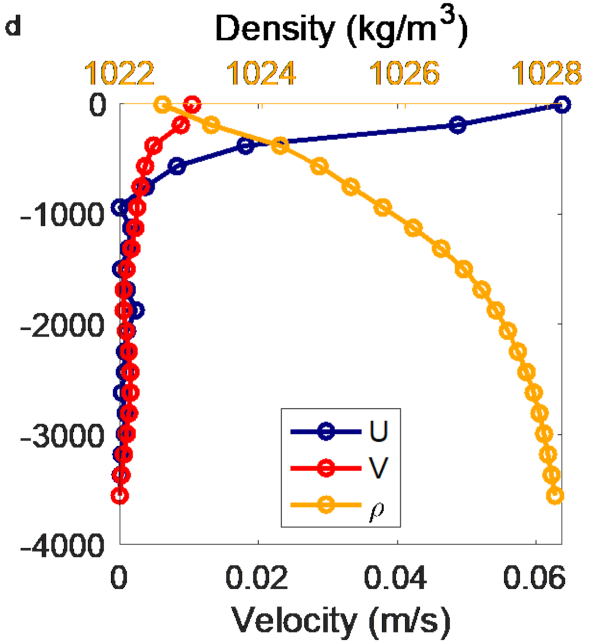
- KE increases
- BT component increases
- Eddy component increases







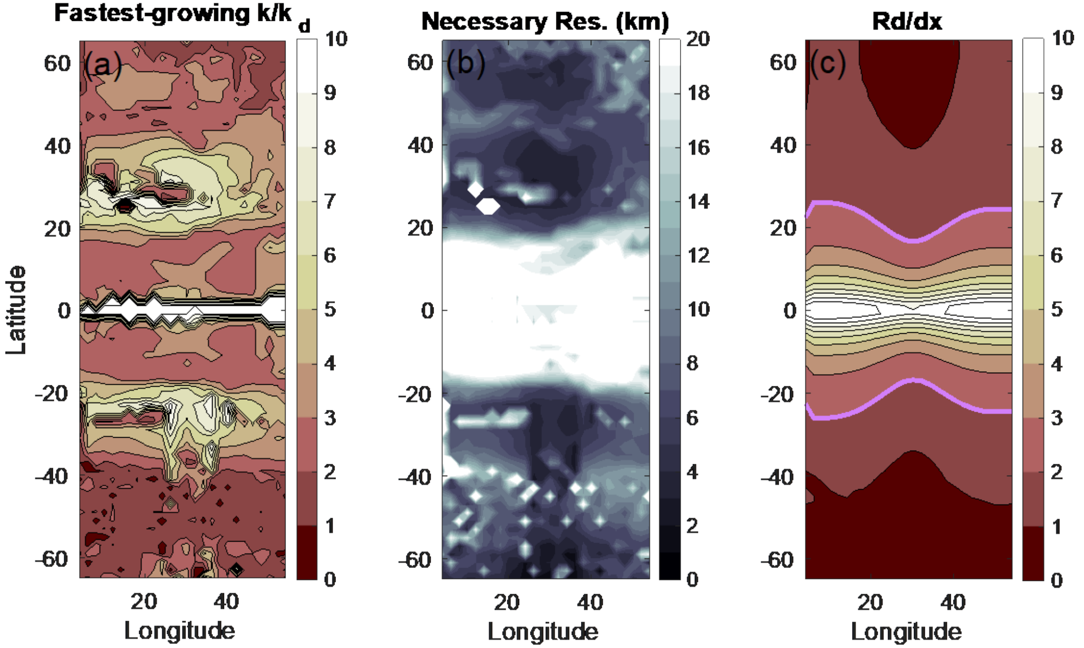




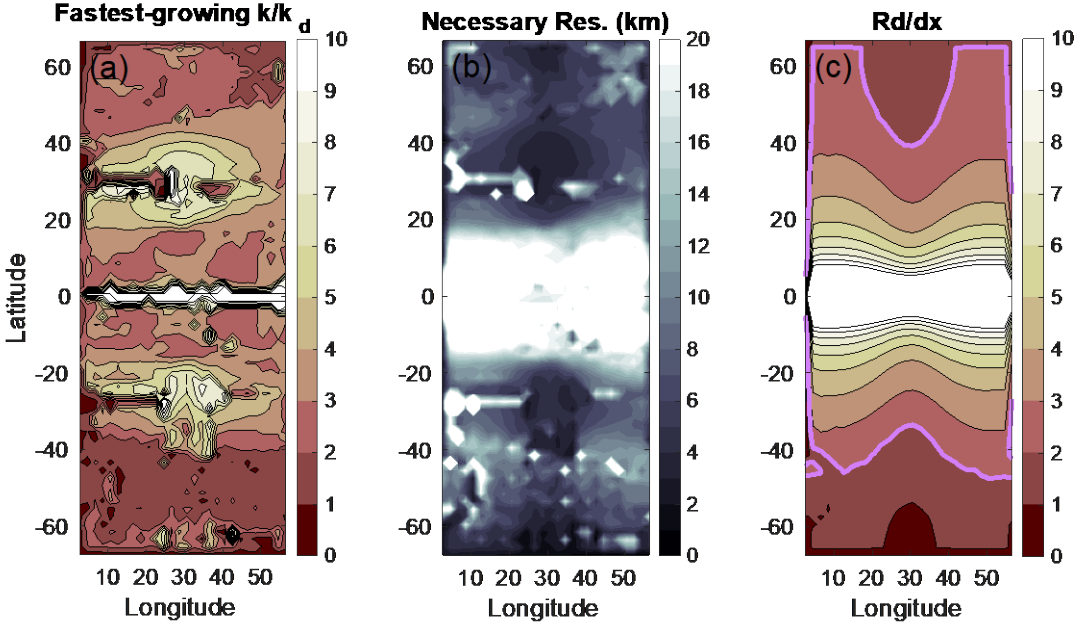
Linear QG instability analysis:

- Average velocity, density profiles over a 2x2° box, interpolate onto 20 linear levels.
- Compute growth rate vs. wavenumber, compare fastest-growing wavenumber to deformation radius Rd wavenumber.
- Fastest growth rates have wavenumbers roughly 2x larger than Rd wavenumber (need finer resolutions).

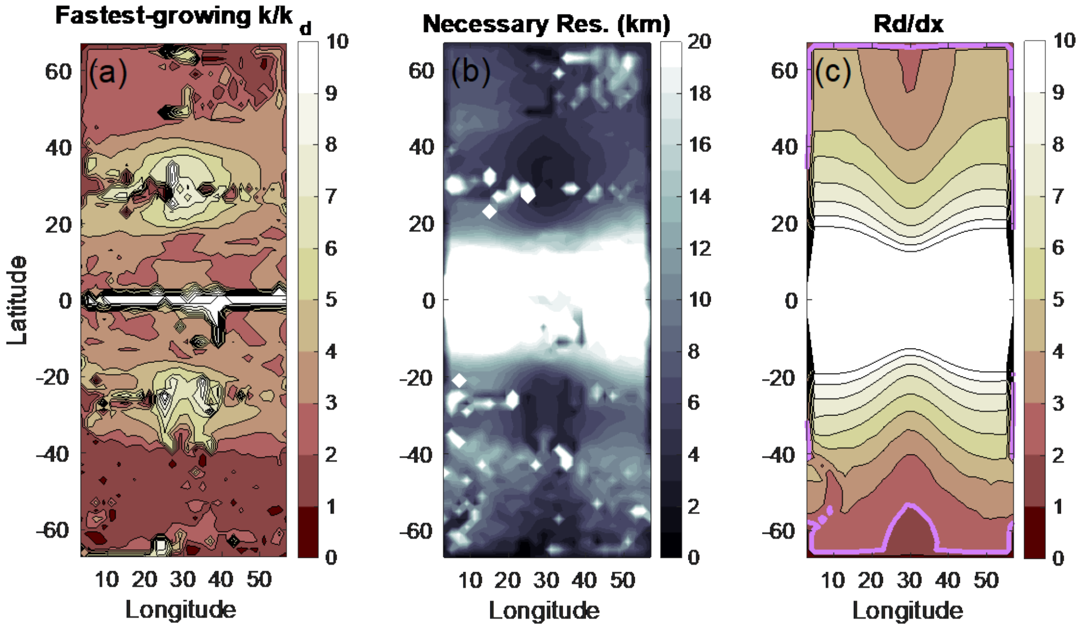
1/4° NeverWorld



1/8° NeverWorld



1/16° NeverWorld



- Agreement on the fastest growing wavenumbers (generally around 2-4x the deformation scale wavenumber)
- 1/4° simulation satisfies neither criterion for capturing mesoscale eddies.
- 1/8° generally partially captures deformation radius, not fastest growing mode.
- 1/16° captures deformation radius and the fastest growing mode with exception of gyre regions.

Comparing BT/BC KE vs. resolution

1/4 Degree

1/8 Degree

1/16 Degree

Averaging 100
5-day averages