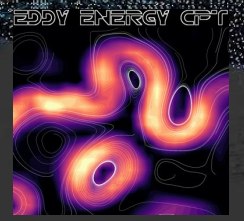
A backscatter-only parameterization for mesoscale eddies

Elizabeth Yankovsky
In collaboration with Scott Bachman, Shafer Smith, Laure Zanna



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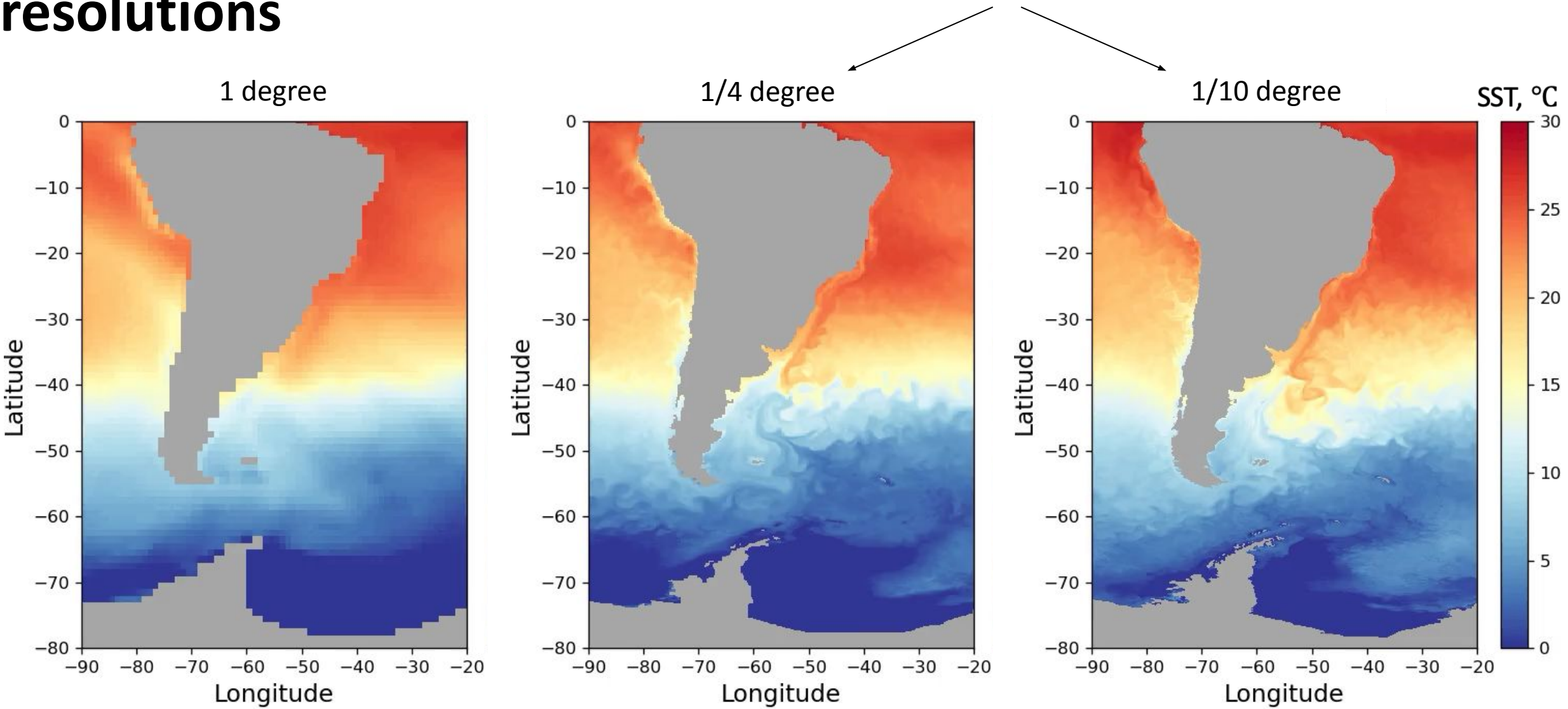
Background: NASA Visualization Studio

https://elizabethyankovsky.github.io

Motivation: parameterization at eddy-permitting resolutions



NOAA GFDL CM2 Suite, animations by E. Yankovsky

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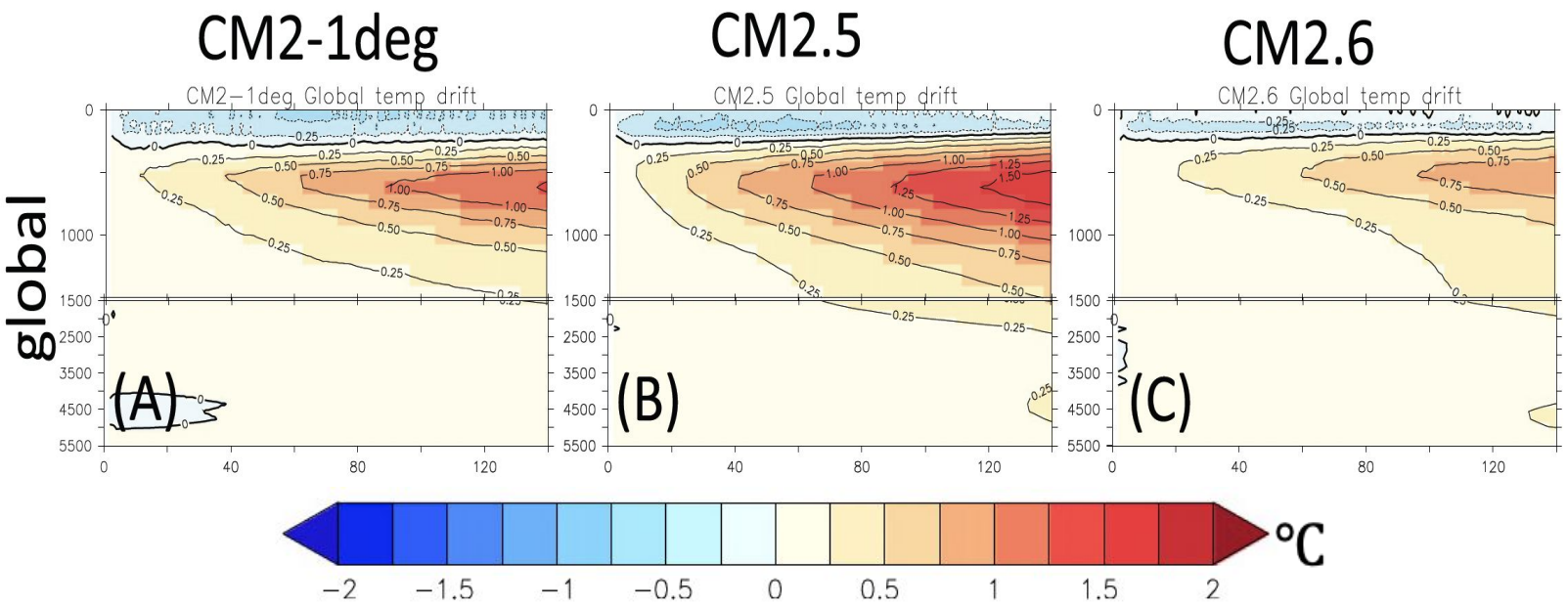


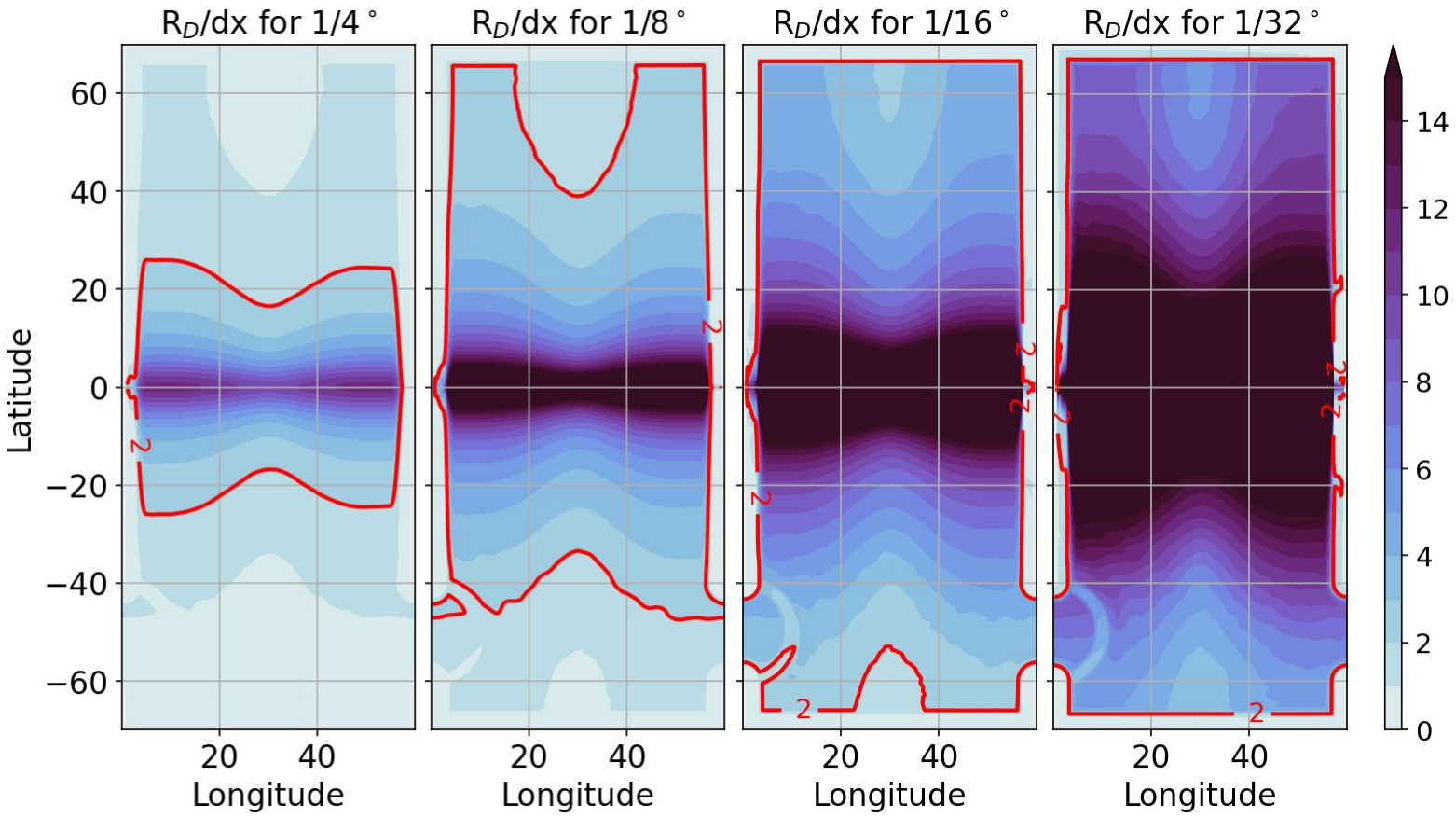
Globally-averaged drift of potential temperature vs. depth for the GFDL CM2 model suite. Griffies et al., Journal of Climate (2014).

Under-represented eddies lead to errors in climate prediction.

Energy pathways, tracer distributions, heat uptake all hinge upon accurate representation of eddies.

Methodology: an idealized resolution hierarchy

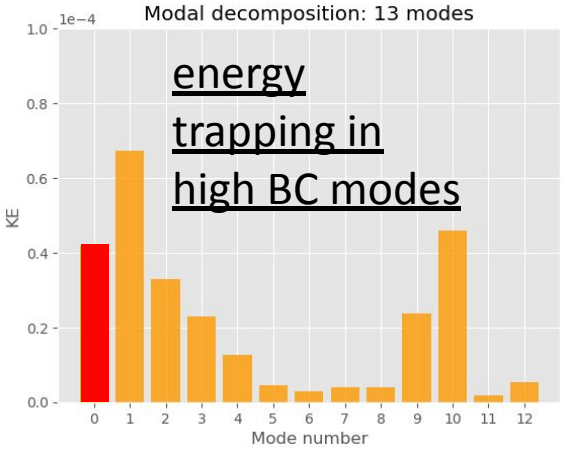
- R_D is deformation scale
- Higher R_D/dx→ increased eddy resolution (>2 eddy resolving)
- Idealized NW2 is broadly consistent with more realistic OM4



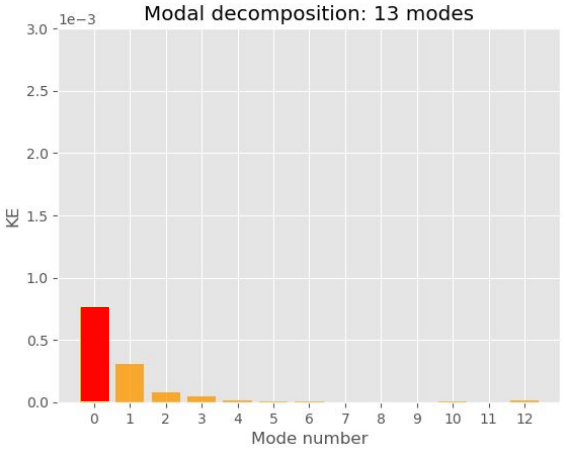
Yankovsky, Smith, and Zanna (2022)

Decomposition into quasigeostrophic vertical modes

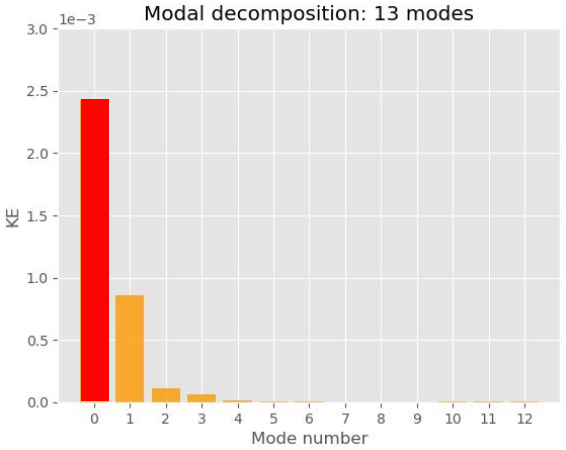
1/4 Degree



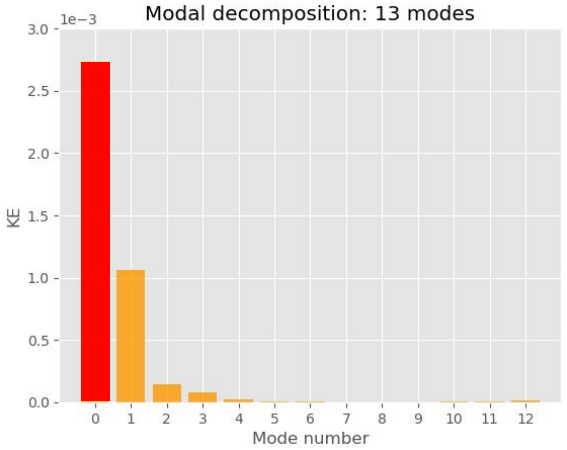
1/8 Degree

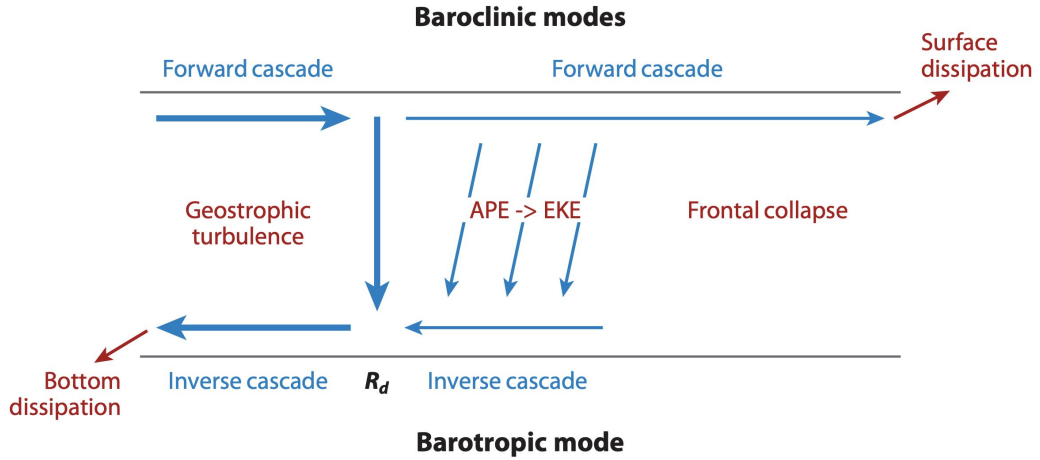


1/16 Degree



1/32 Degree





Yankovsky, Smith, and Zanna (2022)

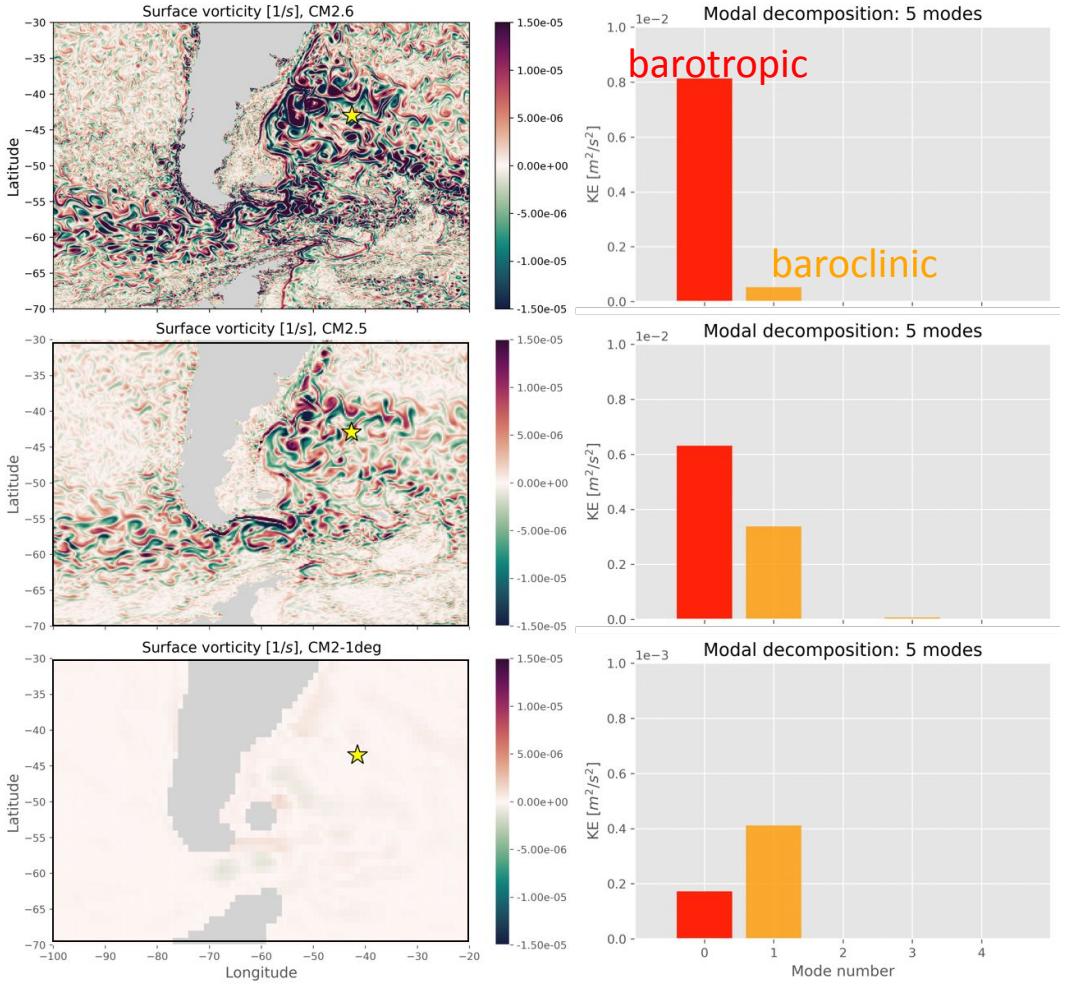
- Eddies facilitate energetic transfers into graver vertical modes.
- Inverse cascade happens primarily in gravest mode (BT).
- If eddies are unresolved, barotropization and inverse cascade aren't captured. How can we mediate this problem?

Left: Diagram from Ferrari and Wunsch (2009)

10 km resolution

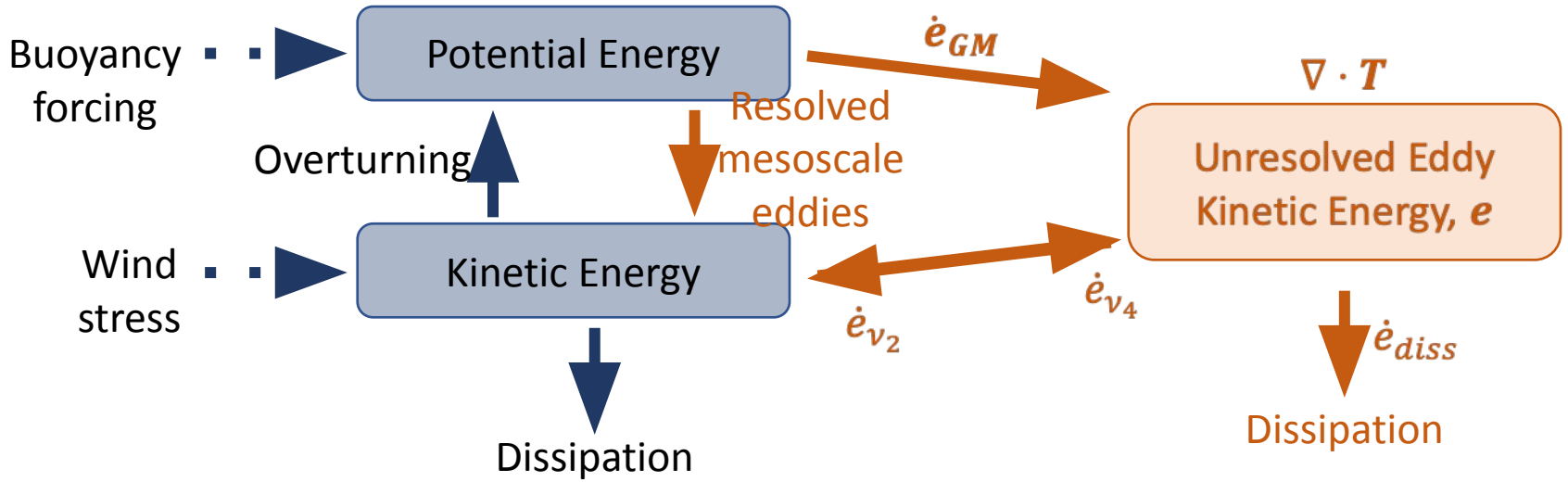
25 km resolution

100 km resolution



We see the same inaccuracies of flow vertical structure in global models at coarse & eddy-permitting resolutions

Scale-aware eddy parameterization



- Parameterize interactions of the subgrid MEKE with the resolved flow using a 2D budget (Cessi 2008; Eden & Greatbach 2008; Marshall & Adcroft 2010, Jansen et al. 2020):

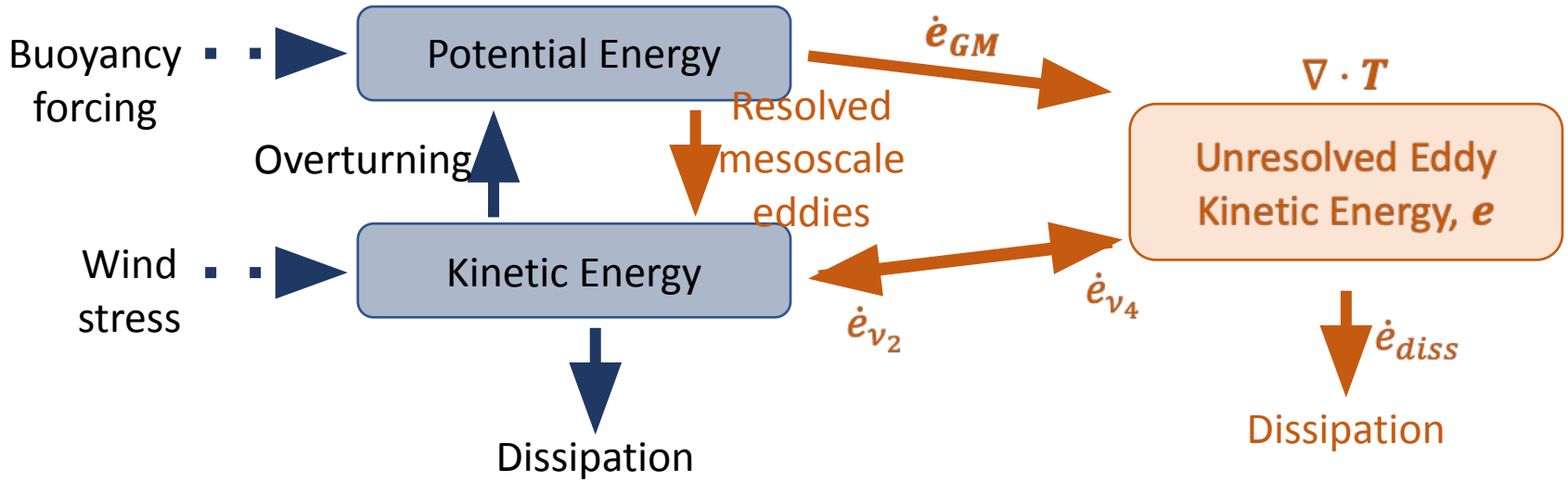
$$\partial_t e = \dot{e}_{GM} + \dot{e}_{\nu_4} - \dot{e}_{\nu_2} - \dot{e}_{diss} - \nabla \cdot \boldsymbol{T}$$

Source: APE removal by GM

Source: resolved dissipation

Sink: "Backscatter" reinjection of KE

Scale-aware eddy parameterization



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$$\partial_t e = \cancel{\dot{e}_{GM}} + \dot{e}_{\nu_4} - \dot{e}_{\nu_{2(z)}} - \dot{e}_{diss} - \nabla \cdot \boldsymbol{T}$$

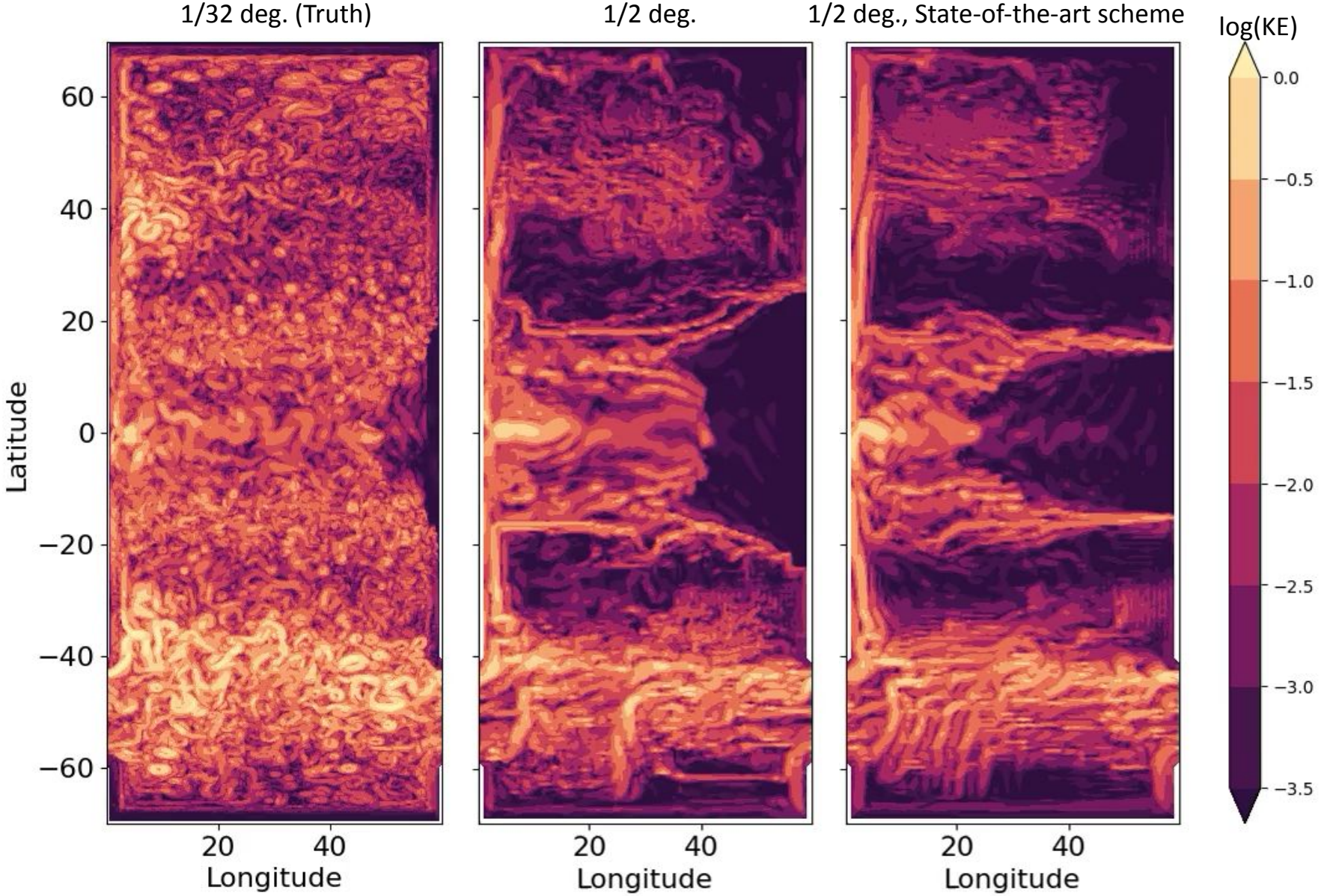
Source: APE removal by GM

Source: resolved dissipation

Sink: "Backscatter" reinjection of KE

We remove GM, prescribe $\nu_2(z)$ with an equivalent barotropic vertical structure.

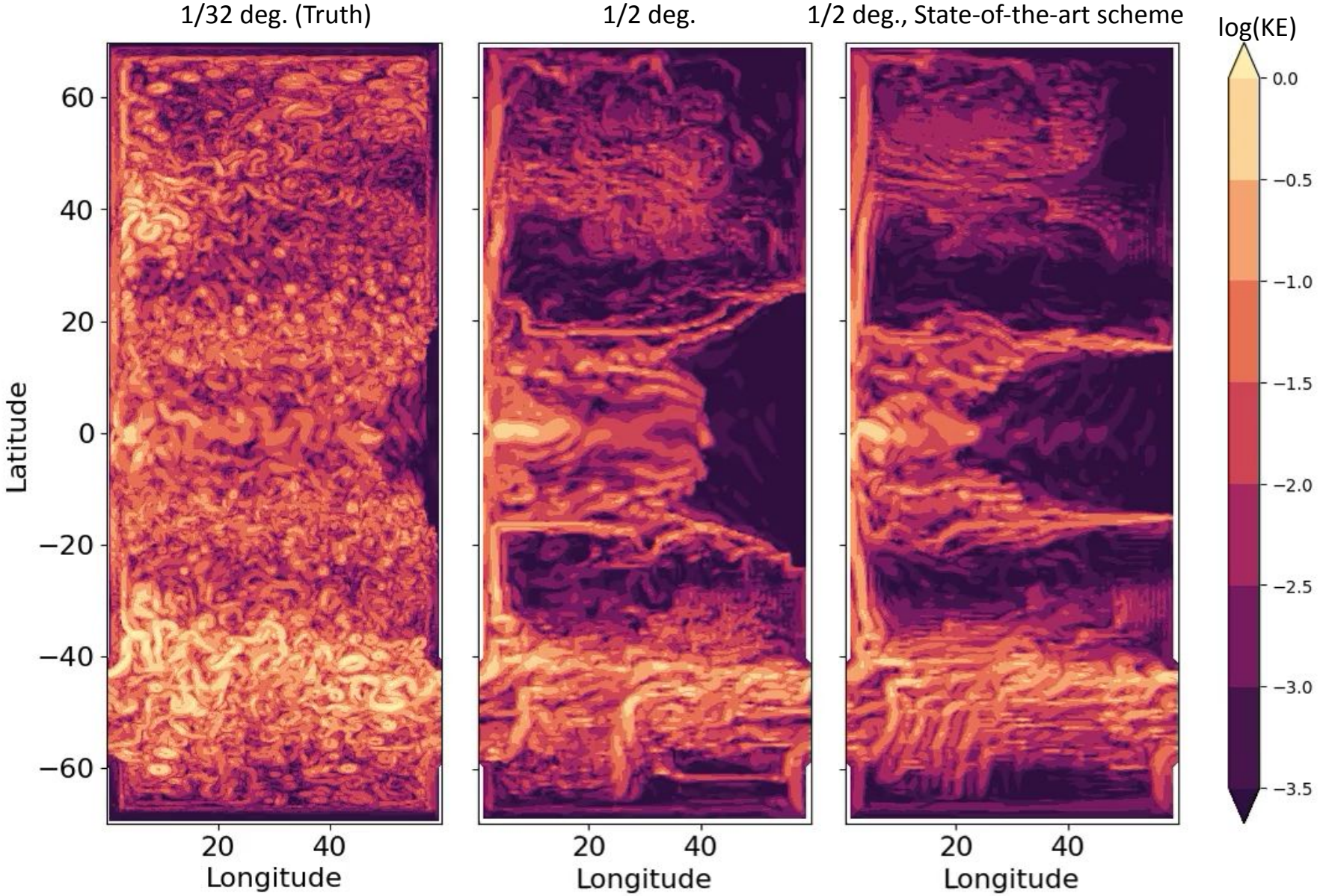
Surface eddy kinetic energy over 500 days



Existing approach does not capture subgrid KE effects of eddies.

Jansen et al. (2020)

Surface eddy kinetic energy over 500 days



Jansen et al. (2020)

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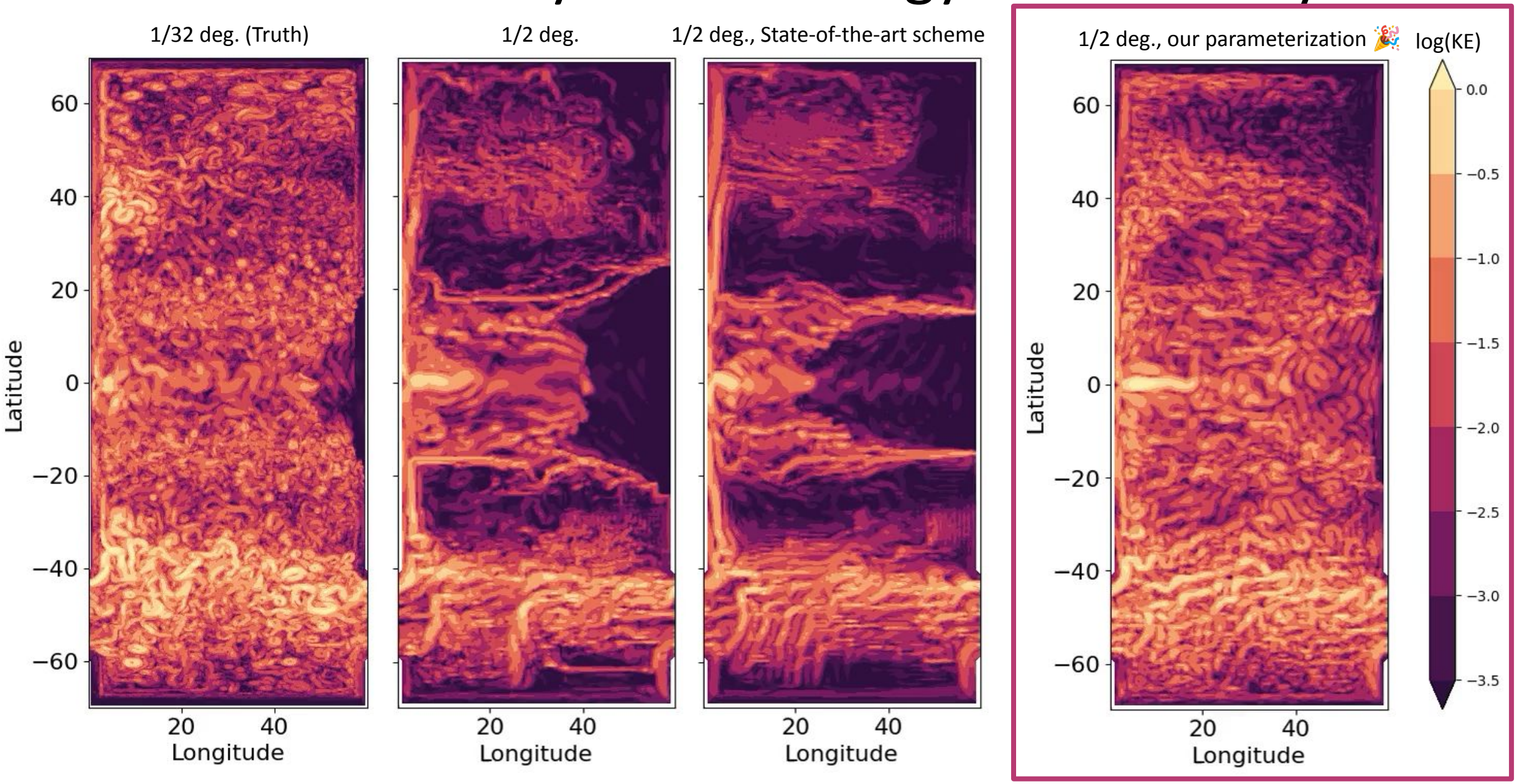
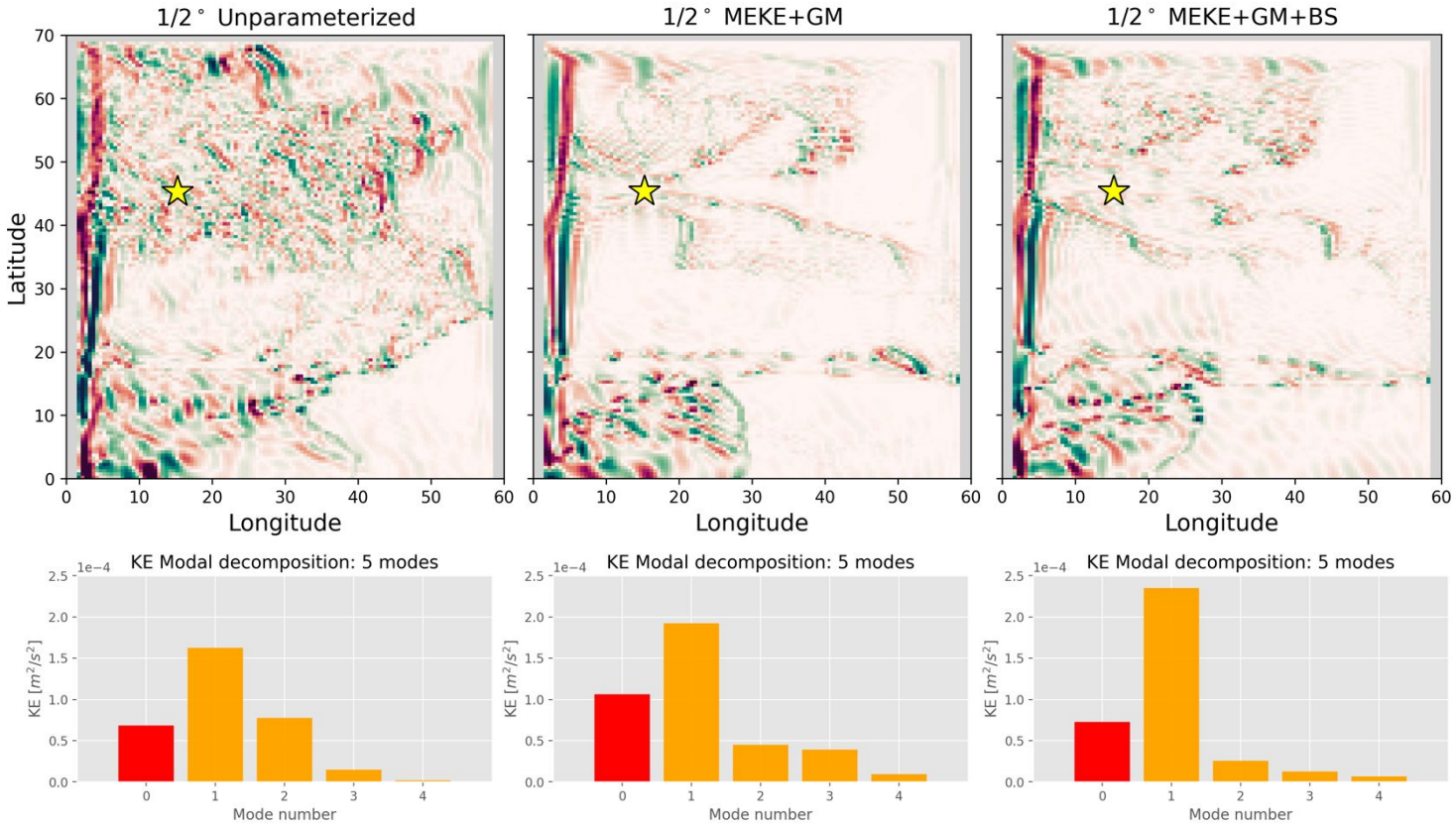


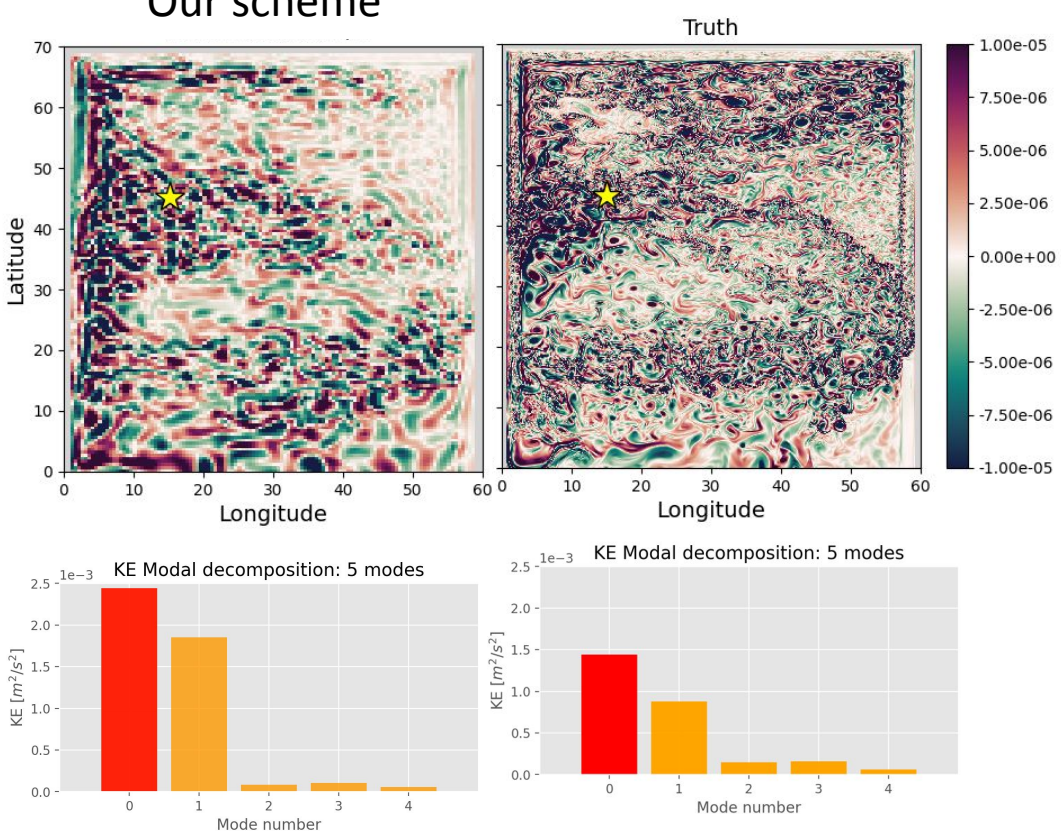
Jansen et al. (2020)

Surface vorticity, modal structure

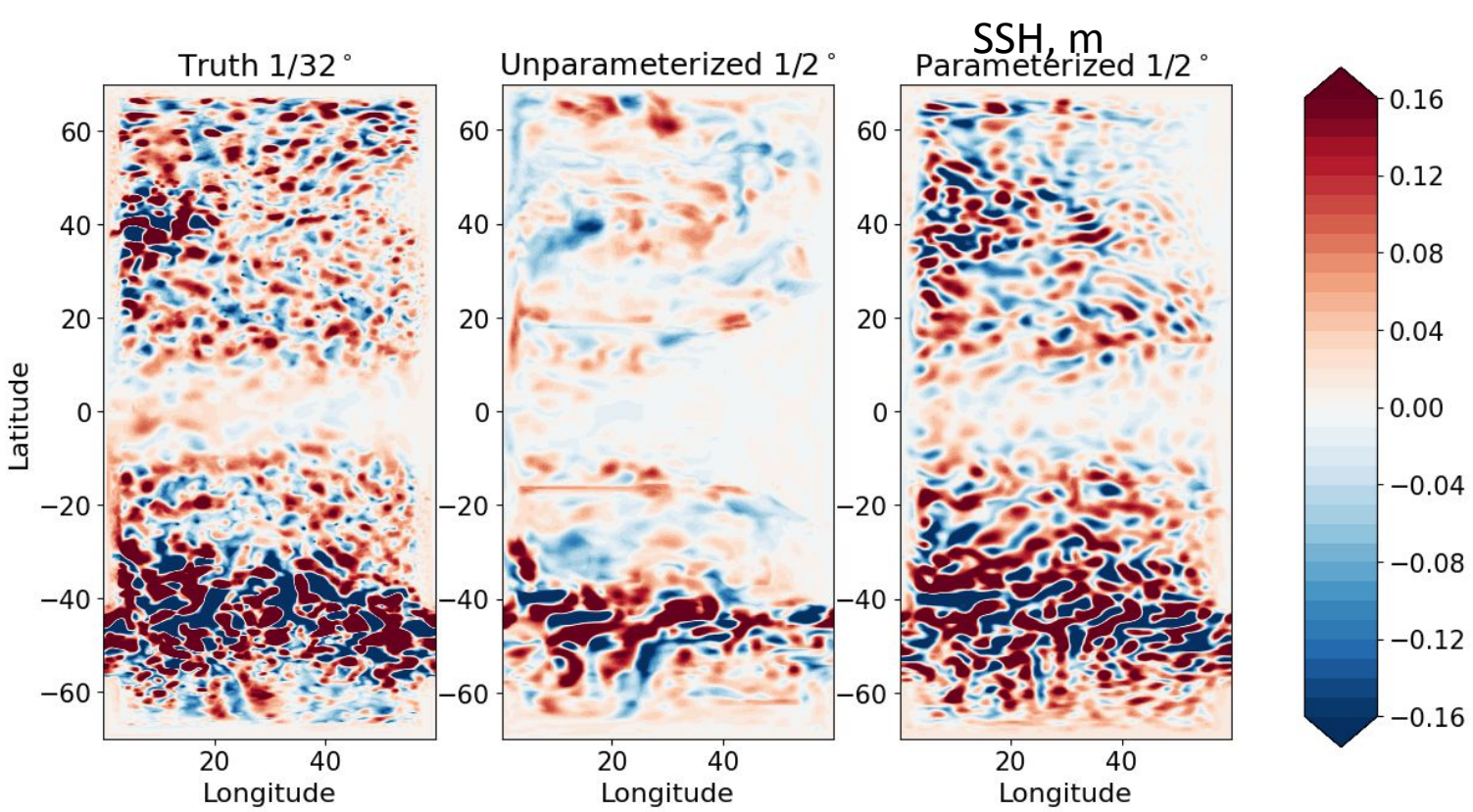
Prior Approach, Jansen et al. (2020)

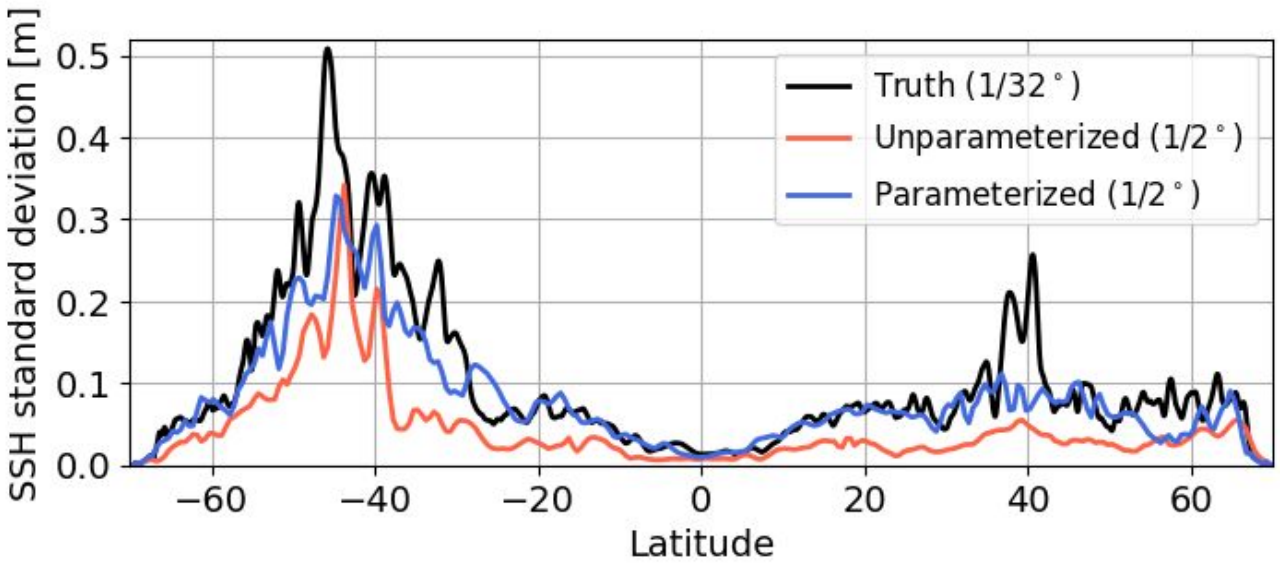
Our scheme

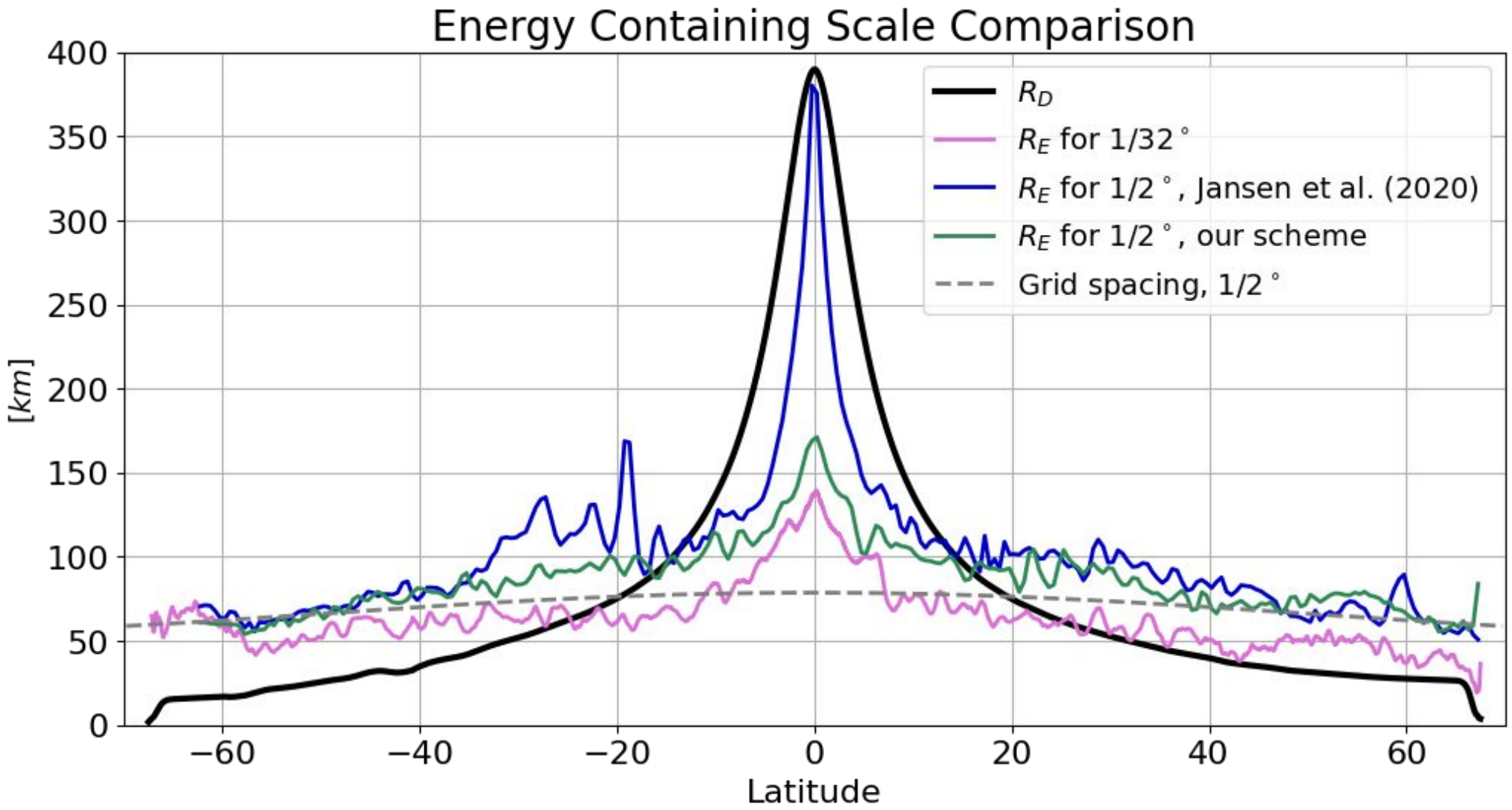




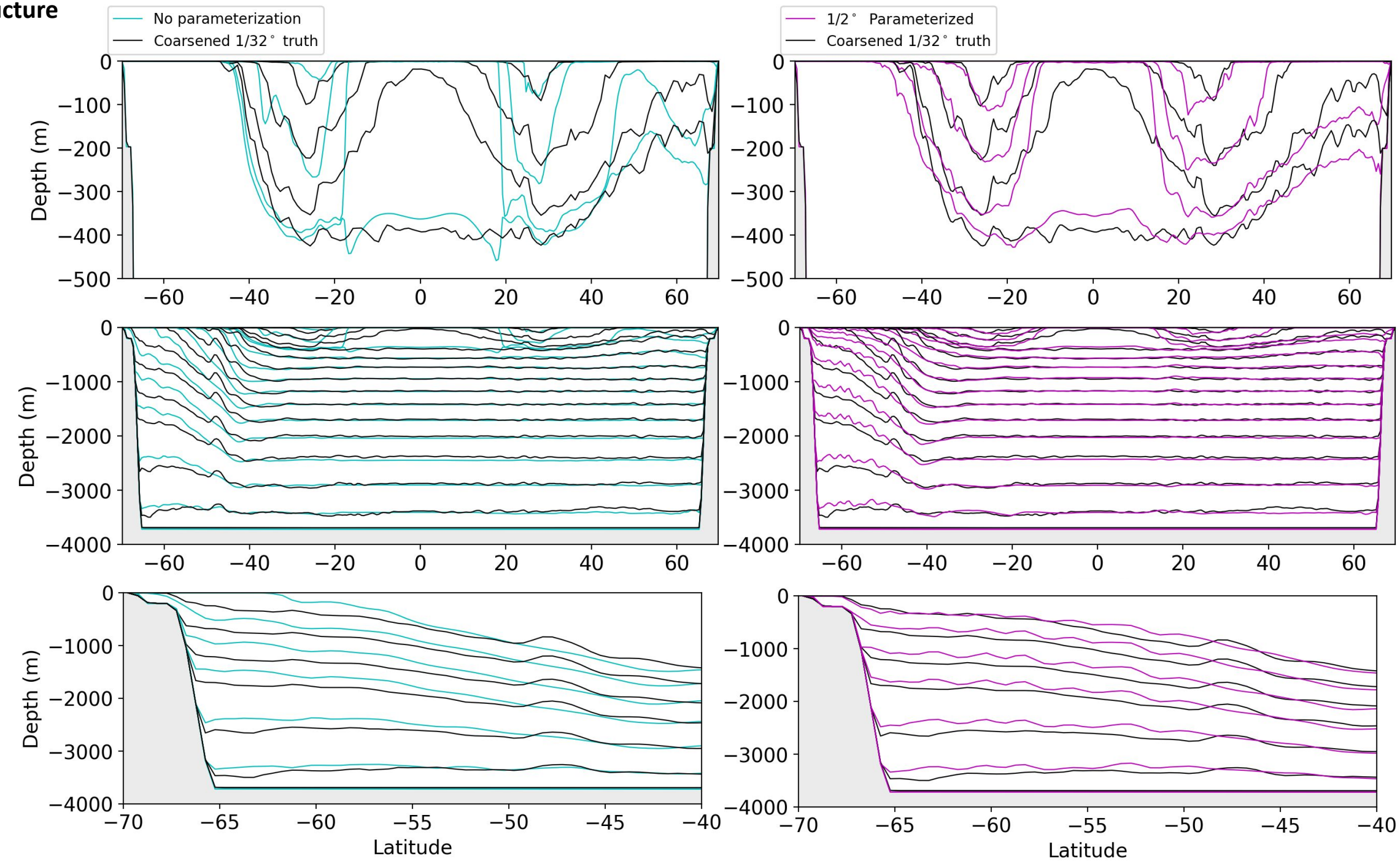
Sea surface height






Energy Containing Scale Comparison
400
350
300
250
200
150
100
50
0
[km]
−60
−40
−20
0
20
40
60
Latitude
R_D
R_E for 1/32 °
R_E for 1/2 °, Jansen et al. (2020)
R_E for 1/2 °, our scheme
Grid spacing, 1/2 °

Isopycnal structure



Contributions

Our study offers two new insights:

1. Buoyancy and momentum effects can **both** be parameterized using a properly formulated KE backscatter **alone**.
2. The key factor in having the backscatter behave physically is to accurately represent vertical structure.

Next steps: constraining the modal structure governing $\nu_2(z)$; considering its scale awareness.

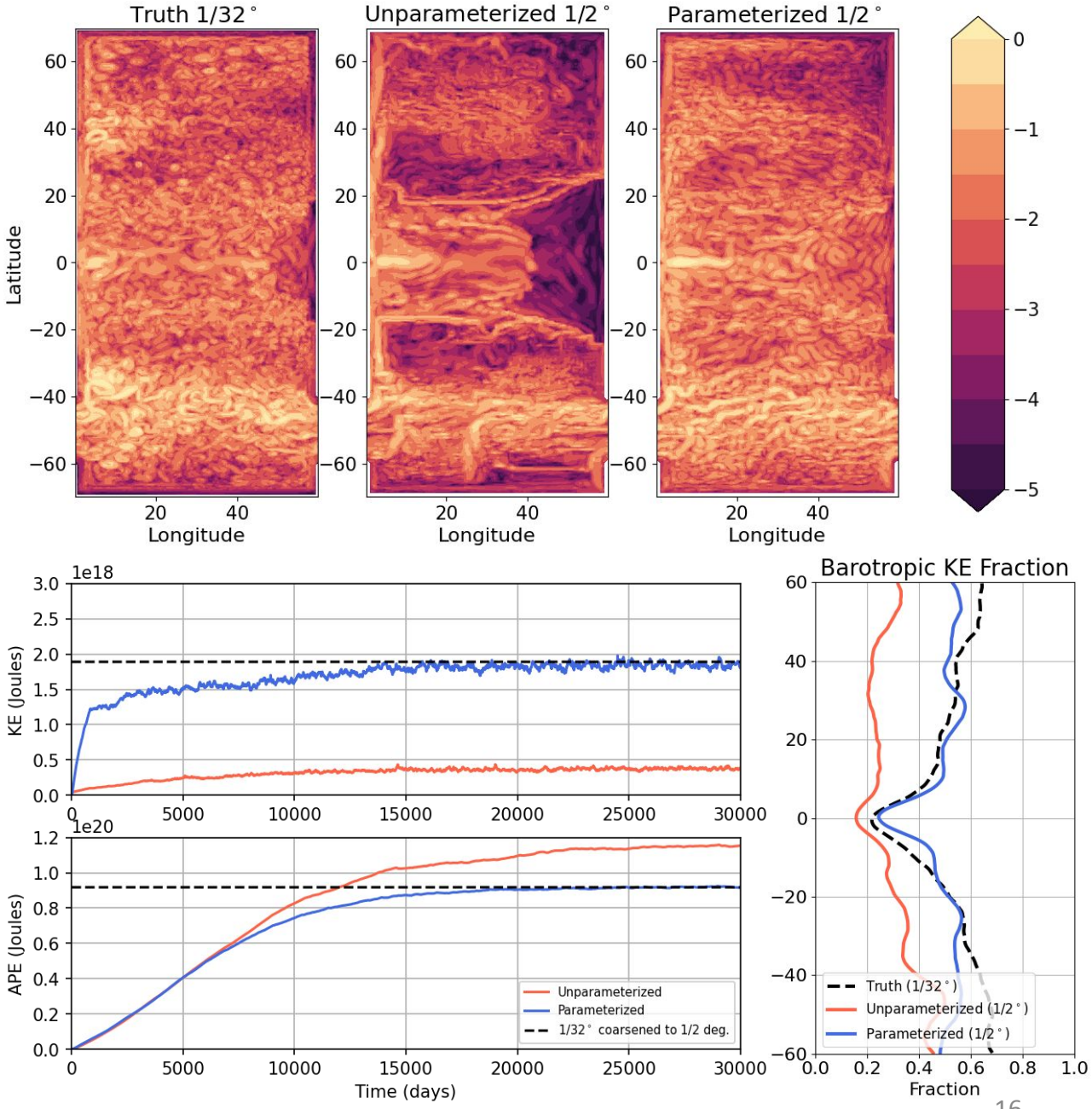
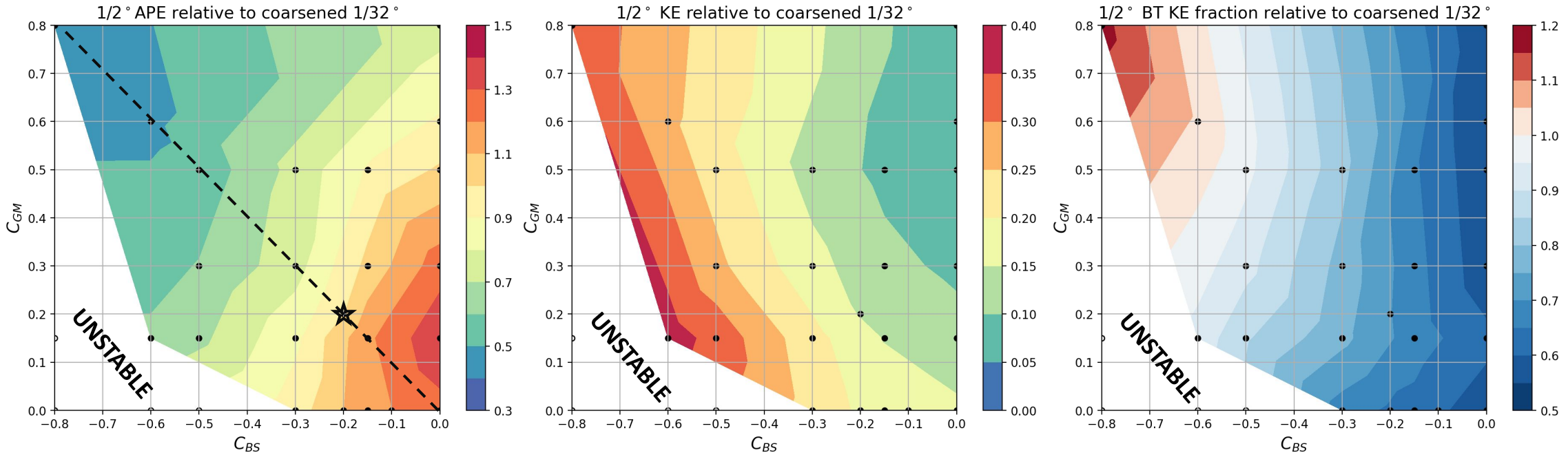


Figure 10: Setting the context of prior parameterization developments.



Can existing parameterizations represent barotropization & eddy energetics?

- Focusing on the role of GM and backscatter

$$\partial_t \boldsymbol{u} + (f+\zeta)\widehat{\boldsymbol{k}} \wedge \boldsymbol{u} + \nabla K + \nabla M = \frac{1}{\rho_0}\frac{\partial \boldsymbol{\tau}}{\partial z} - \nabla \cdot \nu_4 \nabla(\nabla^2 \boldsymbol{u}) + \nu_2 \nabla^2 \boldsymbol{u}, \qquad with\ \nu_2 < 0.$$

- MEKE budget:

$$\partial_t e = \dot{e}_{GM} + \dot{e}_{\nu_4} - \dot{e}_{\nu_2} - \dot{e}_{diss} - \nabla \cdot T$$

- Backscatter and GM terms may be tuned:

$$K_{GM} = c_{GM}\sqrt{2e}\, L_{mix} R(\Delta k_d)$$
$$\nu_2 = c_{BS}\sqrt{2e}\, L_{mix} R(\Delta k_d)$$

Jansen et al. 2019 assume $c_{GM} = -c_{BS}$, tune based on matching global APE

- Consider ½ degree resolution – lower limit of the 'grey zone'