Energizing Turbulence Closures in Ocean Models

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& the *Ocean Transport & Eddy Energy Climate Process Team (CPT)*

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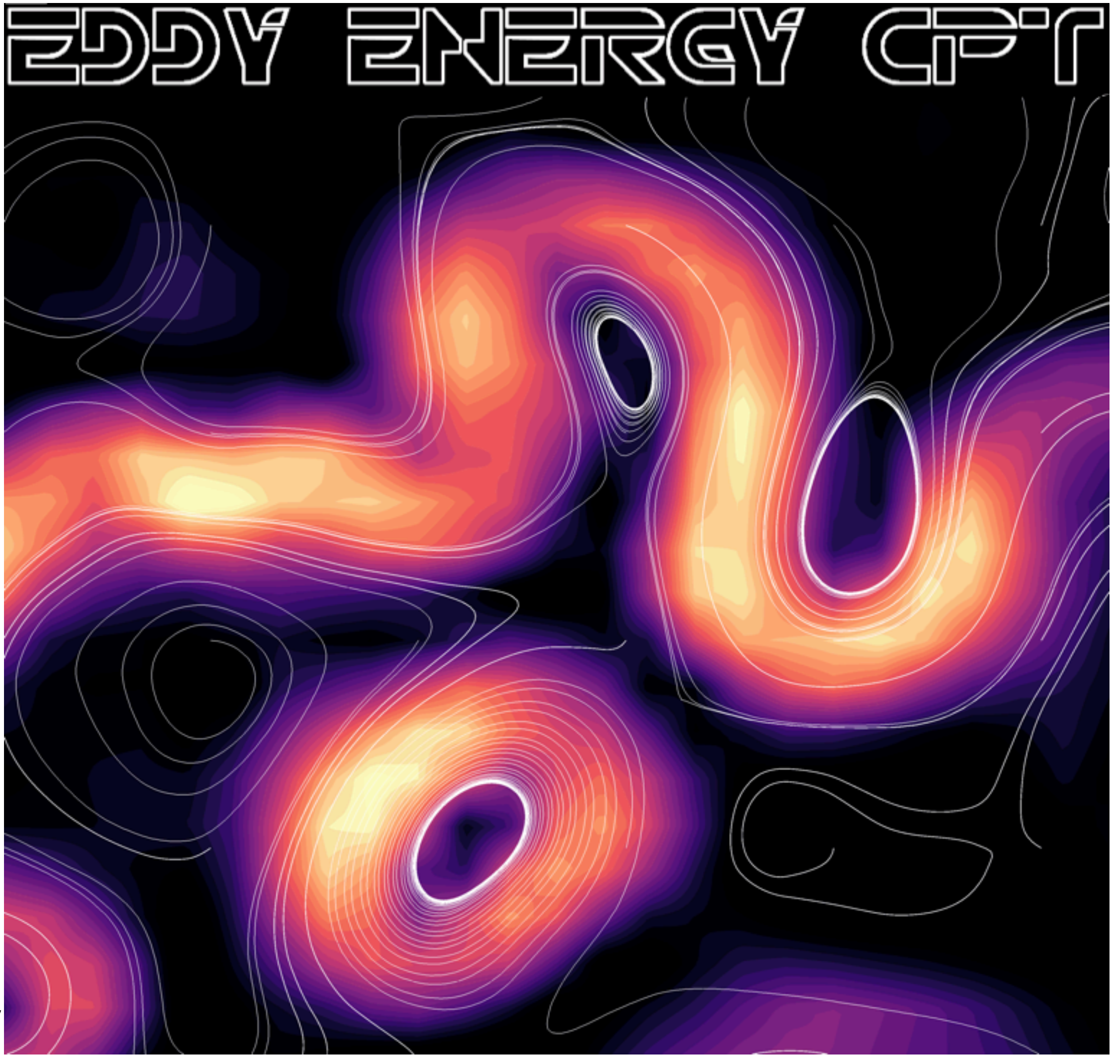
- NCAR
- University of Washington, APL
- Brown University
- University of Chicago
- LANL, DOE



https://ocean-eddy-cpt.github.io/

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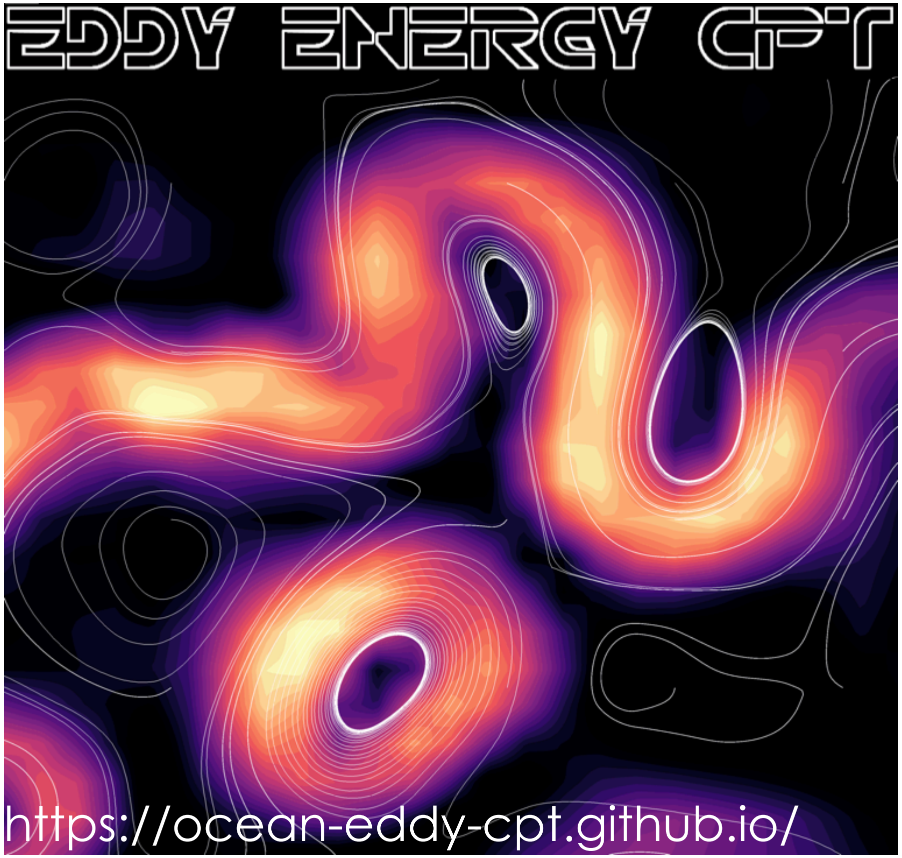
Main goals:

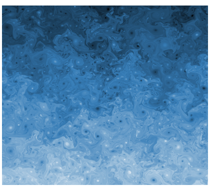
- Improve parameterizations of mesoscale eddies in ocean models though energetics
- Focus on linking (new) momentum, buoyancy, and eddy energy closures, constrained by observations
- Targeting resolution-, scale- and flow-aware implementations in ocean models (MOM6 at GFDL and NCAR, and MPAS)

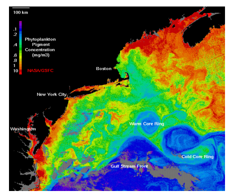


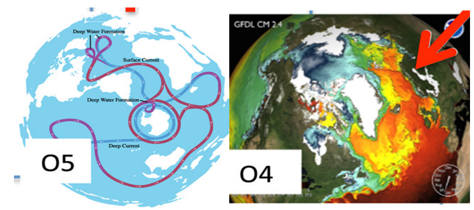
- **Today: I will focus on the motivation and a subset of work being carried out as part of the ocean eddy CPT**

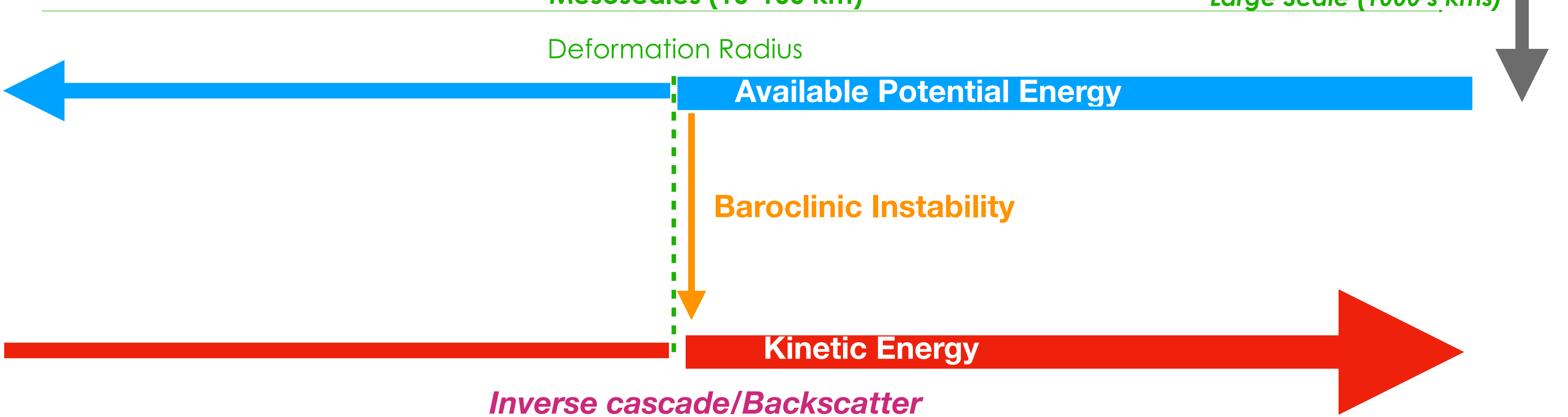
Energy Cycle

- Sources, sinks and transfer of energy across scales:
  ➡ are key to maintain the circulation & transport in the ocean
  (e.g., Wunsch & Ferrari 2004; Ferrari & Wunsch 2009)





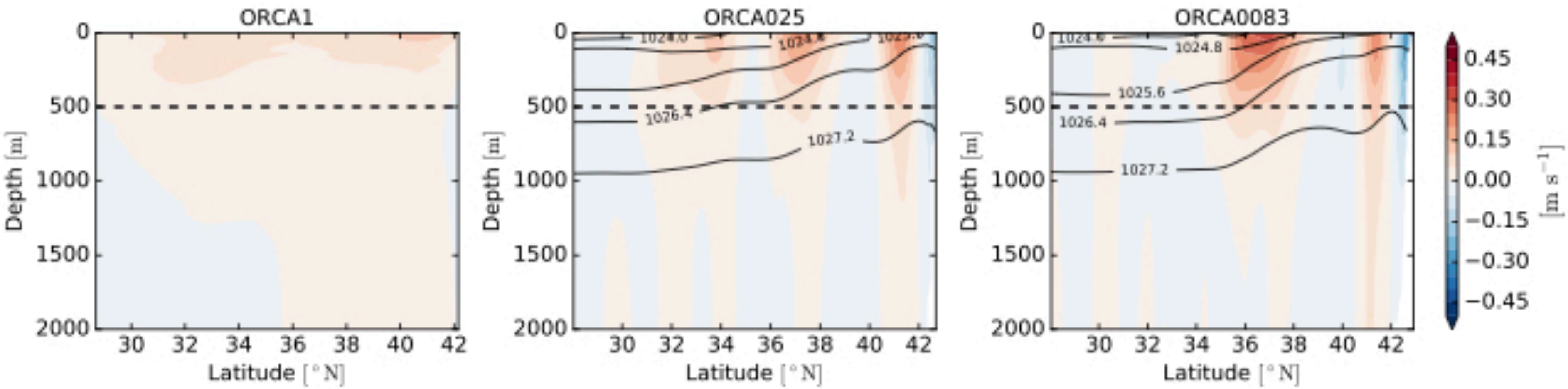




adapted from Salmon, 1998 & Vallis, 2006; Zanna et al 2020

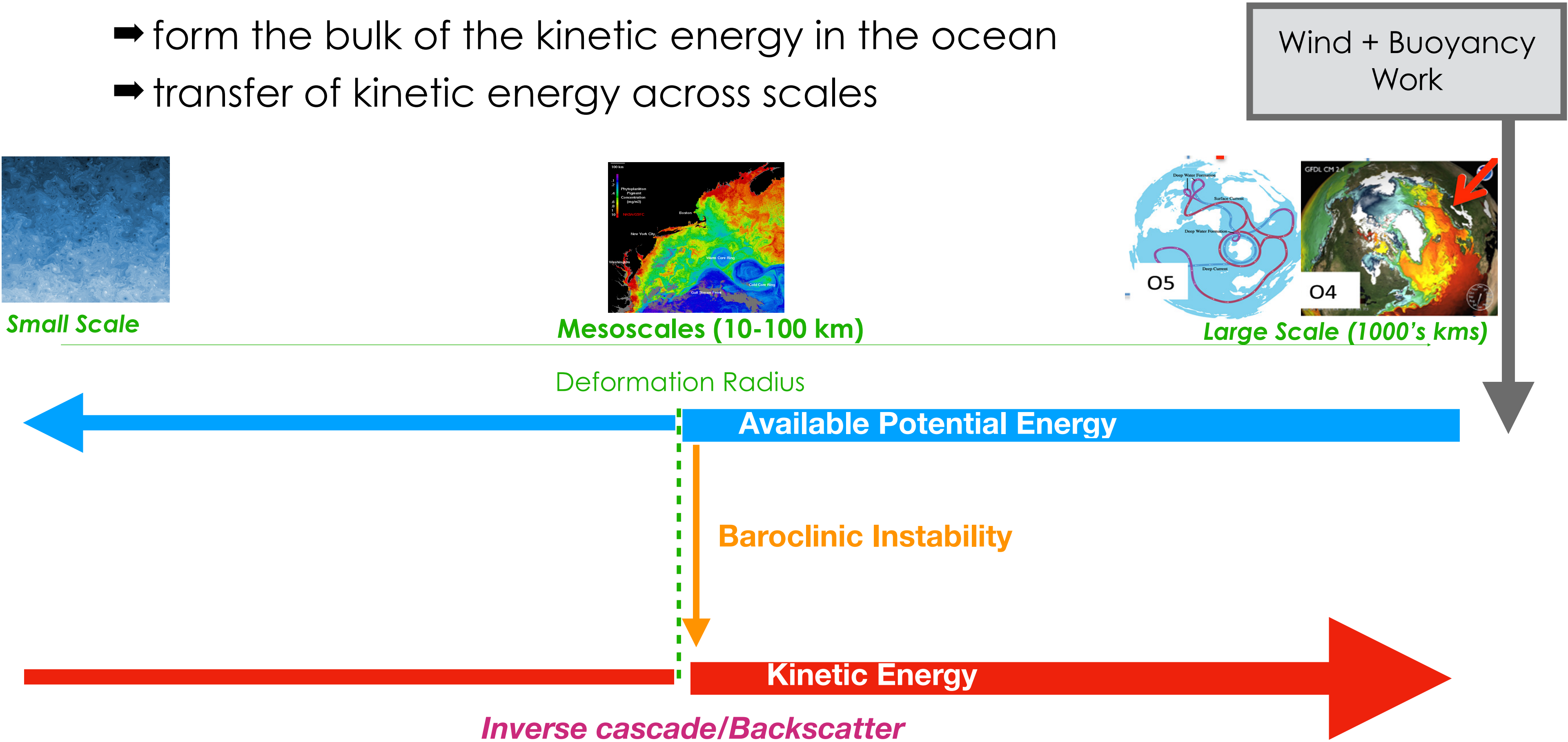
Energy Cycle

- Sources, sinks and transfer of energy across scales:
  - ➡ are key to maintain the circulation & transport in the ocean *(e.g., Wunsch & Ferrari 2004; Ferrari & Wunsch 2009)*
  - ➡ impact the lateral and vertical transport in global models *(e.g., Kjellsson & Zanna, 2017)*



Energy Cycle & Mesoscale Eddies

- **Mesoscale eddies are a major player in the energy cycle:**
  - ➡ extract energy from the mean flow
  - ➡ form the bulk of the kinetic energy in the ocean
  - ➡ transfer of kinetic energy across scales



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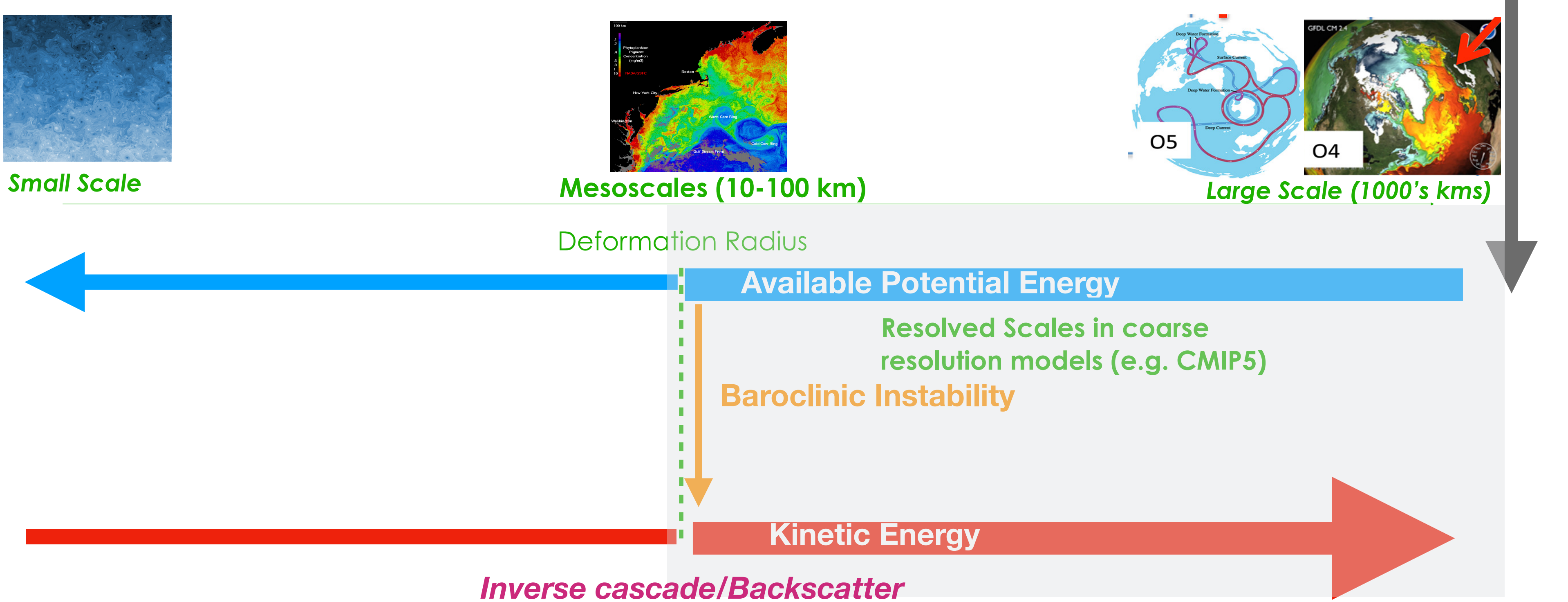
Energy Cycle & Eddy Parameterizations

- **Gent-McWilliams (1990): mimics baroclinic instability**
  - ➡ extremely successful in reducing spurious convection & mixing
  - ➡ net sink of available potential energy
  - ➡ no accounting of eddy energy



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Keeping track of eddy energy

- *Using a prognostic equation for eddy energy*

- 3D or 2D (depth-averaged) mesoscale eddy kinetic energy equation *(e.g., Cessi 2008; Eden & Greatbatch, 2009; Marshall & Adcroft 2010; Jansen et al 2019)*

$$\frac{\partial}{\partial t}E = \text{Sources + Sinks + Transport}$$

  - For example, the eddy energy can be used to inform the Gent-McWilliams coefficient *(e.g., Adcroft et al., 2019; and more advanced energy framework of Marshall et al. GEOMETRIC)*

➡ But

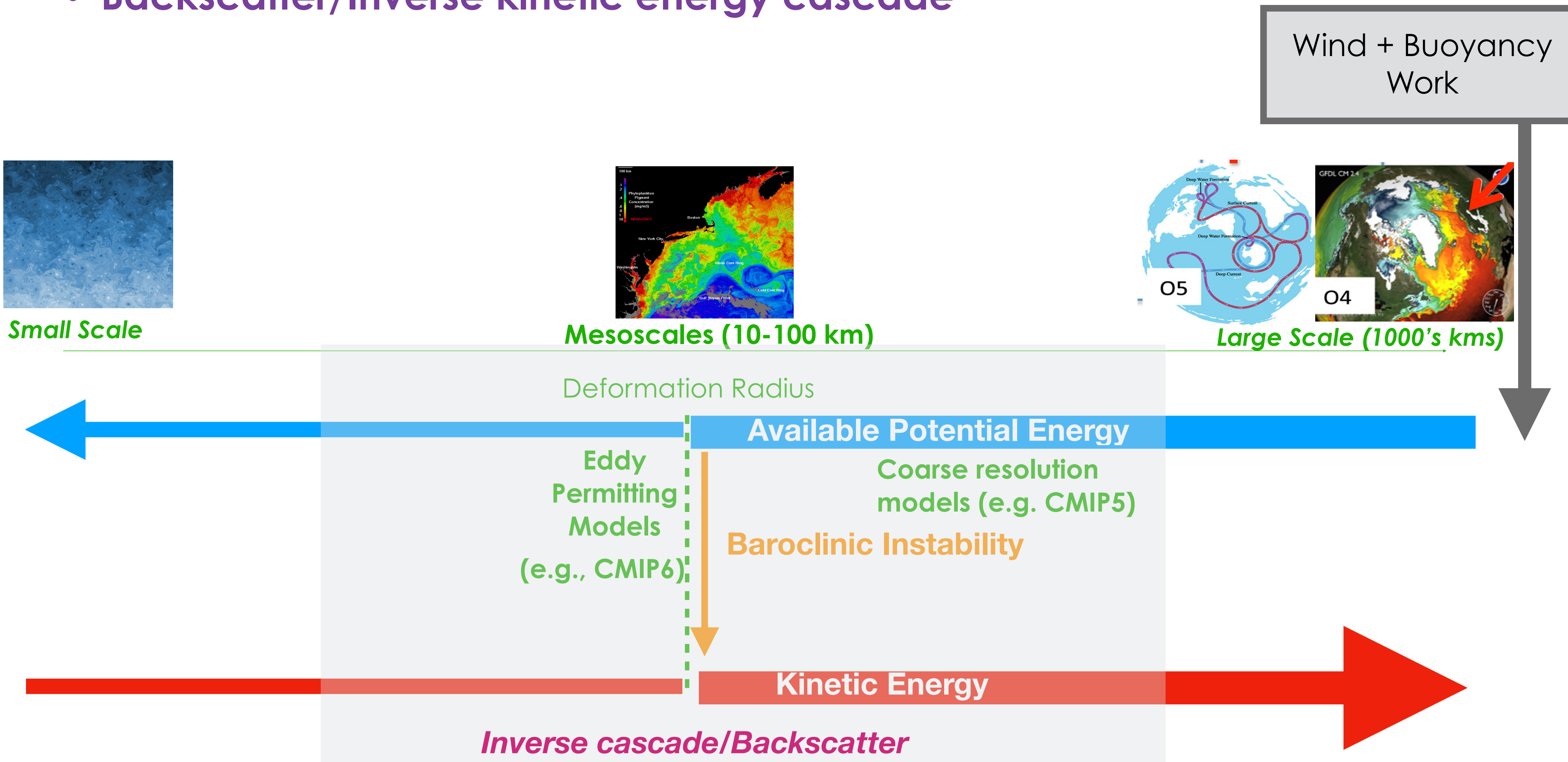
1) we are still missing some energy pathways

2) we must consider the increase in horizontal resolution of global models (at the deformation scale) - *resolution-aware*

3) we need to rethink momentum closures - *scale- & flow-aware*

Energy Cycle & Eddy Parameterizations

- **Transfer of available potential energy into resolved kinetic energy**
- **Backscatter/Inverse kinetic energy cascade**



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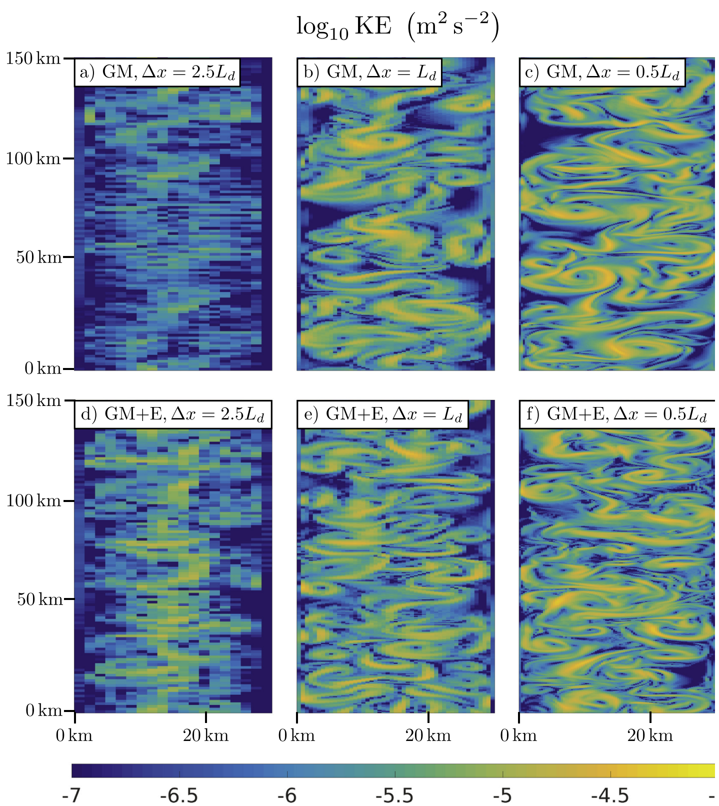
Potential Energy into resolved kinetic energy

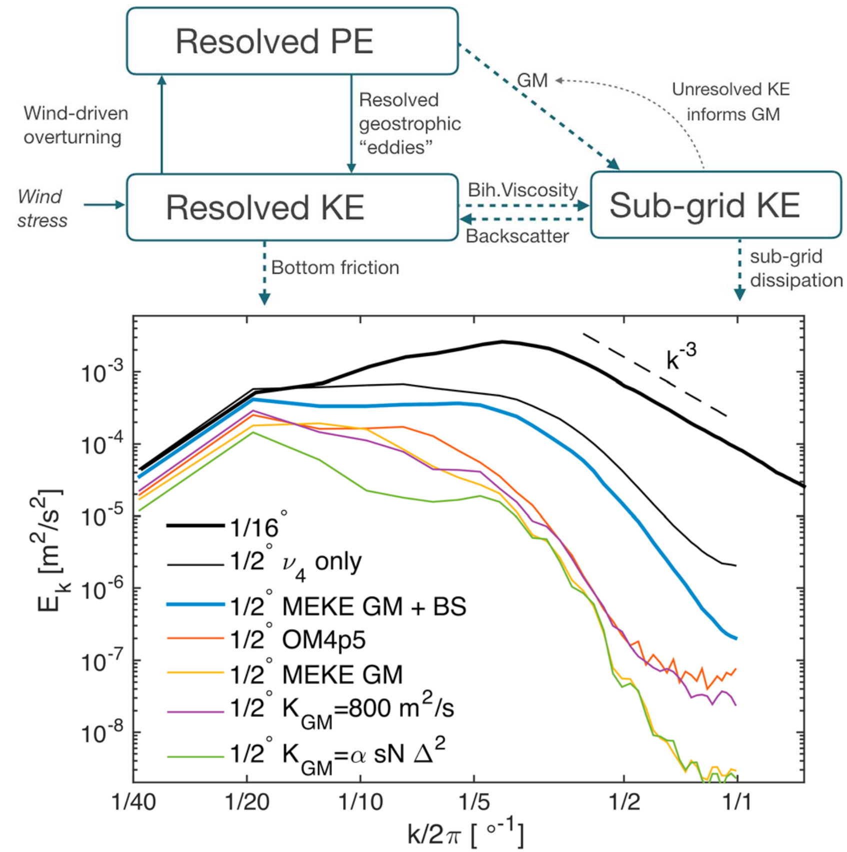
➡ New schemes which re-injects available potential energy removed by Gent-McWilliams into resolved scales *(Bachman 2019; Jansen et al 2019)*

➡ Mimicking both baroclinic instability & energy backscatter

Bachman 2019



Jansen et al 2019

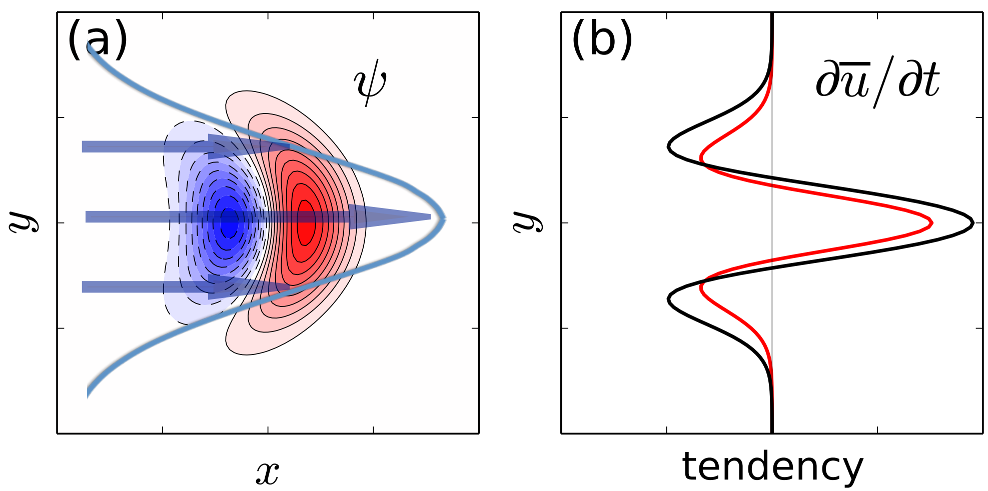


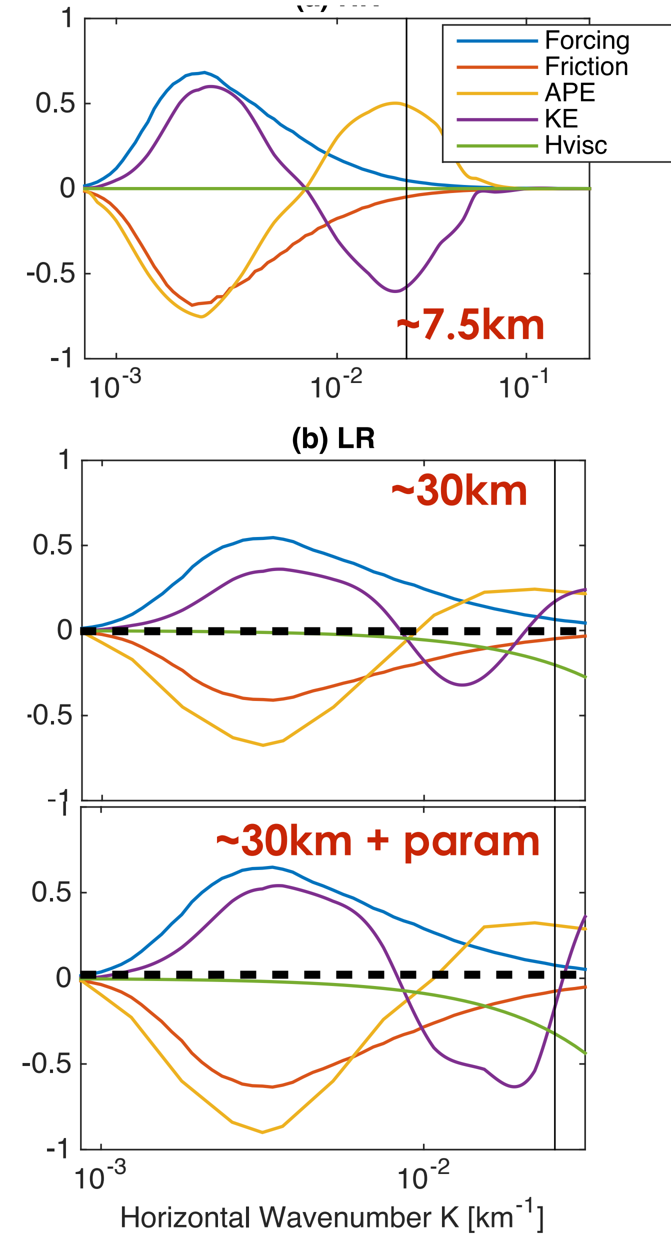
➡ both use anti-viscosity in the momentum equation, is it the most appropriate form?

Kinetic Energy Backscatter/ Momentum Closures

- ➡ Stochastic closures *(e.g., Berloff 2005; Brankart 2013; Porta Mana & Zanna, 2014)*

- ➡ Non-Newtonian closures:
  - ➡ Jet rectification & sharpening via upgradient momentum fluxes *(Starr 1963, Shutts 1986)*
  - ➡ Flow- & Scale-Aware



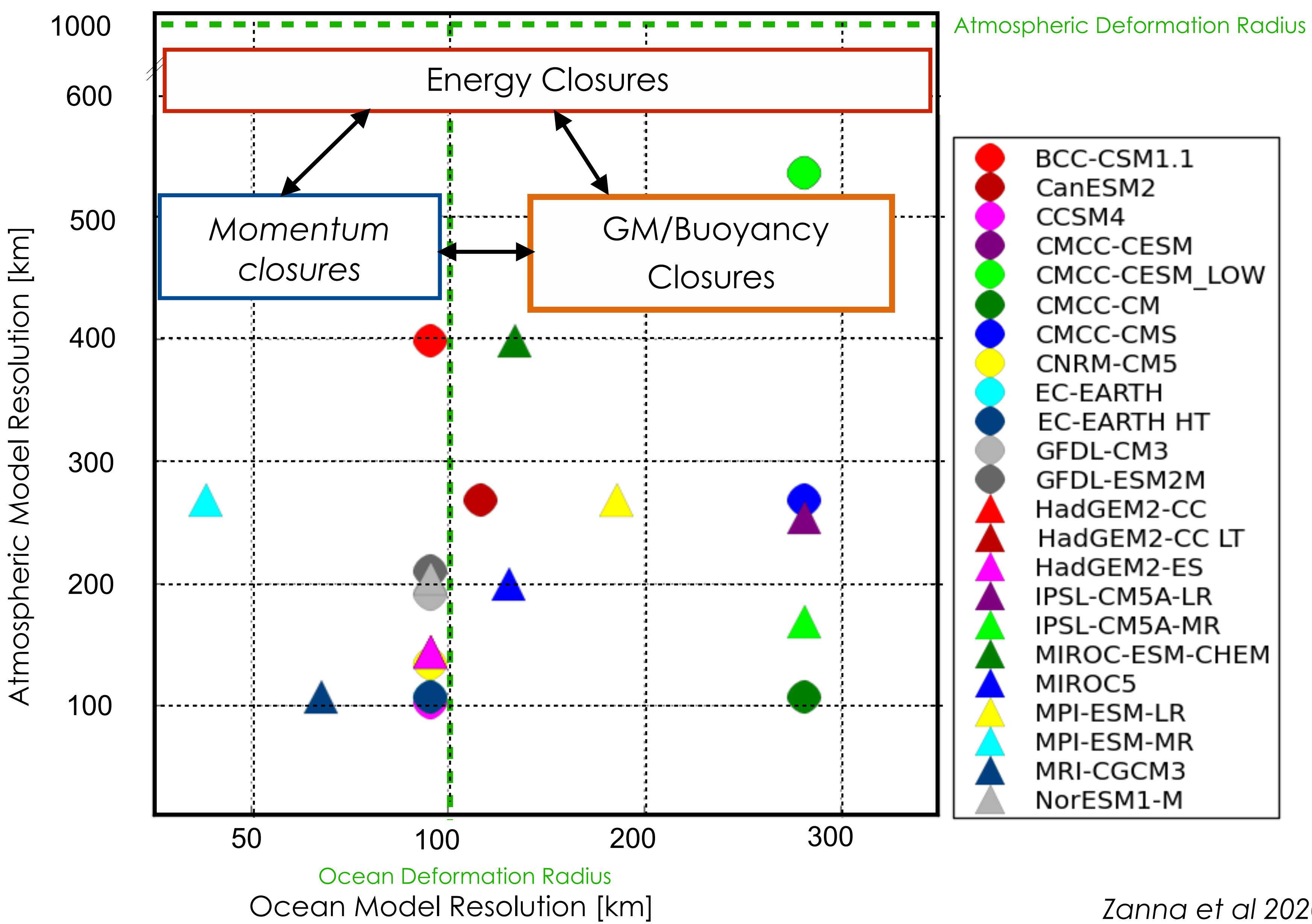


Mana & Zanna, 2014; Anstey & Zanna, 2017; Zanna et al 2017

Concluding Remarks

- Lack of a physically-consistent energy cycle impacts simulated ocean circulation
- Recent eddy turbulence closures targeting energy transfers have shown a reduction in biases in ocean transport **in idealized simulations**

Model Resolution & Closures



Zanna et al 2020

Concluding Remarks

- Lack of a physically-consistent energy cycle impacts simulated ocean circulation
- Recent eddy turbulence closures targeting energy transfers have shown a reduction in biases in ocean transport in idealized simulations
- Challenges ahead, in addition to implementation in global models *(which is underway as many of the parameterizations are implemented in MOM6)*:
    - ➡ Can observations & global high-resolution simulations help constrain the partitioning of energy and its pathways?
    - ➡ Which momentum closure increases the fidelity of the energy cycle?
    - ➡ What is the impact of the vertical structure of eddy energy on transport?

There is a need for observationally-constrained & unified buoyancy and momentum closures, via energetics, for a robust scale- and flow-aware implementation in IPCC-class models