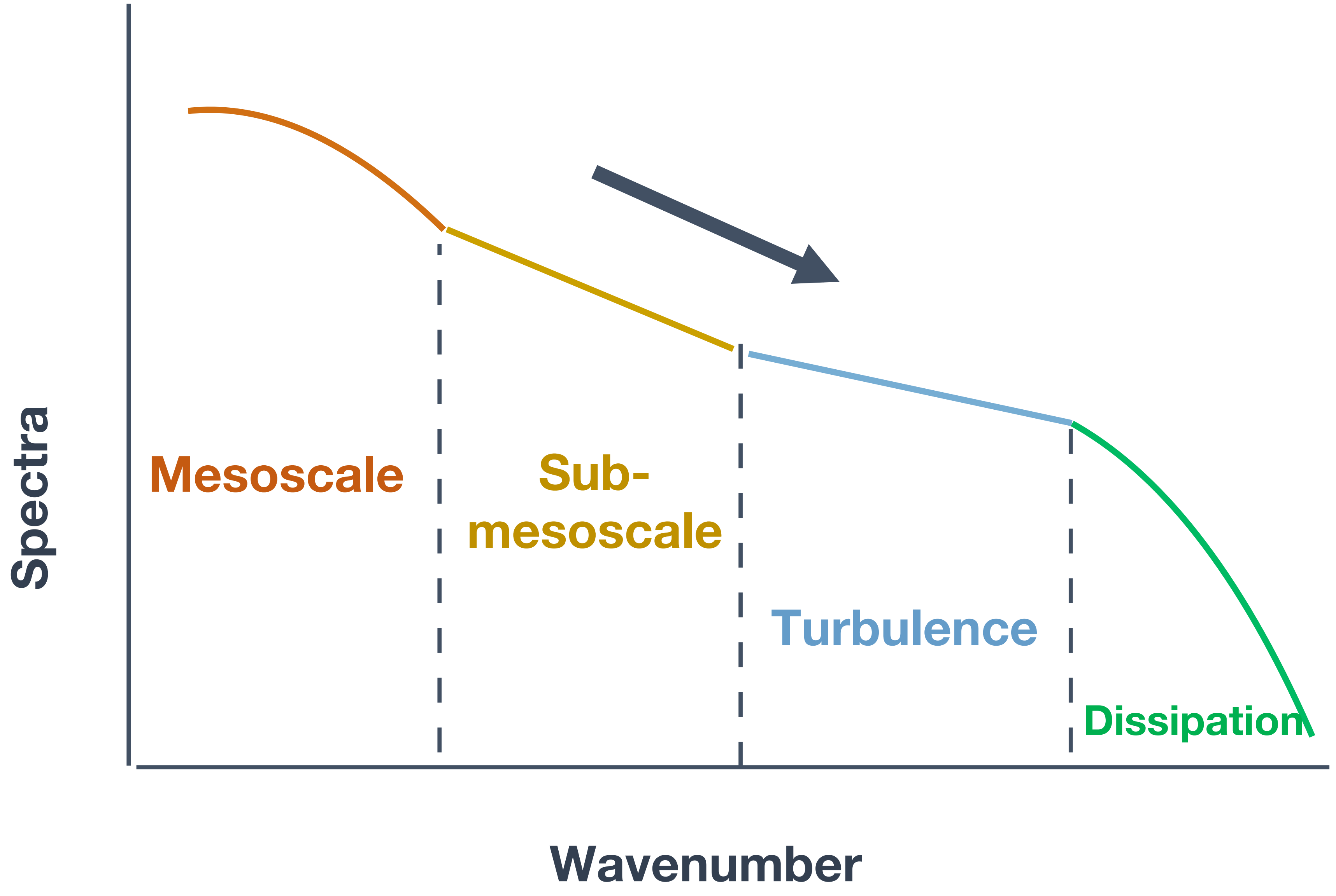
Hidden Dangers in Potential Vorticity

Abigail Bodner

Baylor Fox-Kemper



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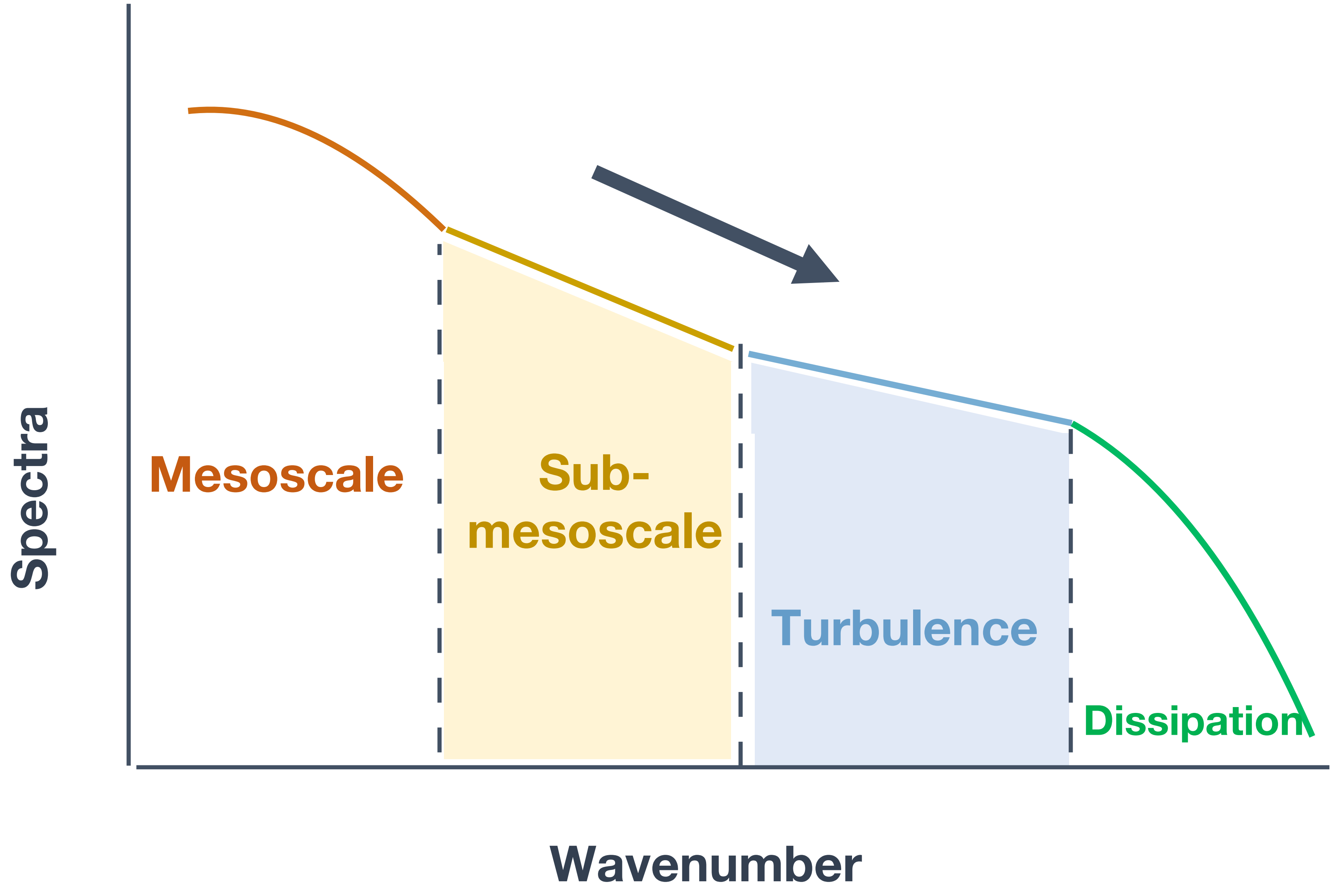
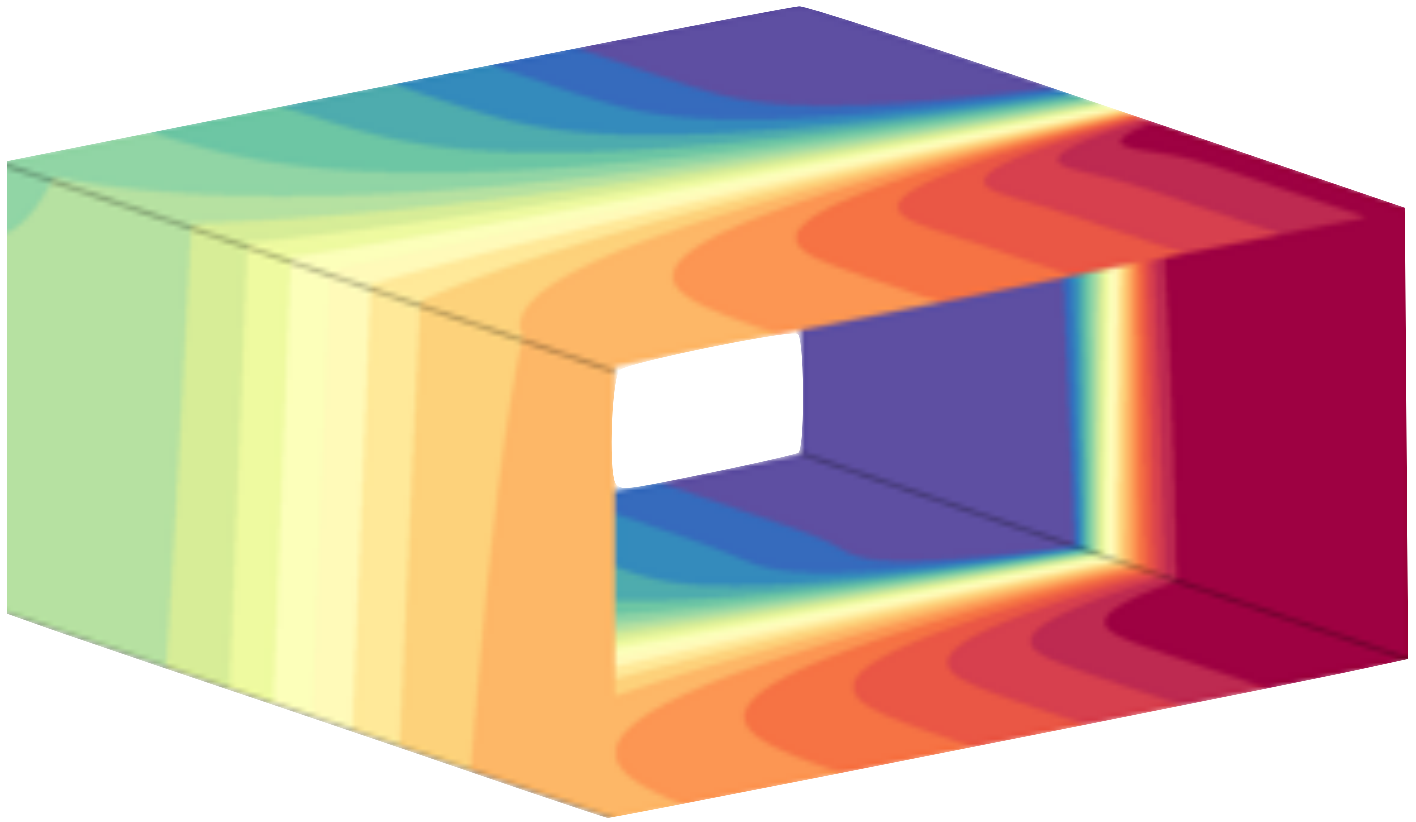
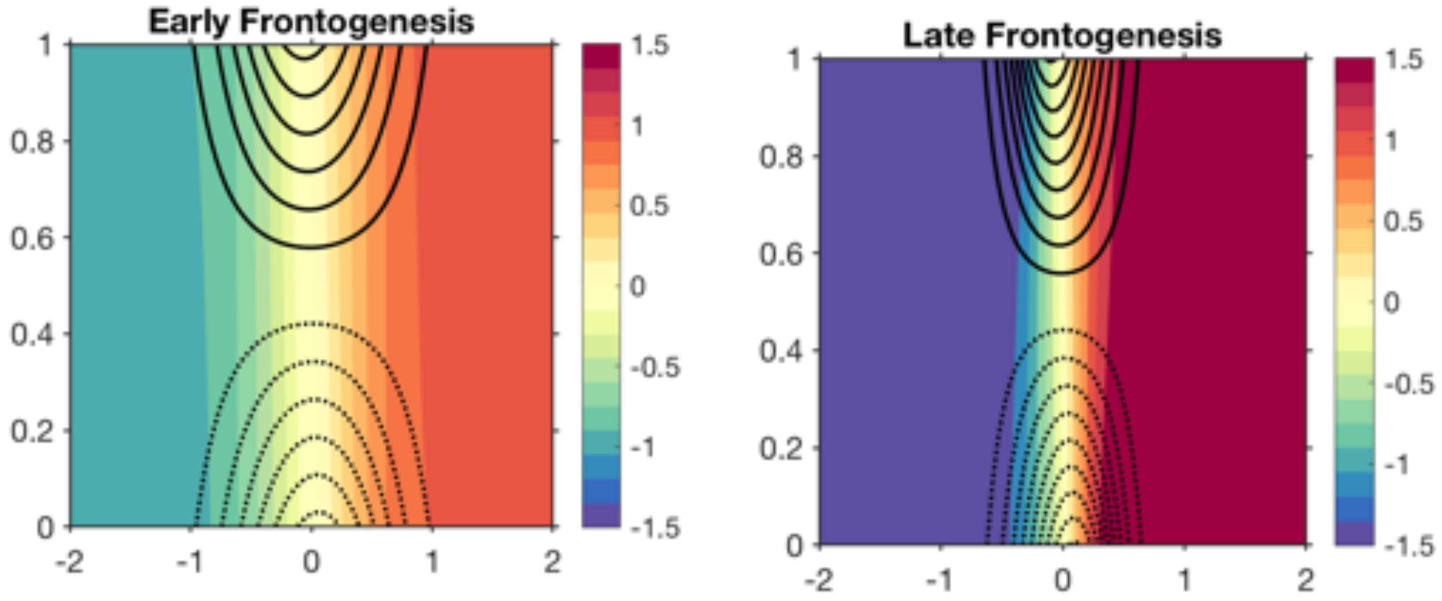


Turbulence affects (submesoscale) frontal dynamics

- Classic theory of fronts predicts that the cross-frontal scale becomes infinitely thin within a finite time

- A modified theory including turbulence helps explain the scale observed





A perturbation approach to understanding the effects of turbulence on frontogenesis.

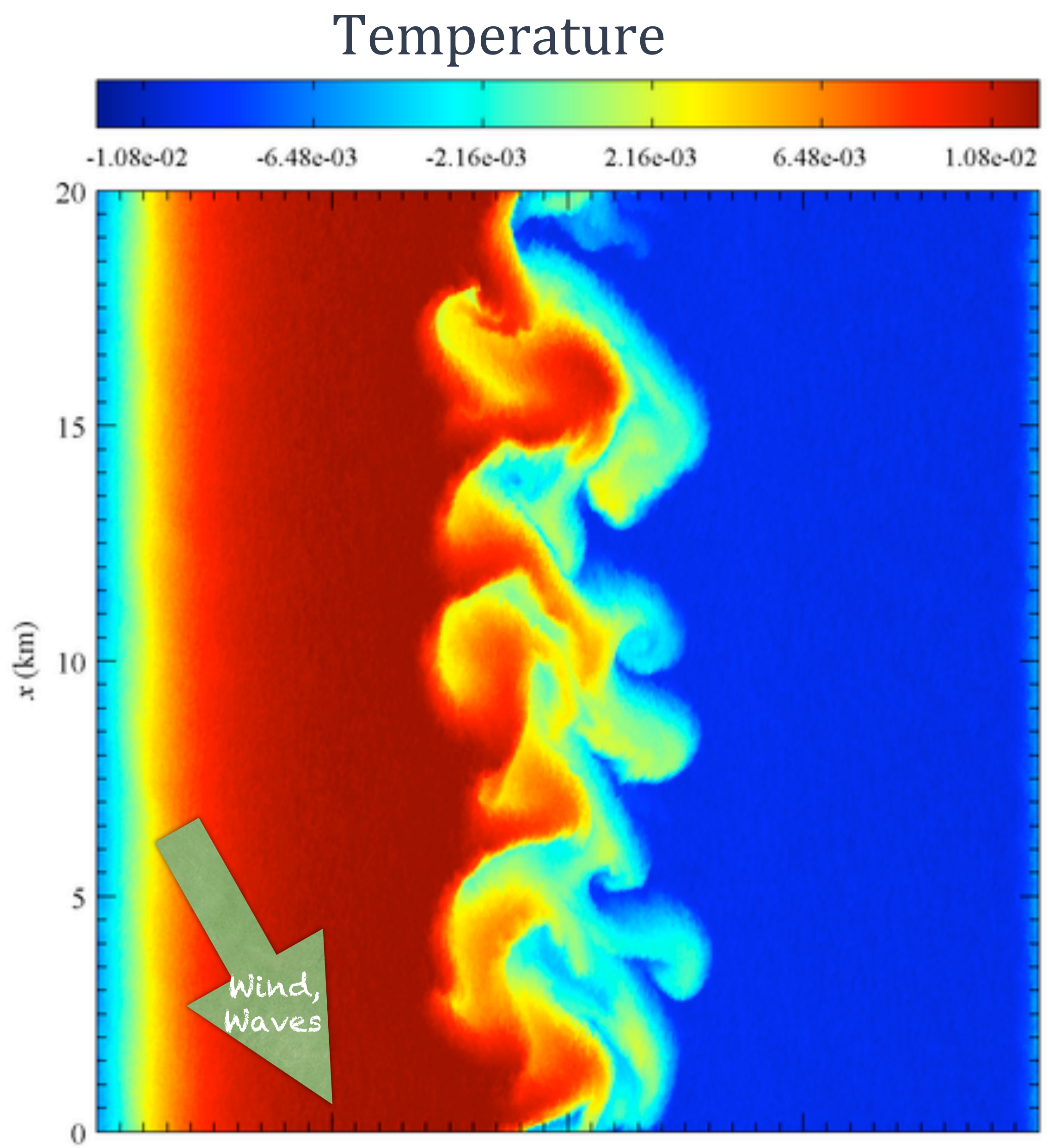
A. Bodner, B. Fox-Kemper, L. Van Roekel, J. McWilliams, and P. Sullivan:

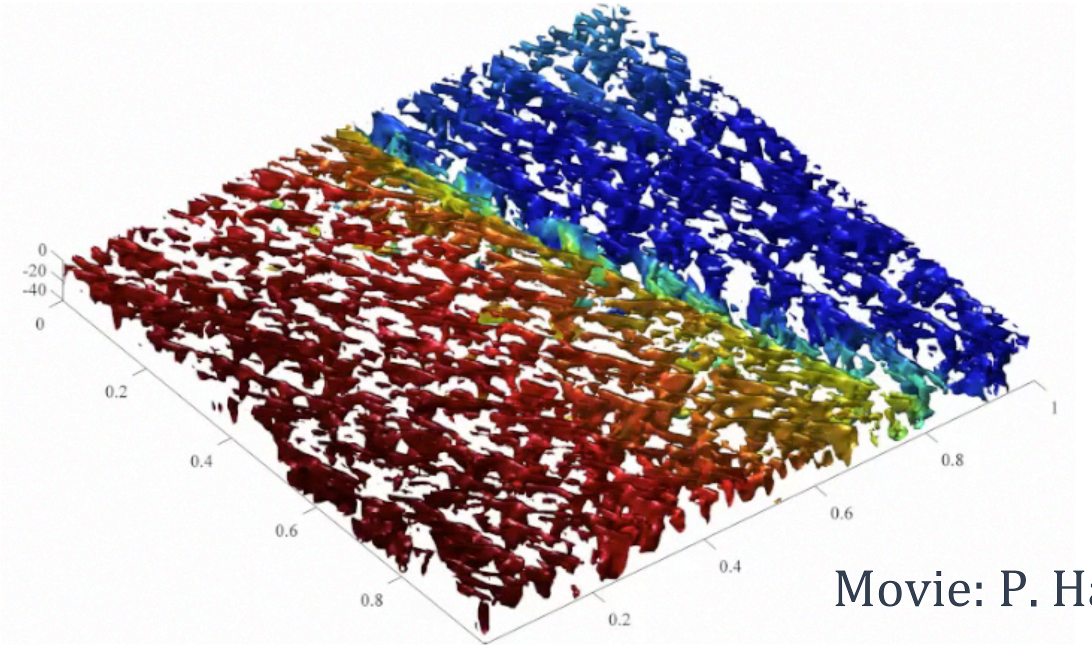
Journal of Fluid Mechanics (under review).

Turbulence affects (submesoscale) frontal dynamics

LES of submesoscale temperature front with Langmuir turbulence (waves & winds).

Domain size: 20km x 20km x -160m
Resolution: 5m x 5m x -1.25m





Movie: P. Hamlington

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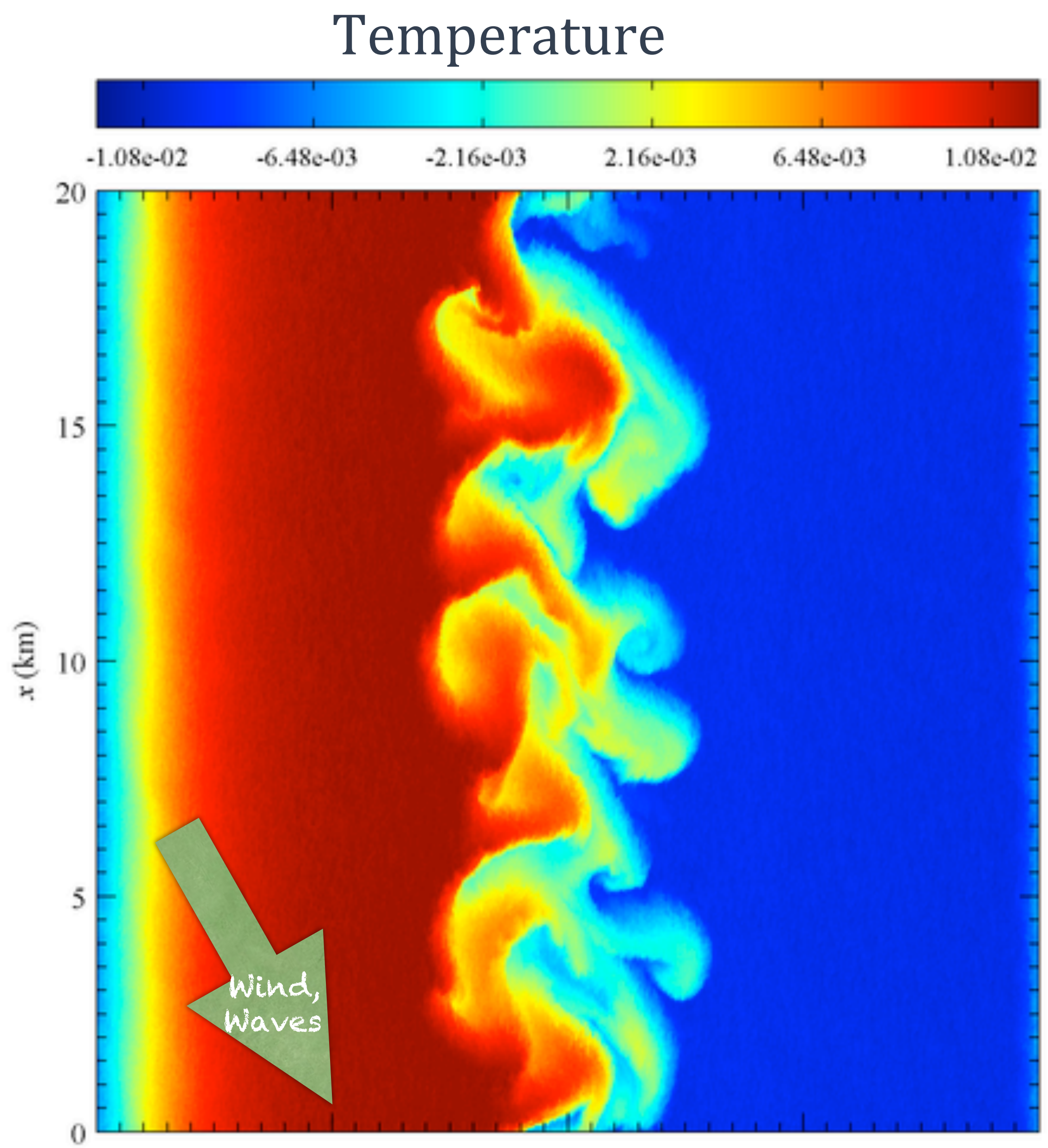
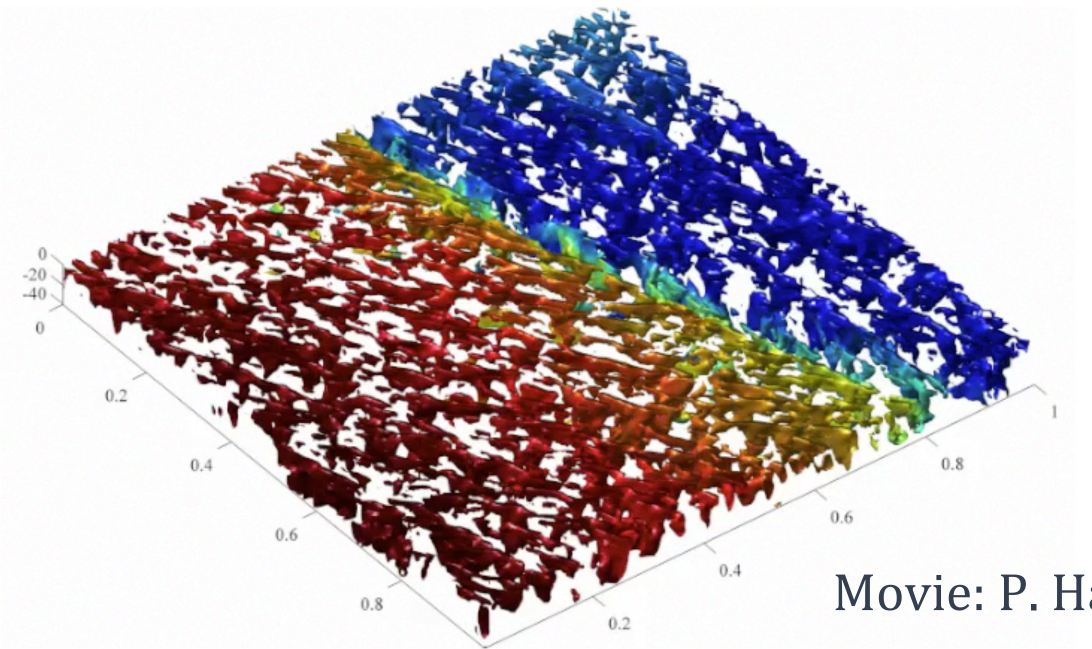
Potential Vorticity

- Fundamental in mesoscale / submesoscale dynamics
- Used to study frictional fluxes

$$q = (f + \nabla \times \vec{u}) \cdot \nabla\theta$$





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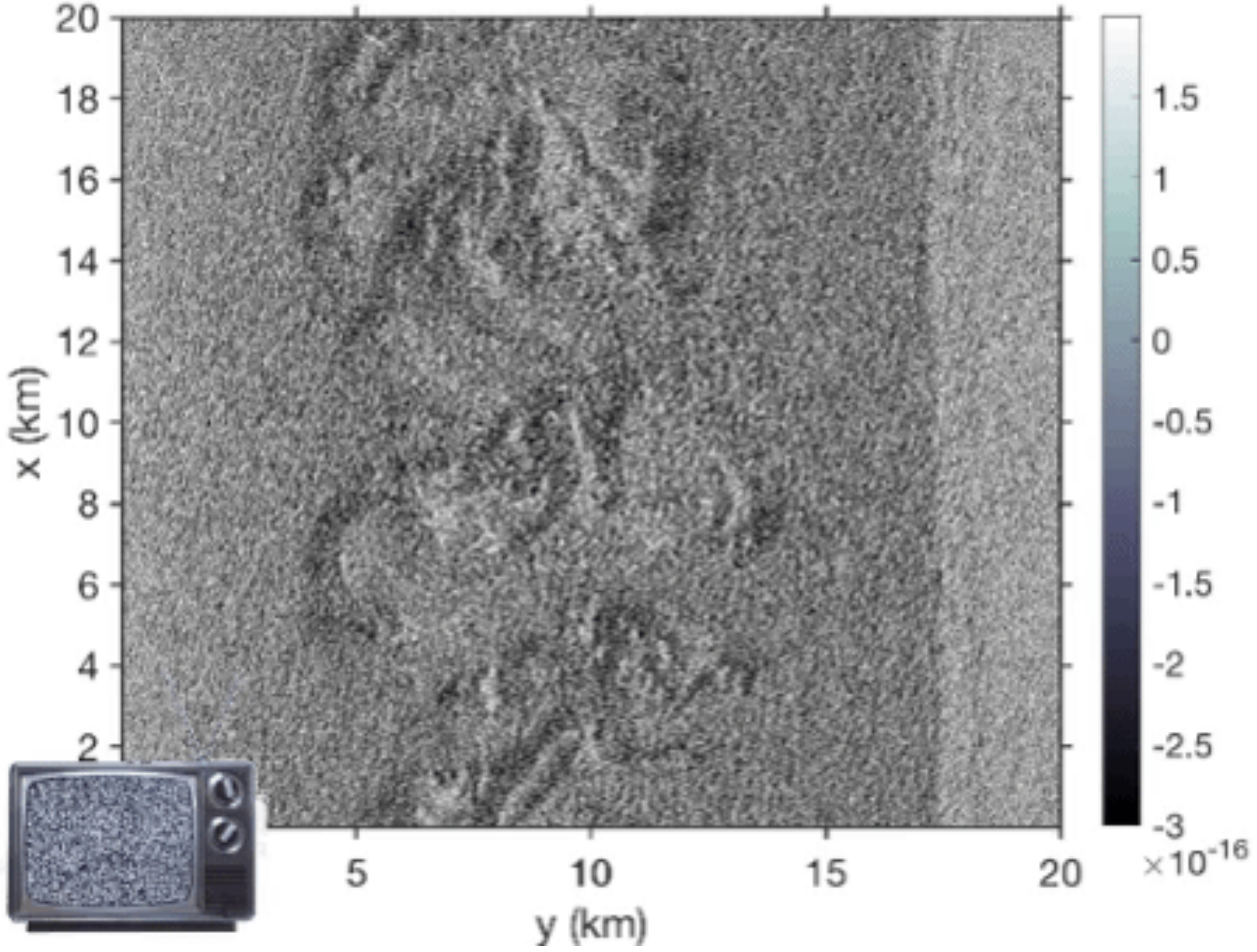

Potential Vorticity in Isotropic Turbulence

$$q = (f + \nabla \times \vec{u}) \cdot \nabla\theta$$

No statistically meaningful directionally

$$\overline{\nabla \times \vec{u}} = 0$$

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Nonlinearity of PV retains gradients

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$$\overline{A'} = 0, \ \overline{B'} = 0 \quad \rightarrow \quad \overline{A'B'} \neq 0$$

Similar to Reynolds average

Spectral Analysis

$$E(k) = \hat{u}(k) \cdot \hat{u}^*(k)$$

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Submesoscale

$$E(k) \propto k^{-2}$$

3D Turbulence

$$E(k) \propto k^{-\frac{5}{3}}$$

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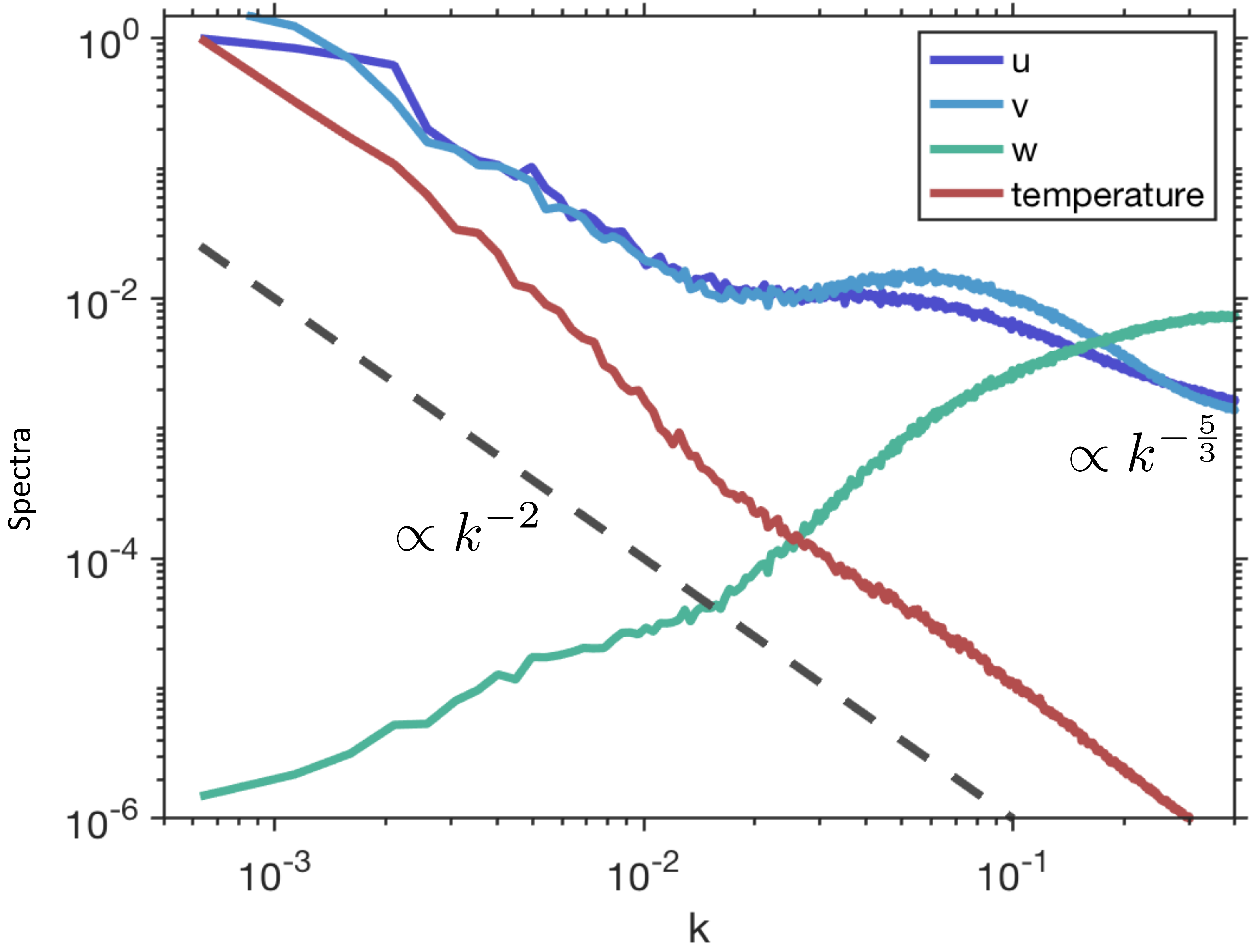
Velocity and Temperature



Data from Hamlington et. al. (2014), Suzuki et. al. (2016)

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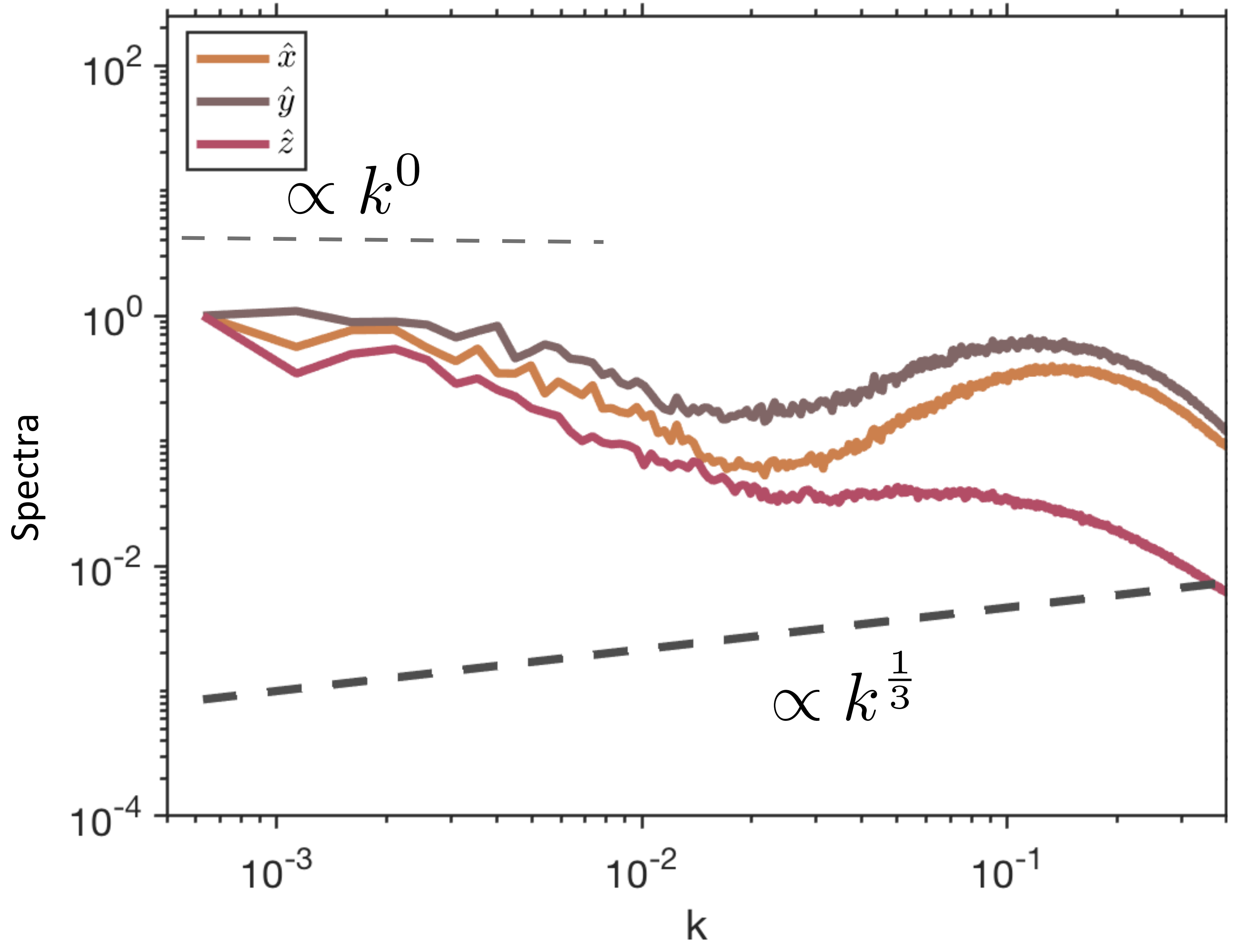
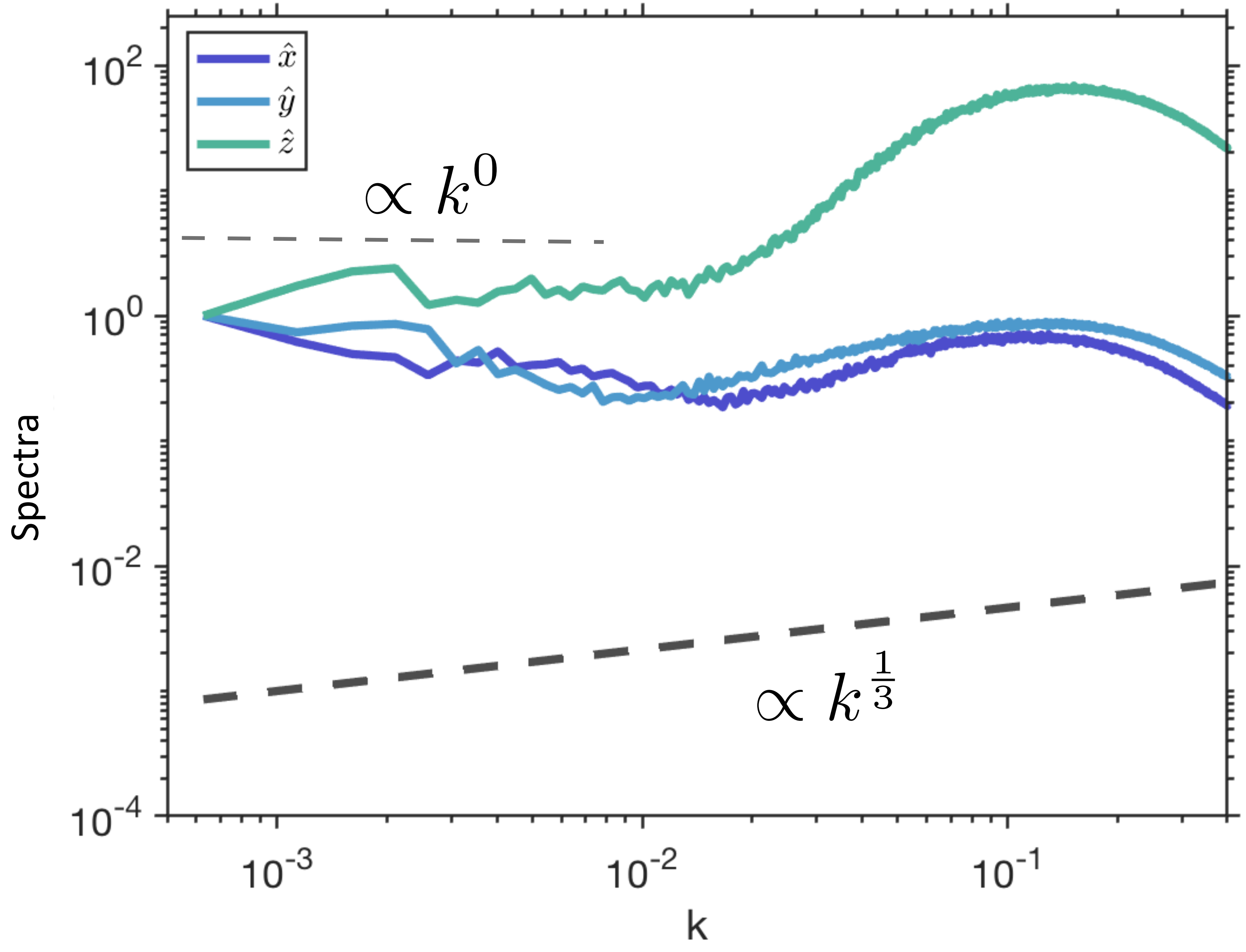
Temperature gradient $\nabla\theta$

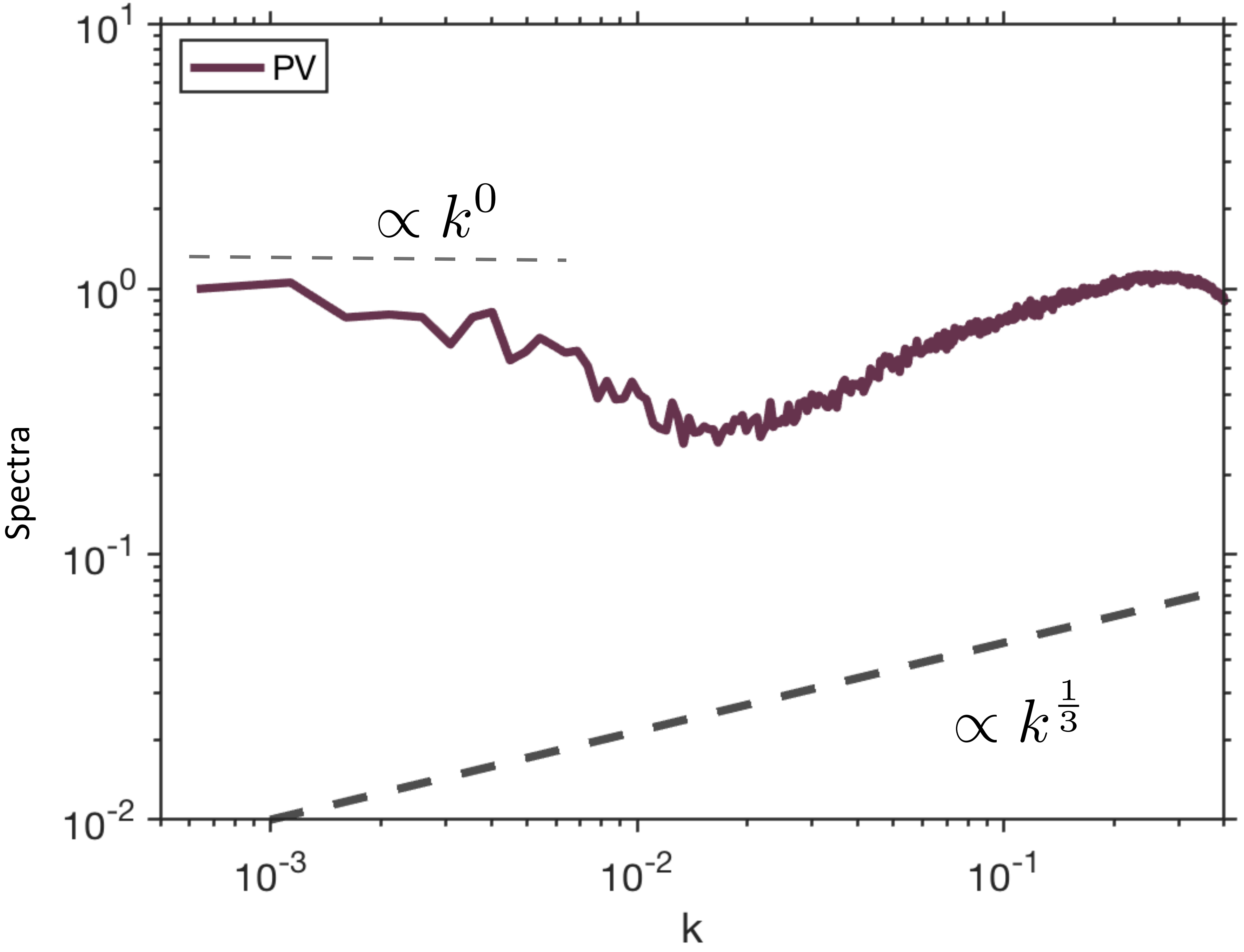


Vorticity $\nabla \times \vec{u}$



Smallest scales dominate !!
Ultraviolet catastrophe !!

Potential Vorticity $q = (f + \nabla \times \vec{u}) \cdot \nabla\theta$



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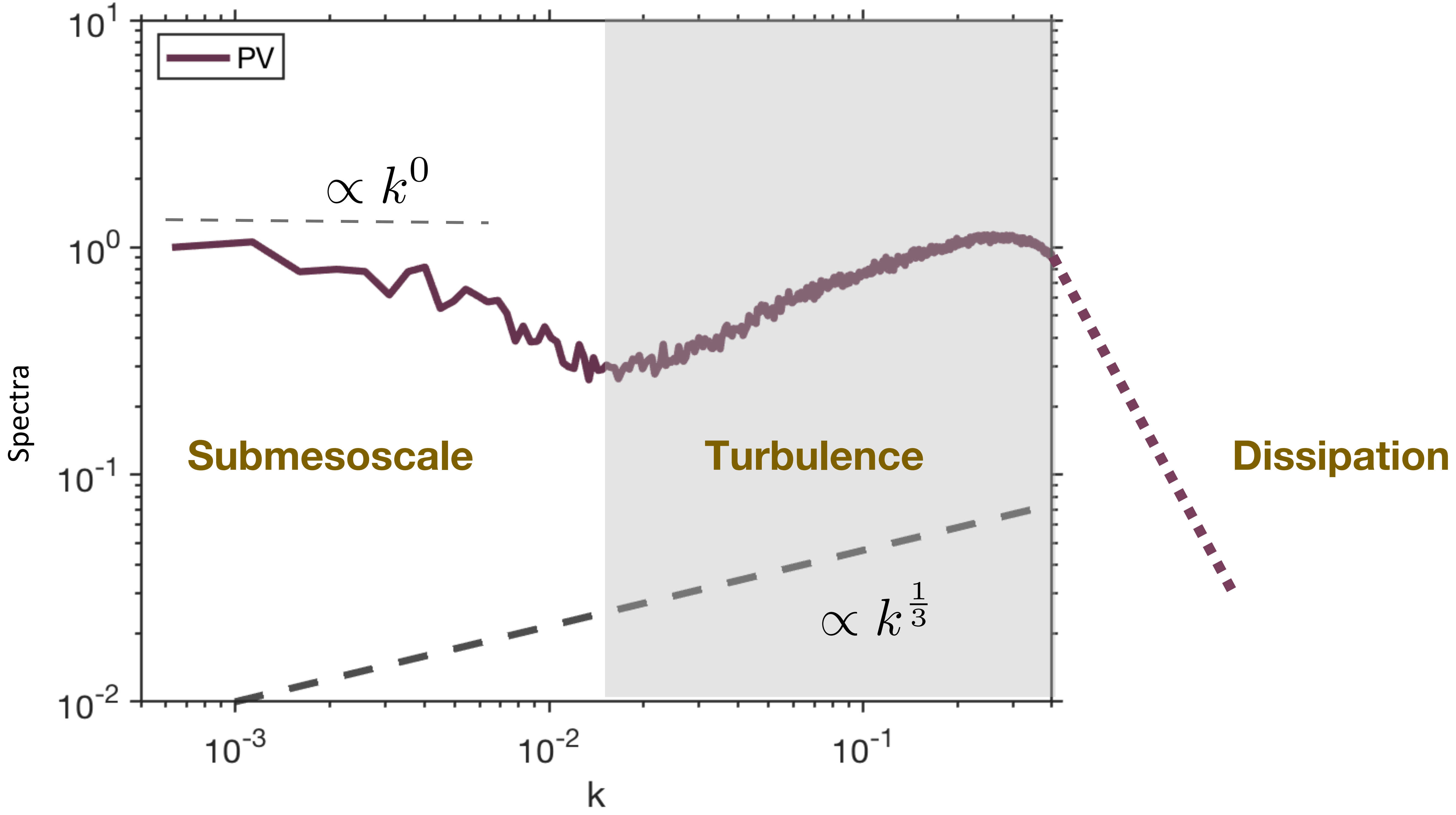
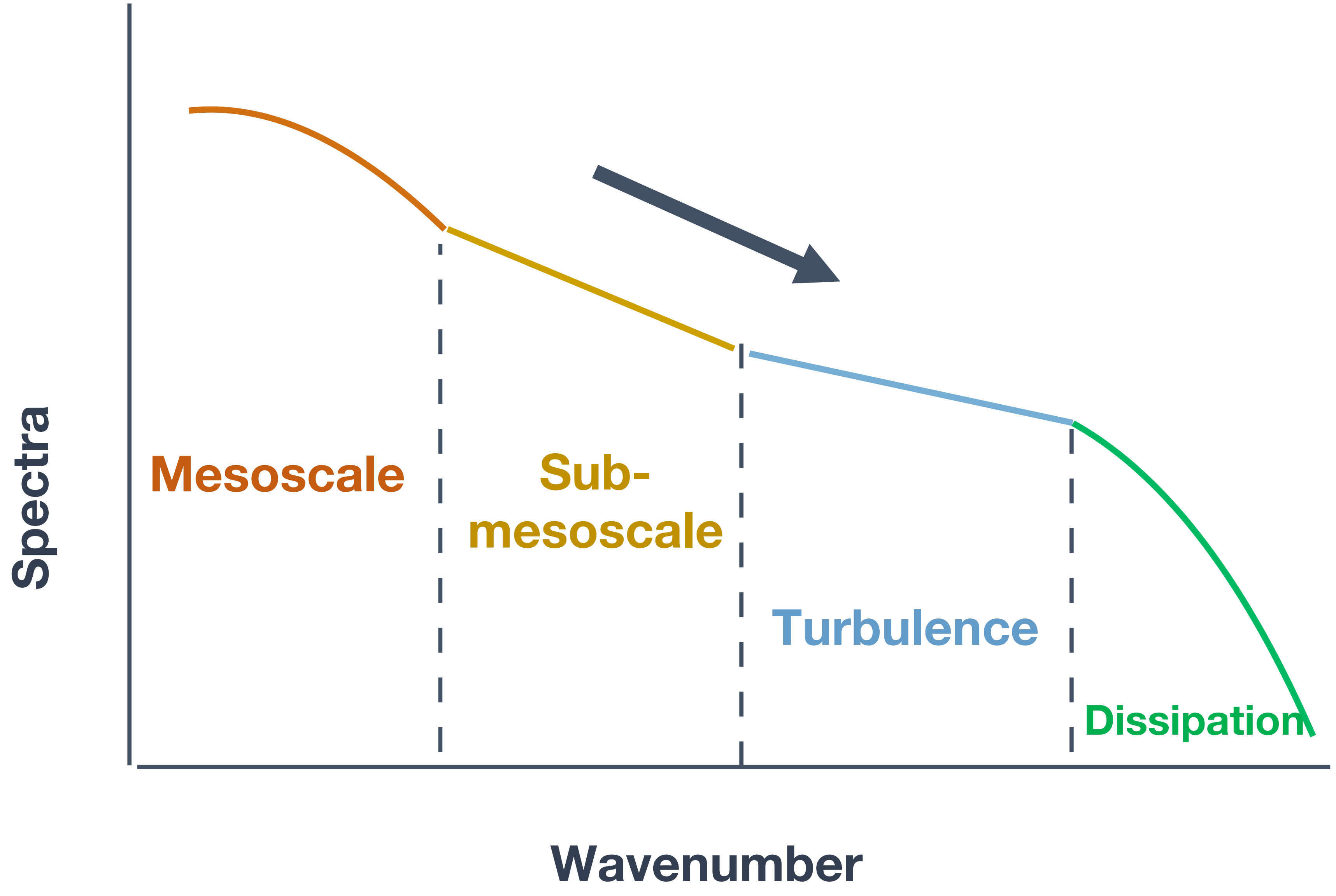
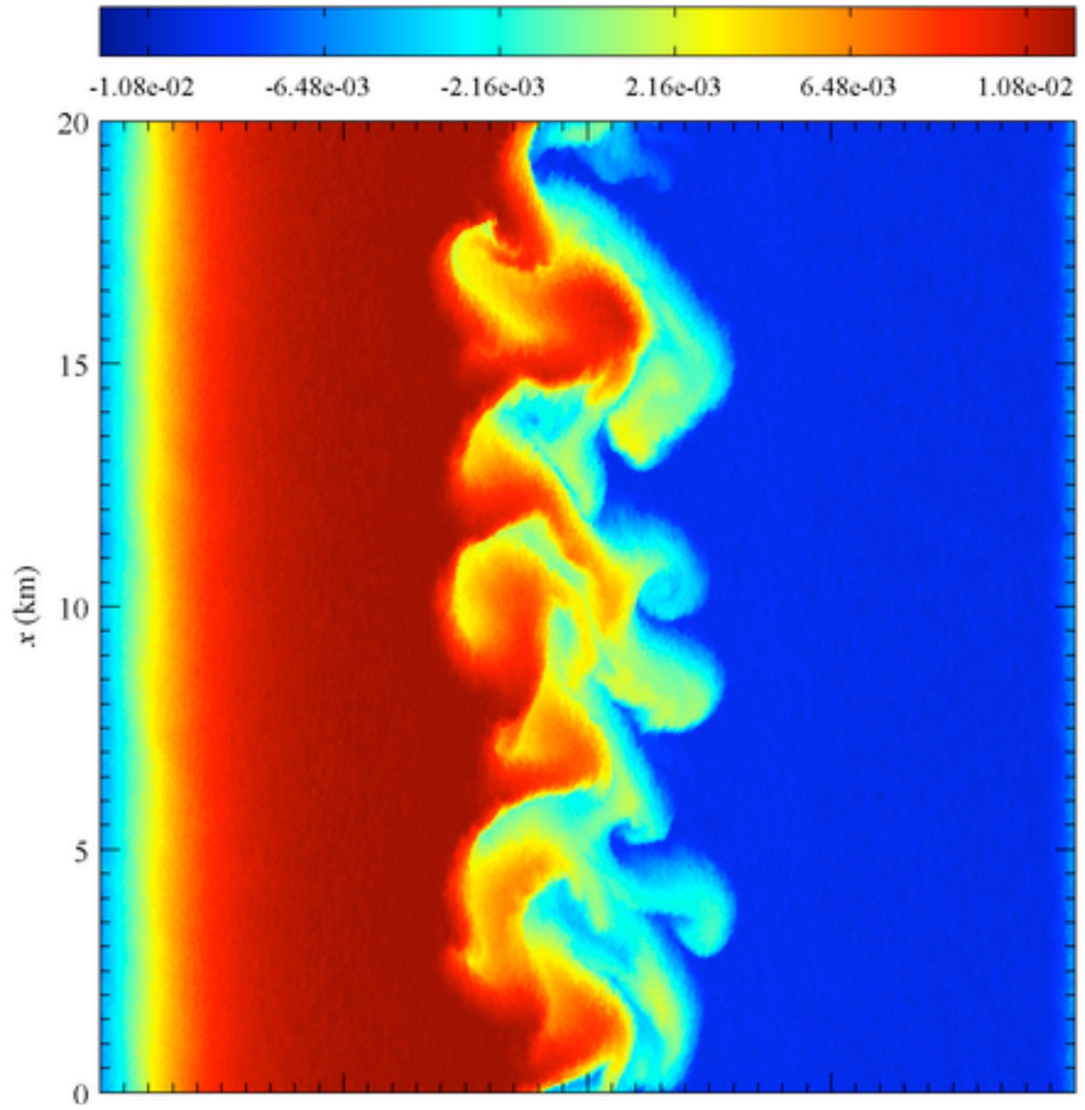


The failure of PV signals the bottom limit of the submesoscales

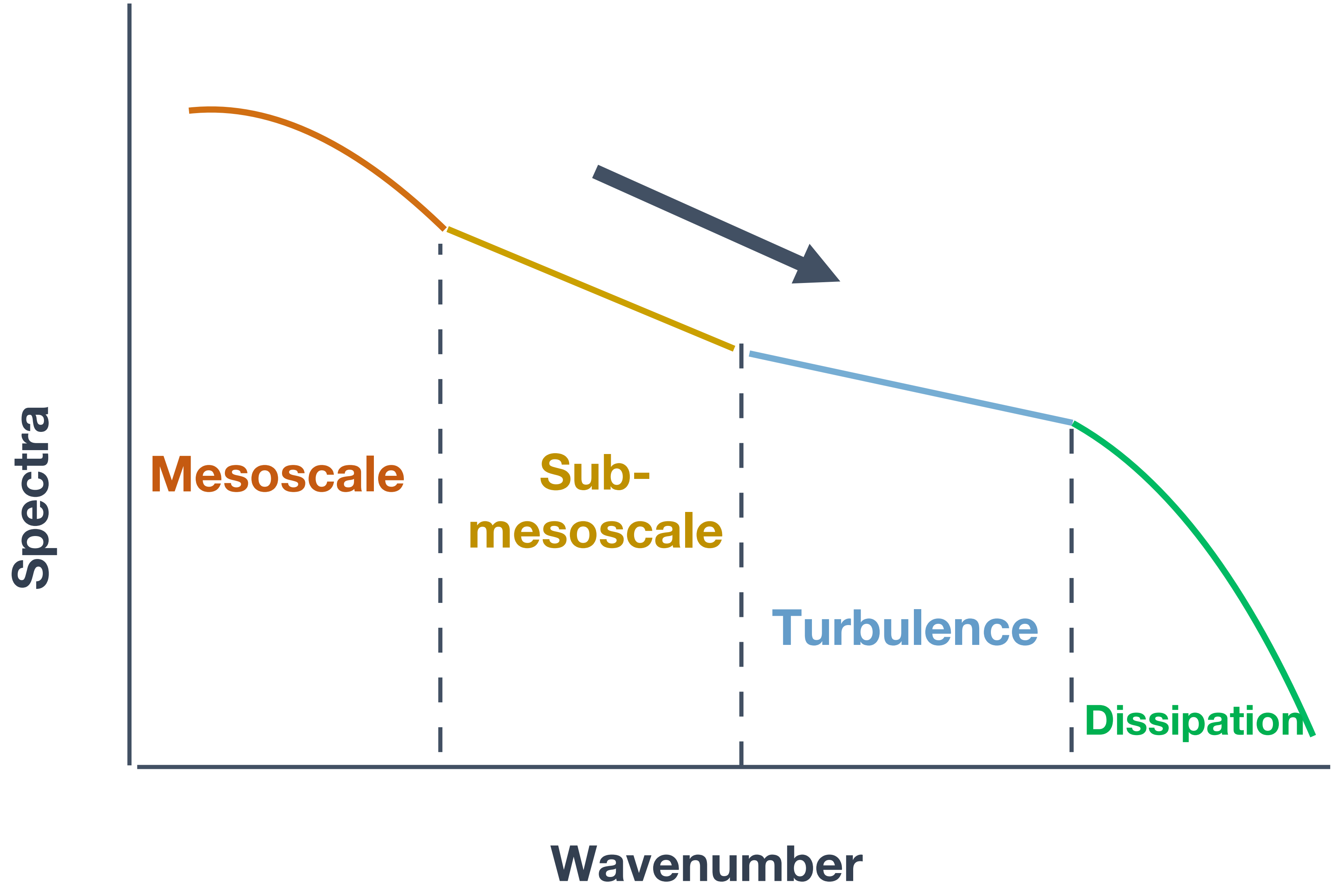
Models such as LES and ROMS rely on smallest scales having the smallest variance

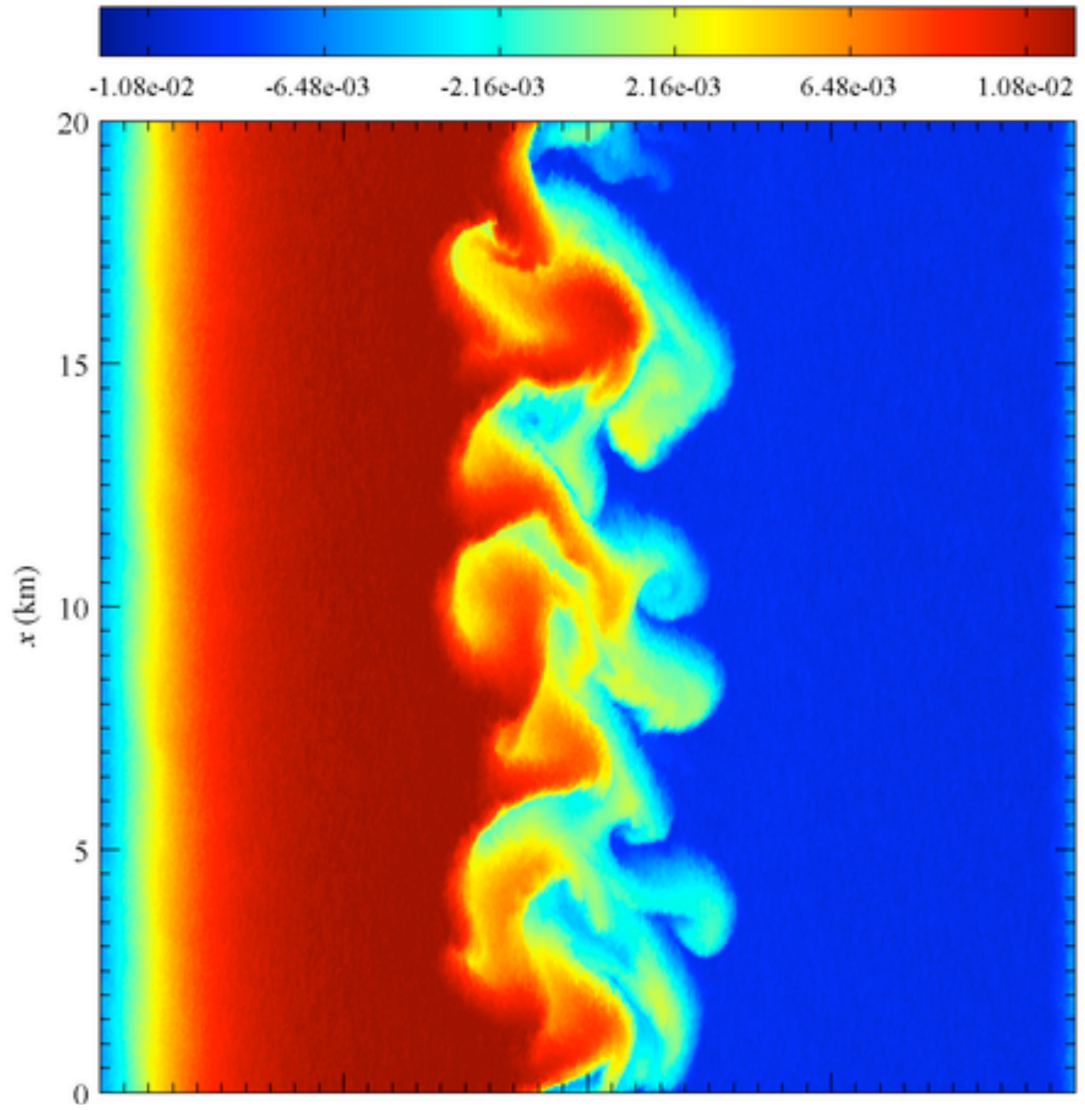




Models such as LES and ROMS rely on smallest scales having the smallest variance

→ Only fully resolved (DNS) potential vorticity is meaningful below the submesoscale





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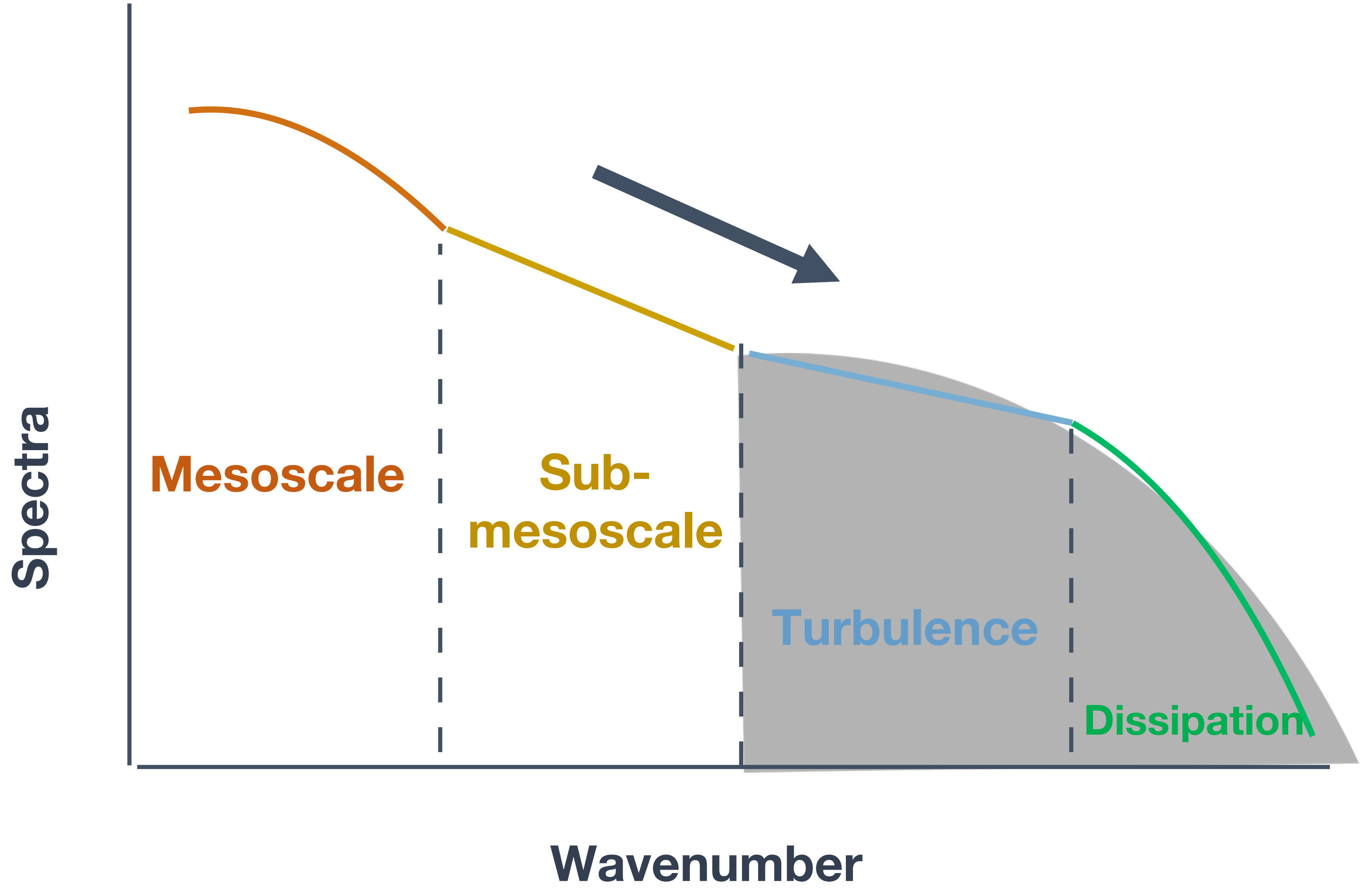
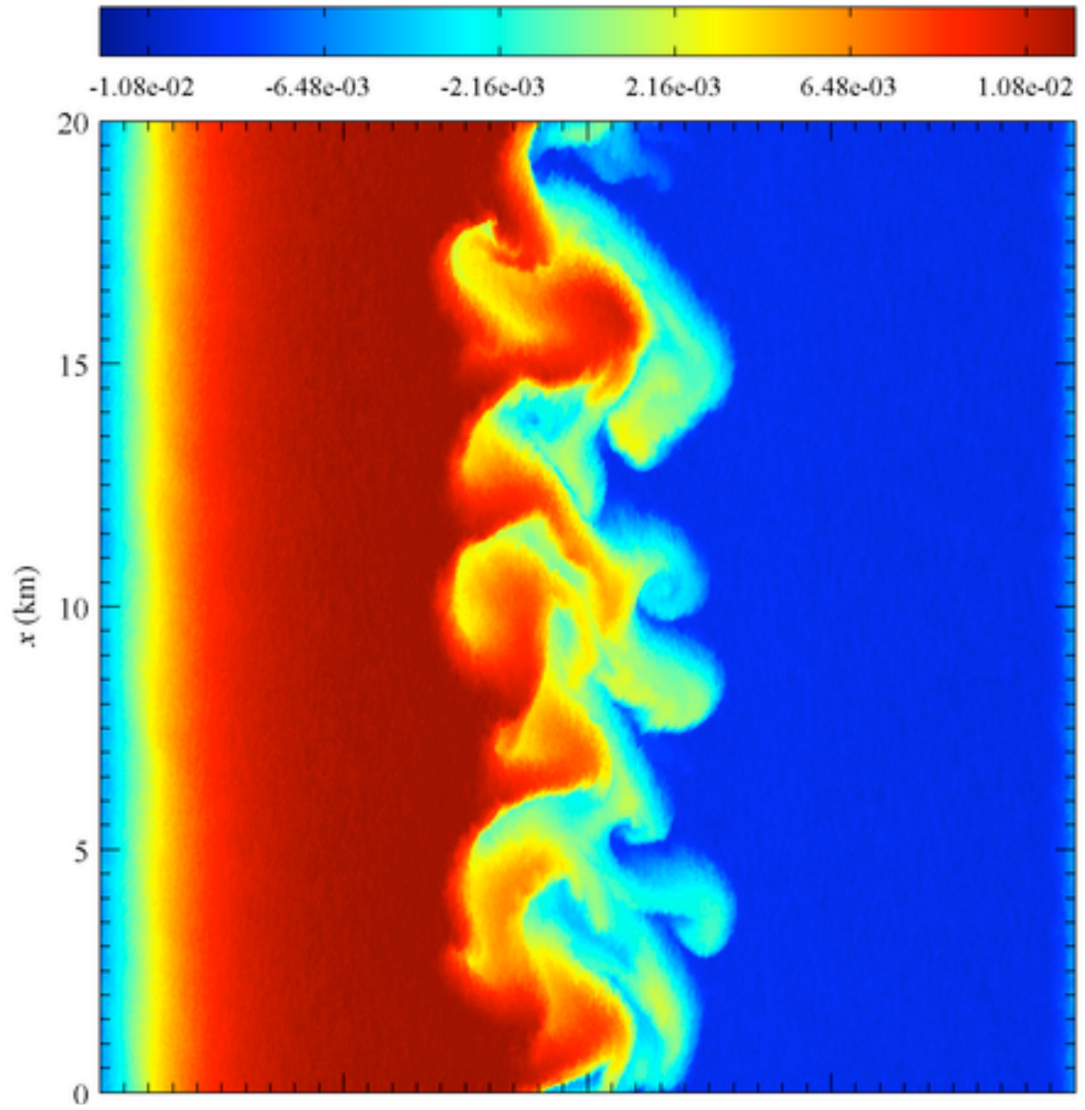
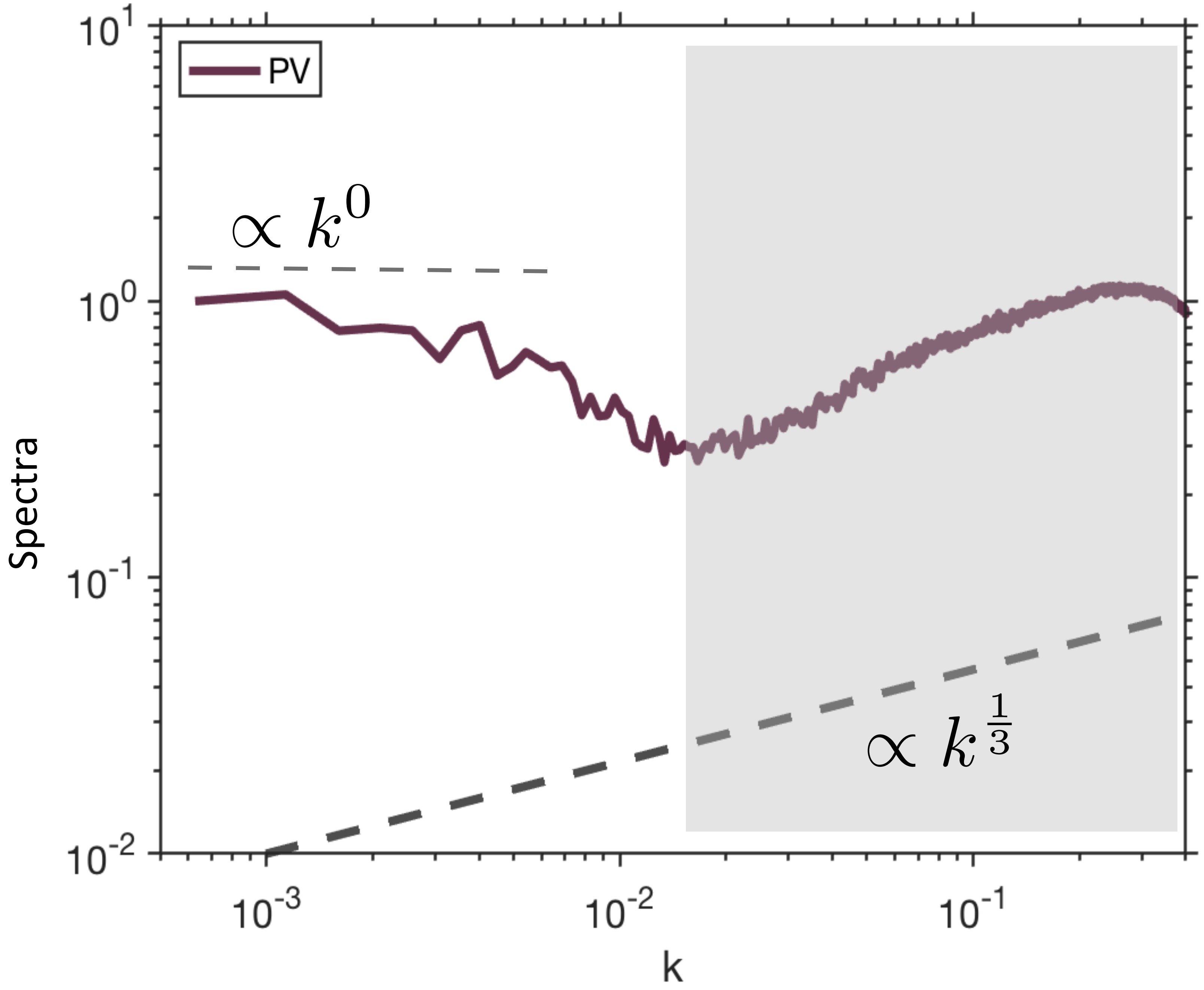




Submesoscale limit defined by potential vorticity



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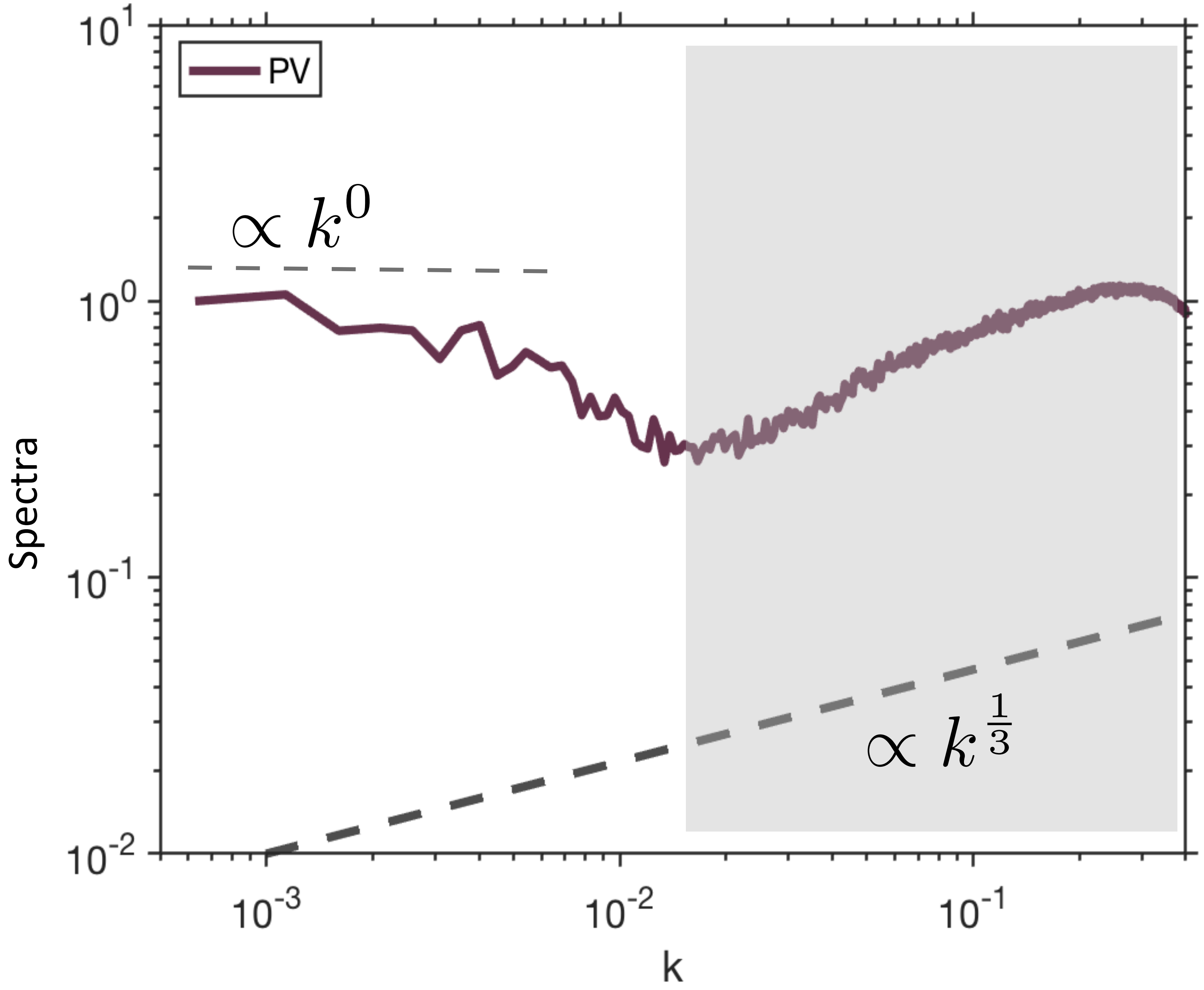
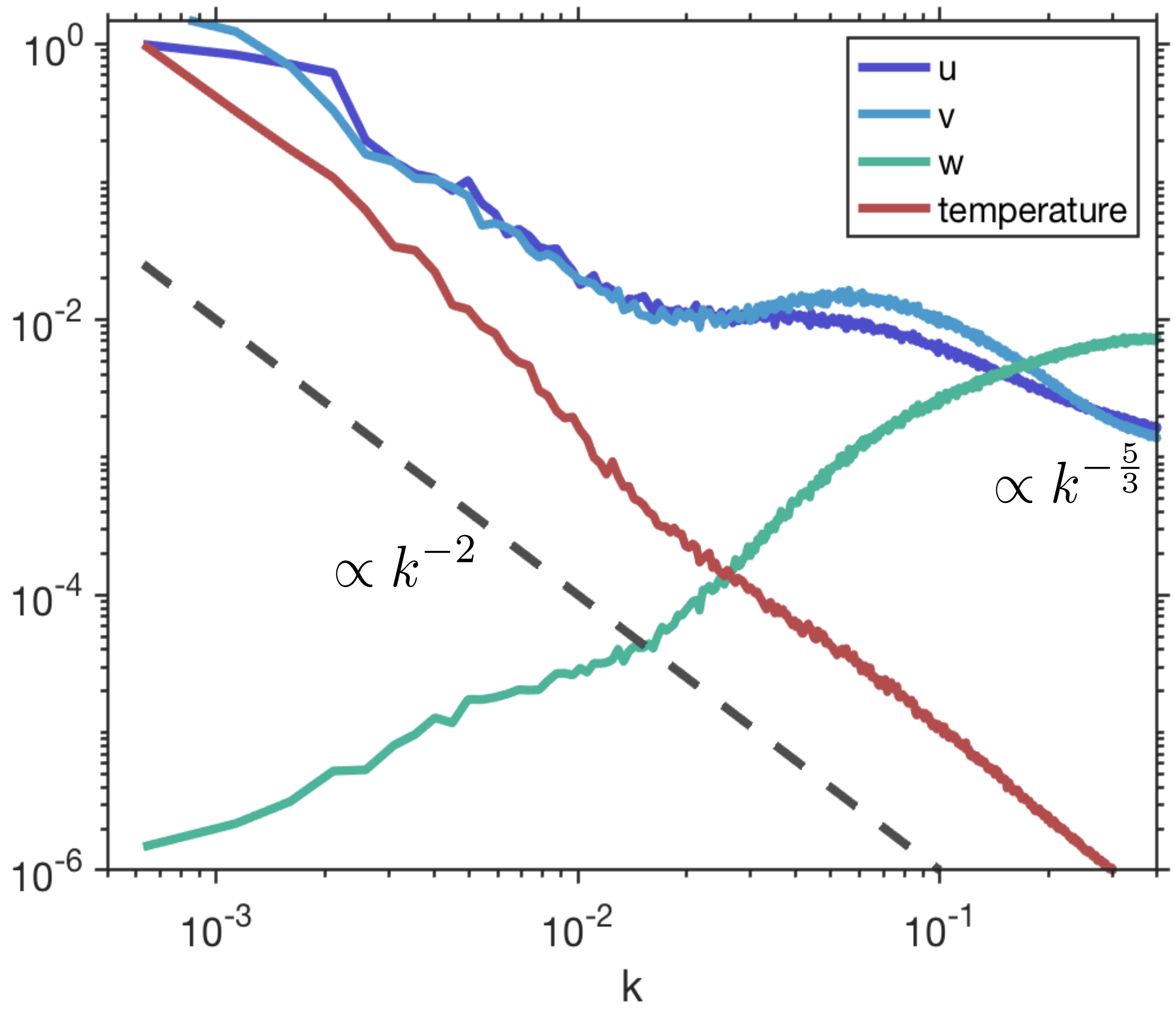


filter velocity and temperature



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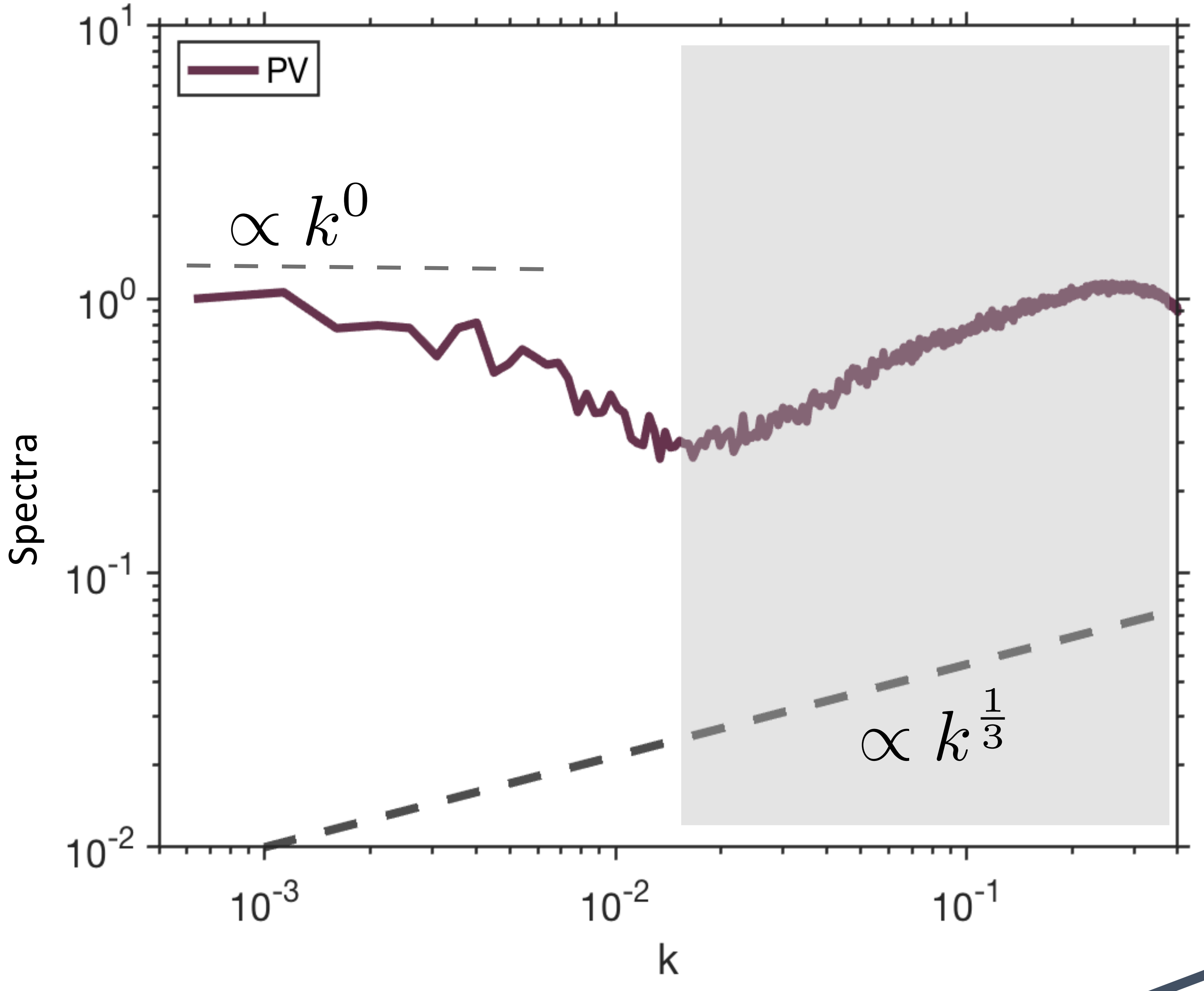

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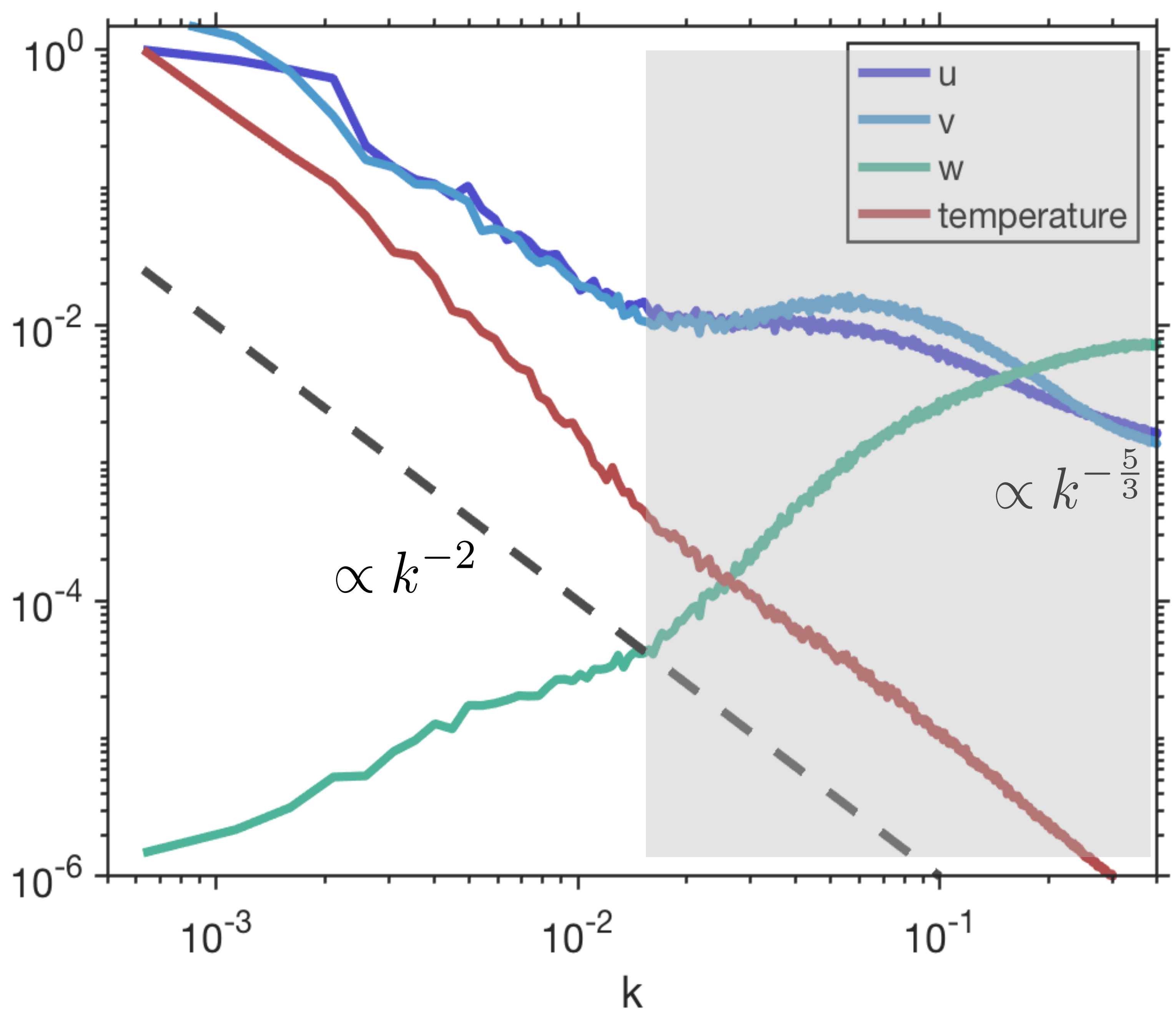
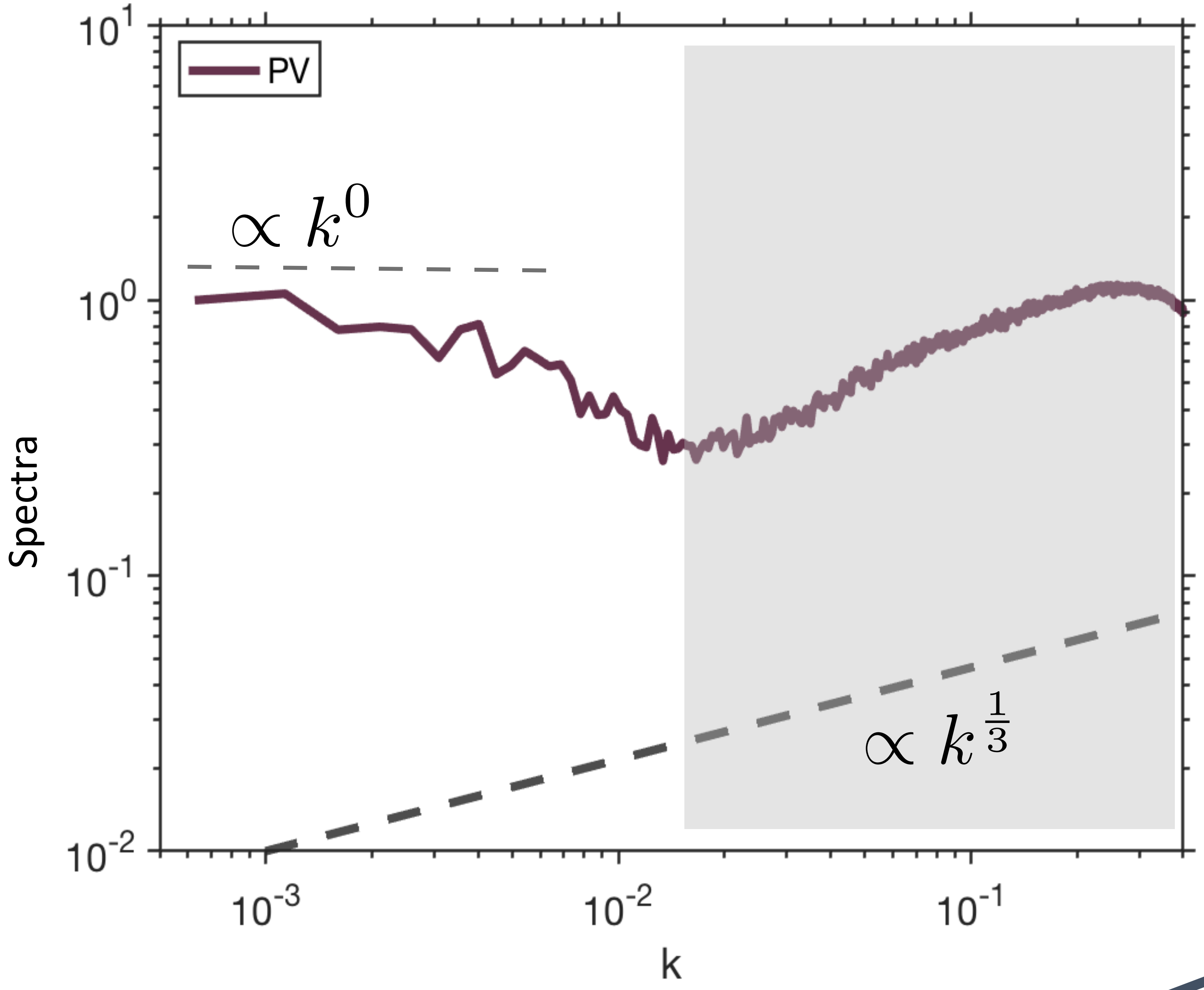


$$\tilde{u},\ \tilde{v},\ \tilde{w},\ \tilde{\theta}$$

Submesoscale limit defined by potential vorticity



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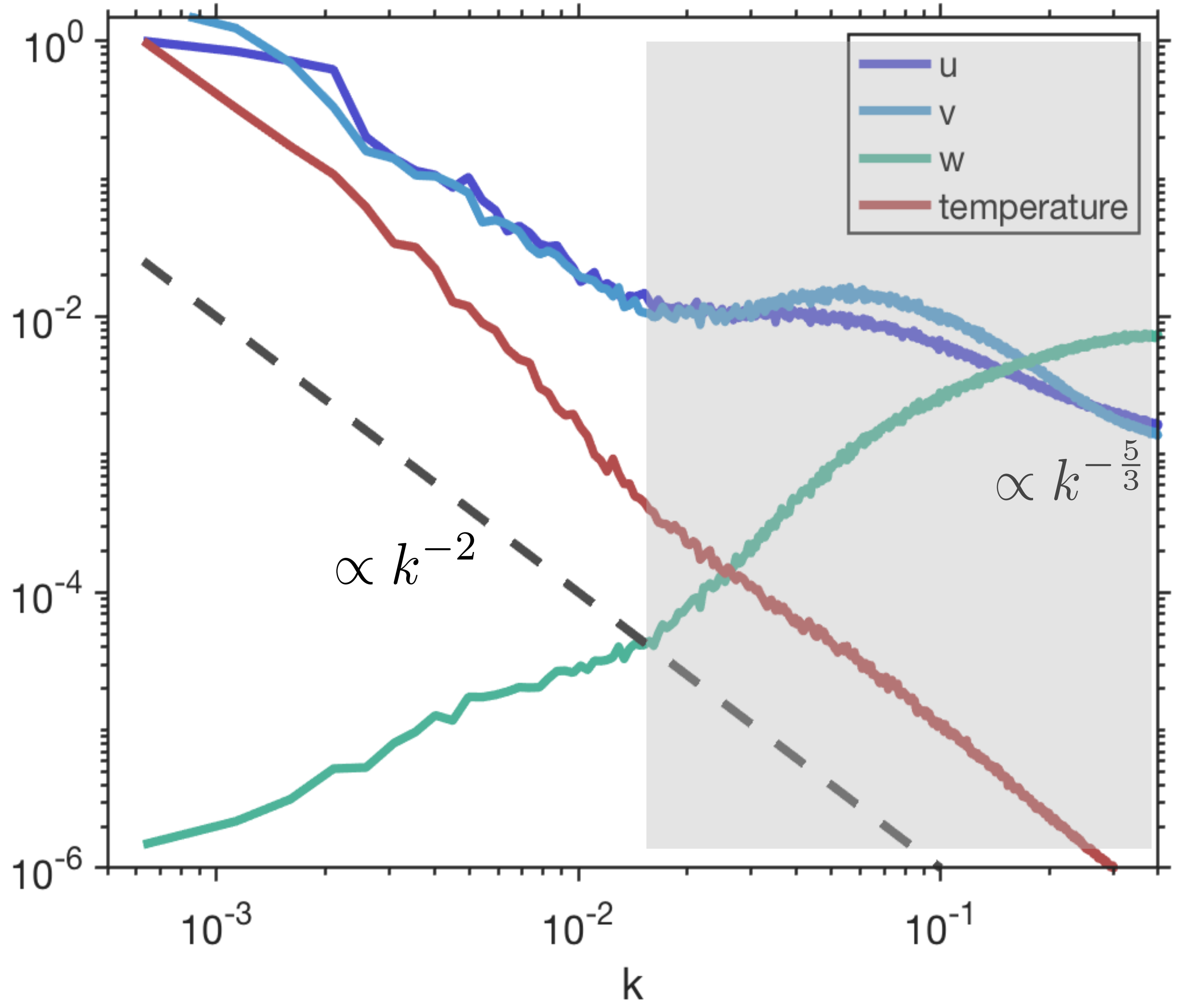
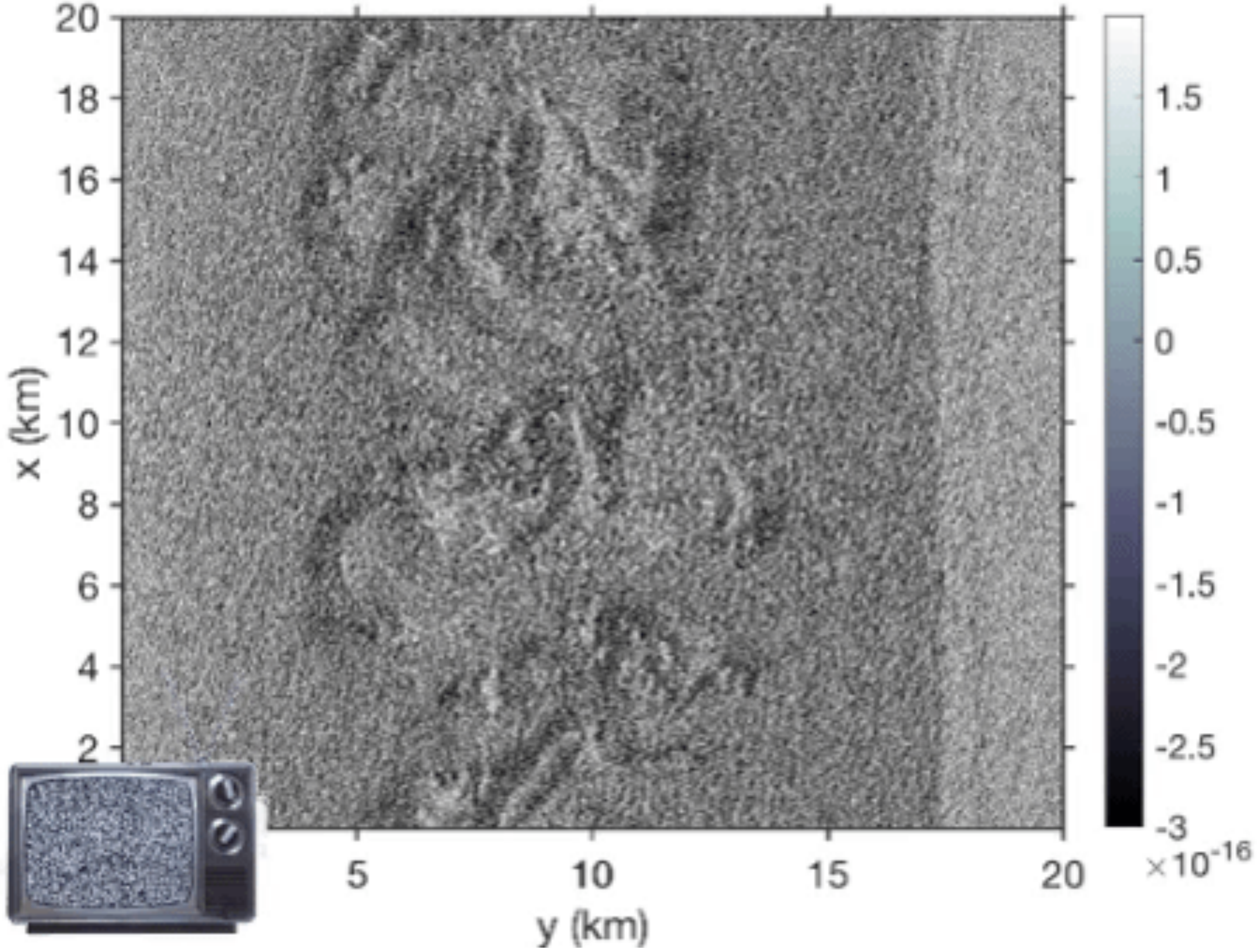


$$\tilde{u},\ \tilde{v},\ \tilde{w},\ \tilde{\theta} \longrightarrow \tilde{q} = (f + \nabla \times \tilde{u}) \cdot \nabla\tilde{\theta}$$

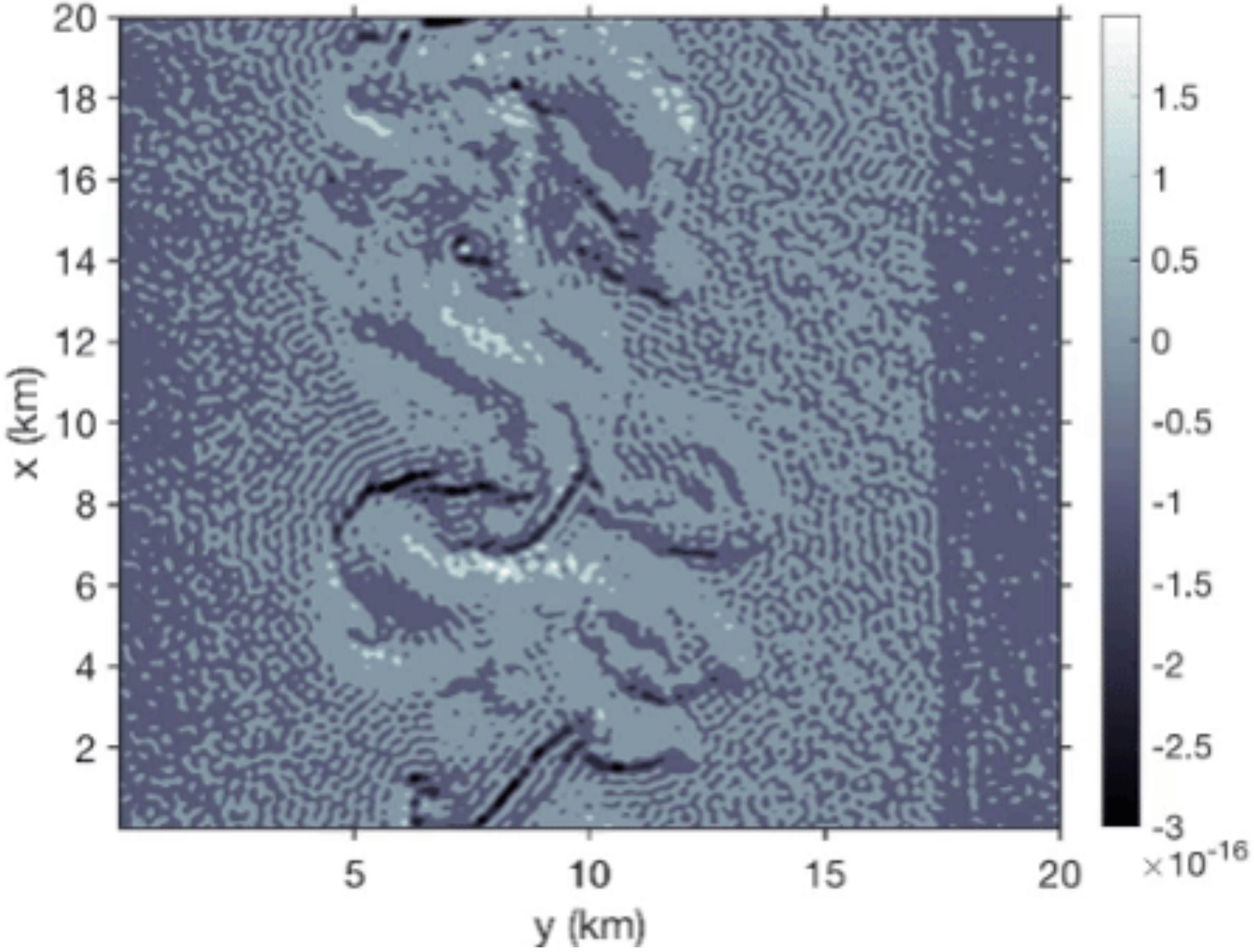
“noisy” potential vorticity

$$q = (f + \nabla \times \vec{u}) \cdot \nabla\theta$$



pre-filtered potential vorticity

$$\tilde{q} = (f + \nabla \times \tilde{u}) \cdot \nabla\tilde{\theta}$$



Summary

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