A Wavenumber–Frequency Spectrum Model for Sheared Convective Atmospheric Boundary Layer Flows

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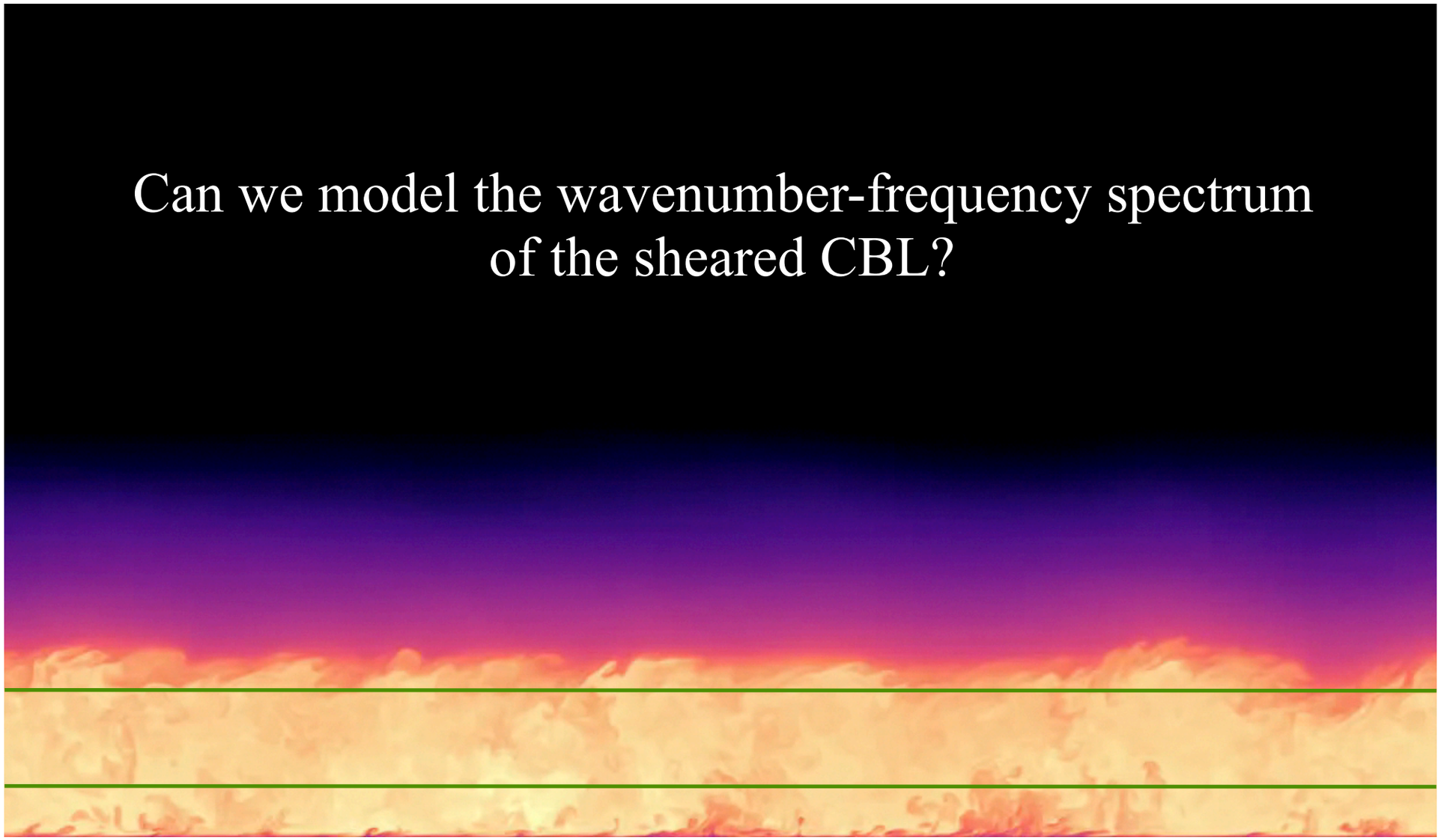
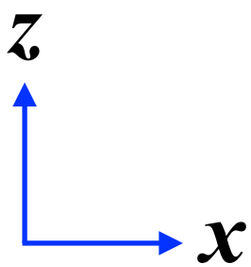
Convective Boundary Layer (CBL)

Vertical Cross-Section of the Buoyancy: Direct Numerical Simulation (DNS)



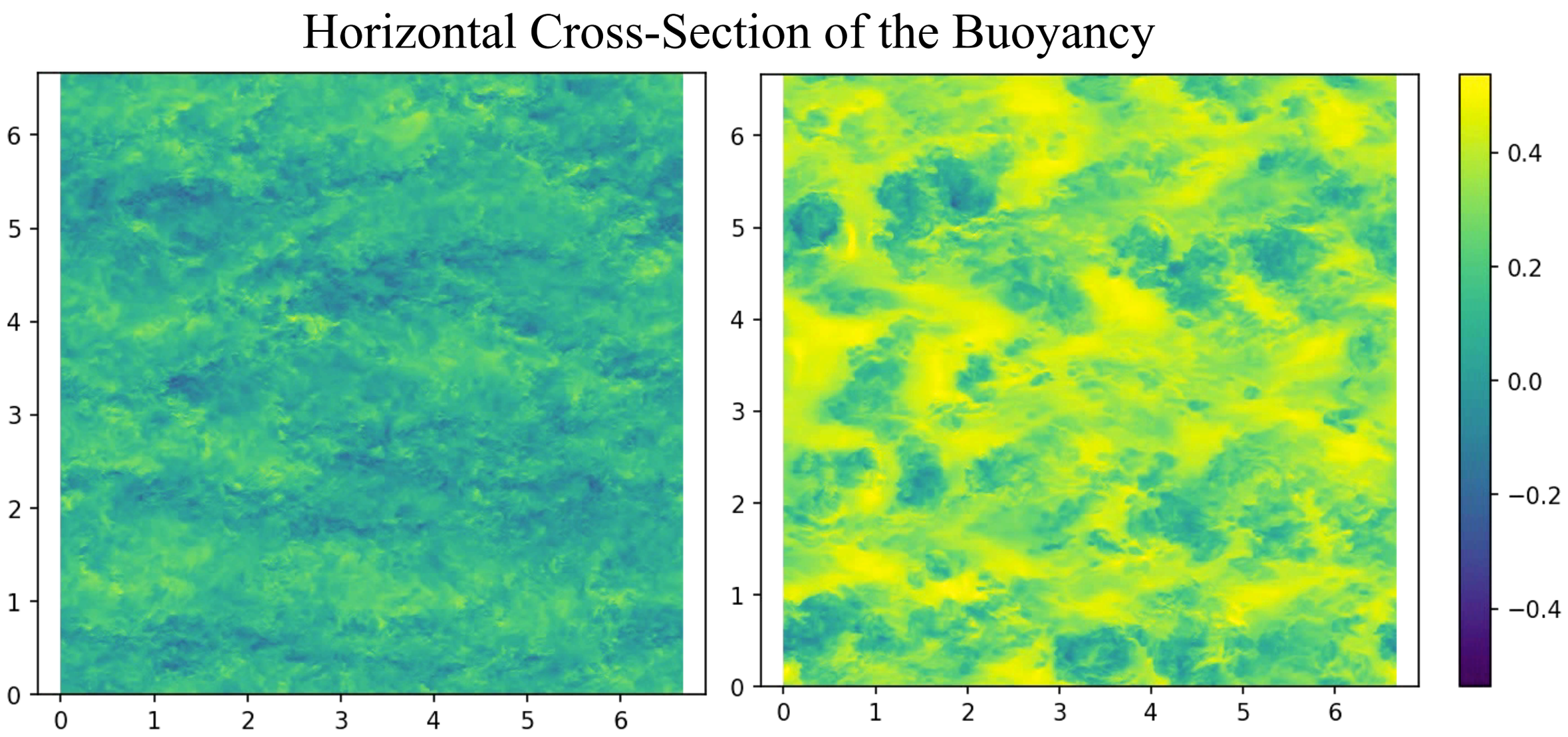
Entrainment Zone

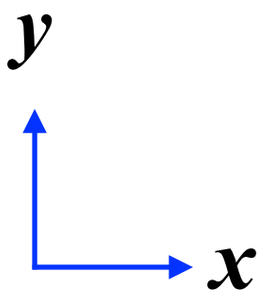
Mixed Layer



Haghshenas and Mellado 2019

Convective Boundary Layer: Mixed Layer and Entrainment Zone



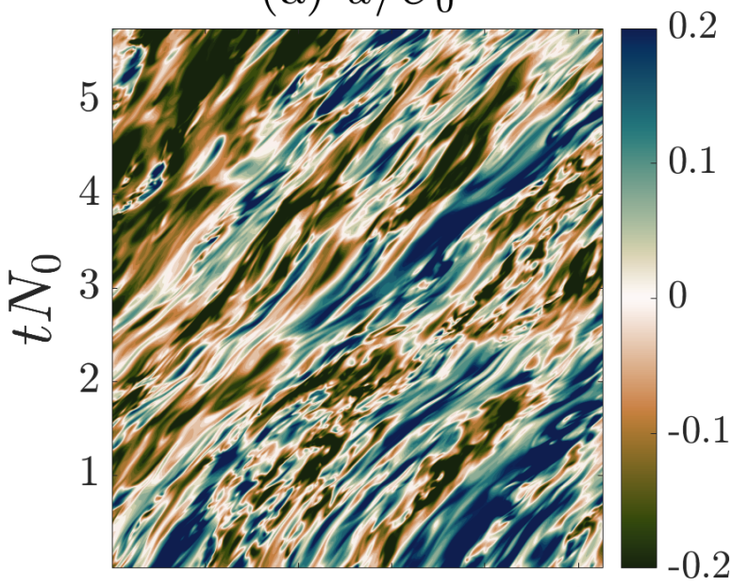


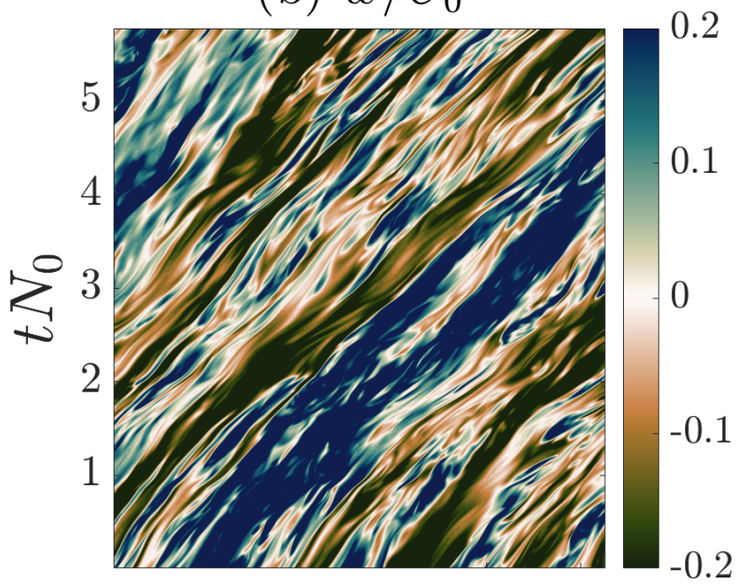
Haghshenas and Mellado 2019

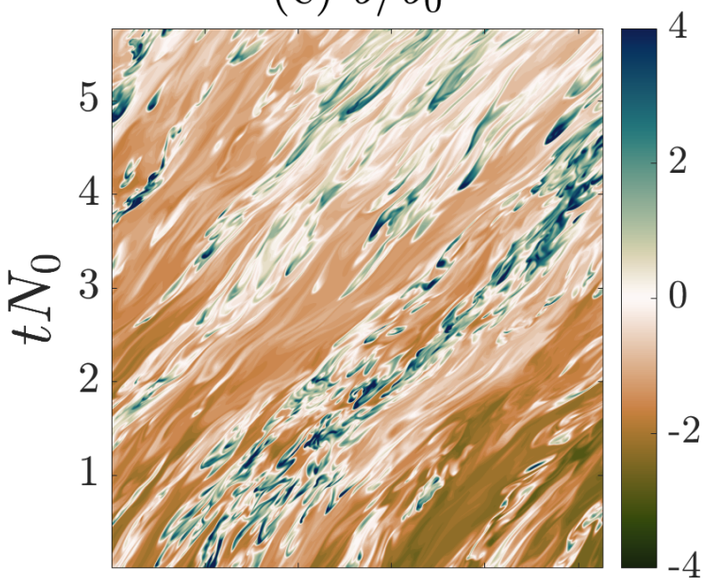
Numerical Simulations: space-time structure

Streamwise Velocity | **Vertical Velocity** | **Buoyancy**

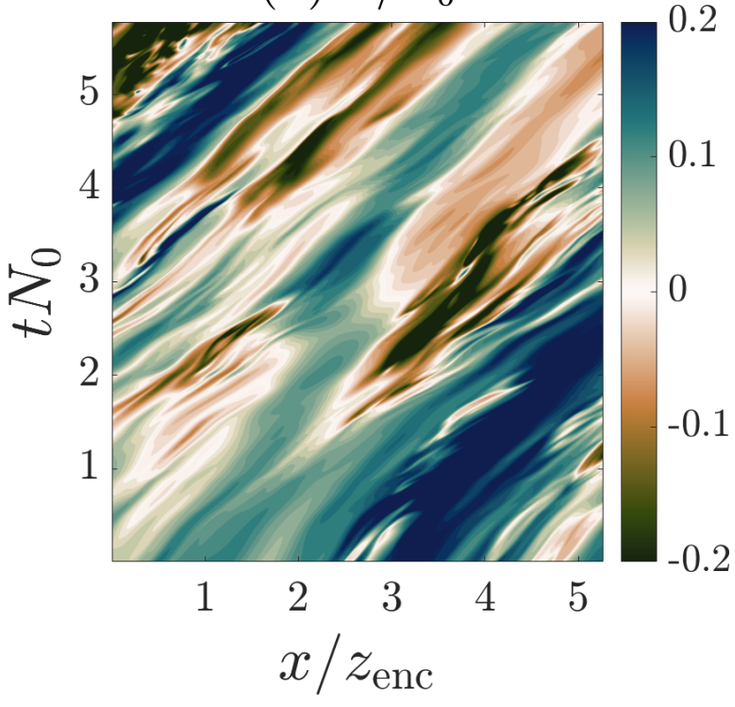
ML

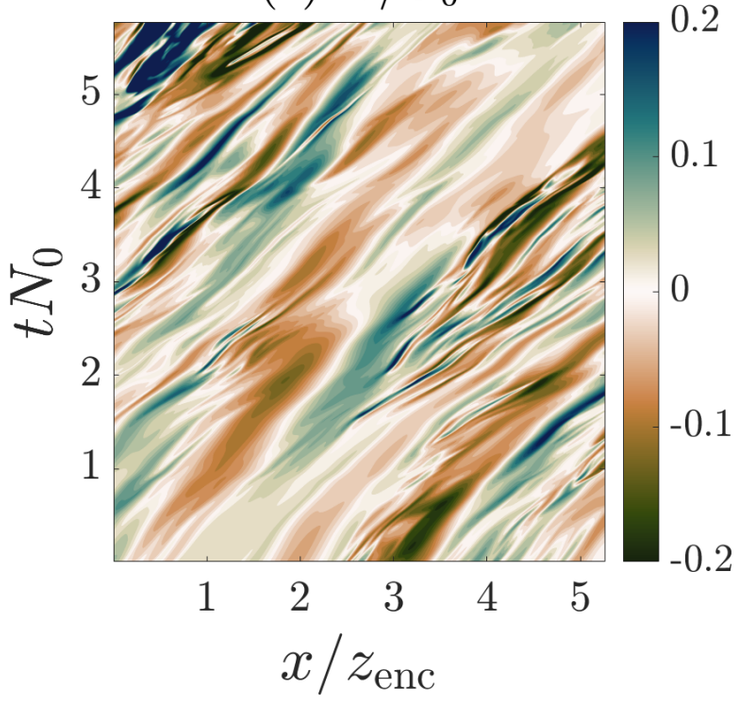


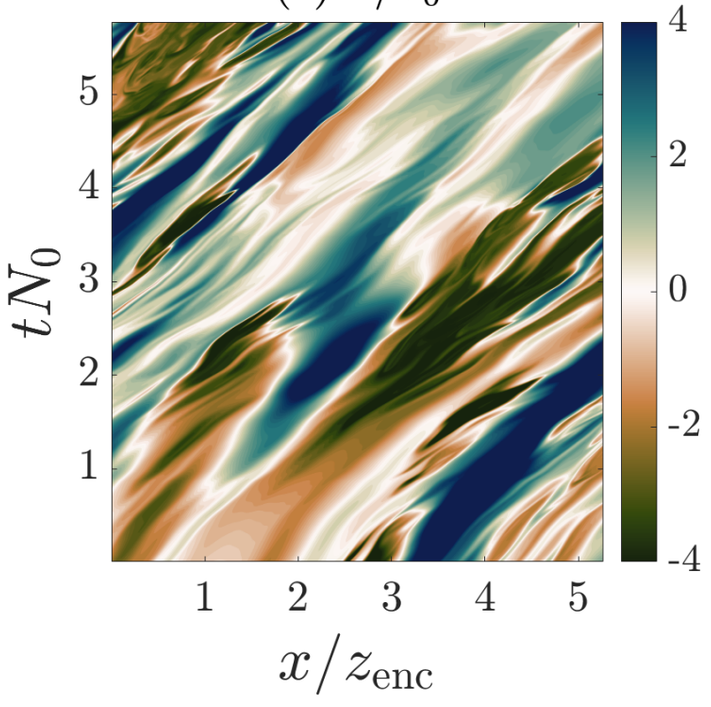




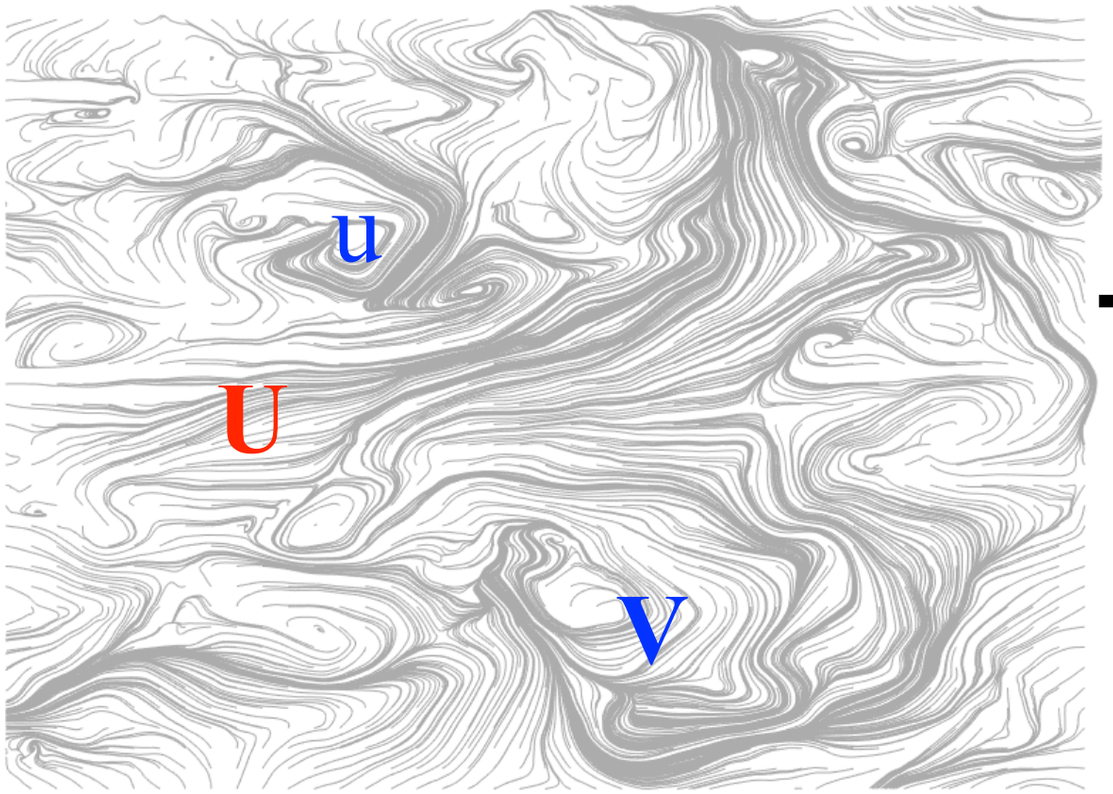
EZ







Linear Random Advection Model (LRAM)



$$\frac{\partial}{\partial t}\boldsymbol{u} + (\mathbf{U} + \mathbf{V}).\nabla \boldsymbol{u} = \mathbf{0}$$

Fourier Transform

Gaussian Large Scale Advection

$$E_u(\boldsymbol{k}, \omega; z) = \frac{E_u(\boldsymbol{k}; z)}{[2\pi\langle(\mathbf{V}\cdot\boldsymbol{k})^2\rangle]^{1/2}} \exp\left[-\frac{(\omega - \boldsymbol{k}\cdot\mathbf{U})^2}{2\langle(\mathbf{V}\cdot\boldsymbol{k})^2\rangle}\right]$$

Wavenumber Spectrum

Doppler Shift

Doppler Broadening

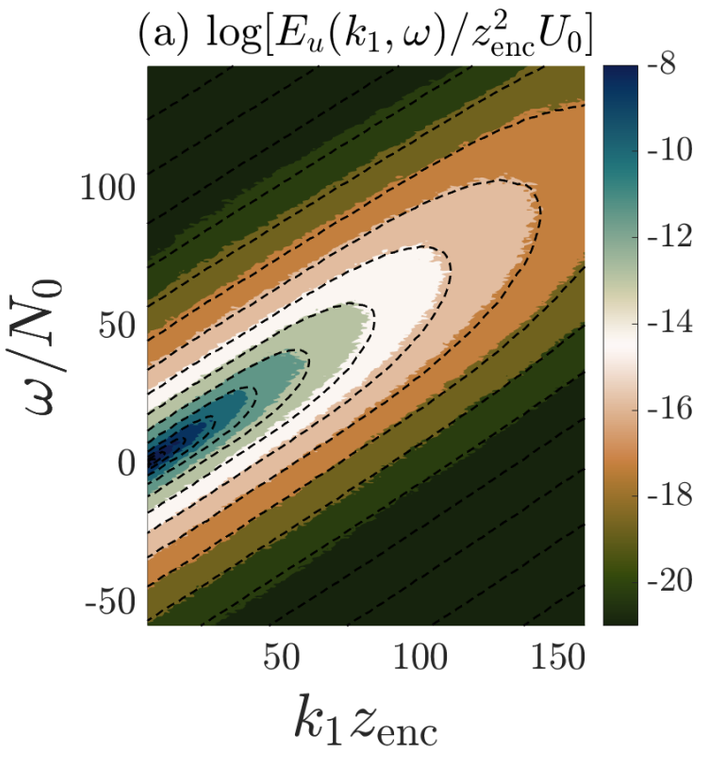
$E_w(\boldsymbol{k}, \omega; z)$ ✓

$E_b(\boldsymbol{k}, \omega; z)$ ✓

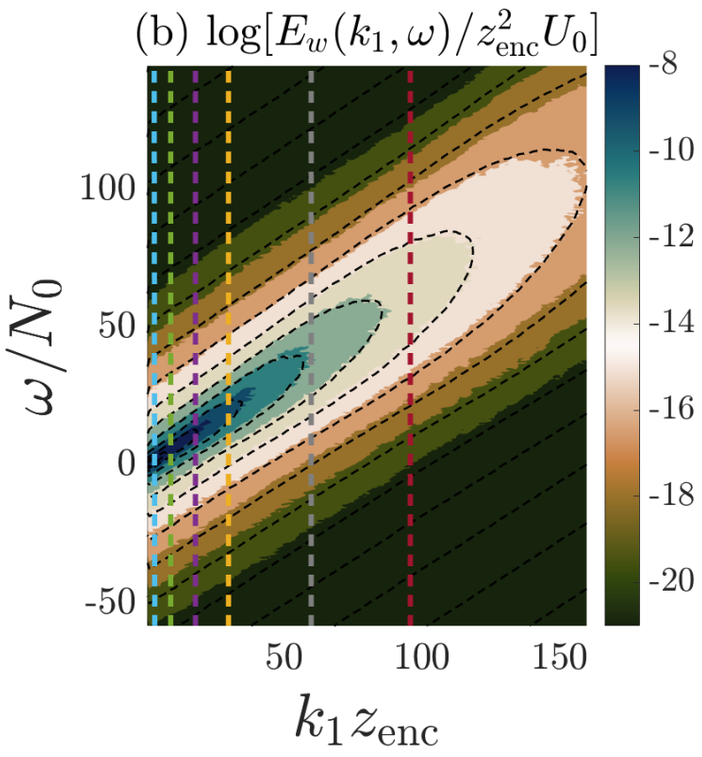
Wilczek and Narita 2012
Ali et al. 2022

Wavenumber-Frequency Spectra: LRAM vs. DNS

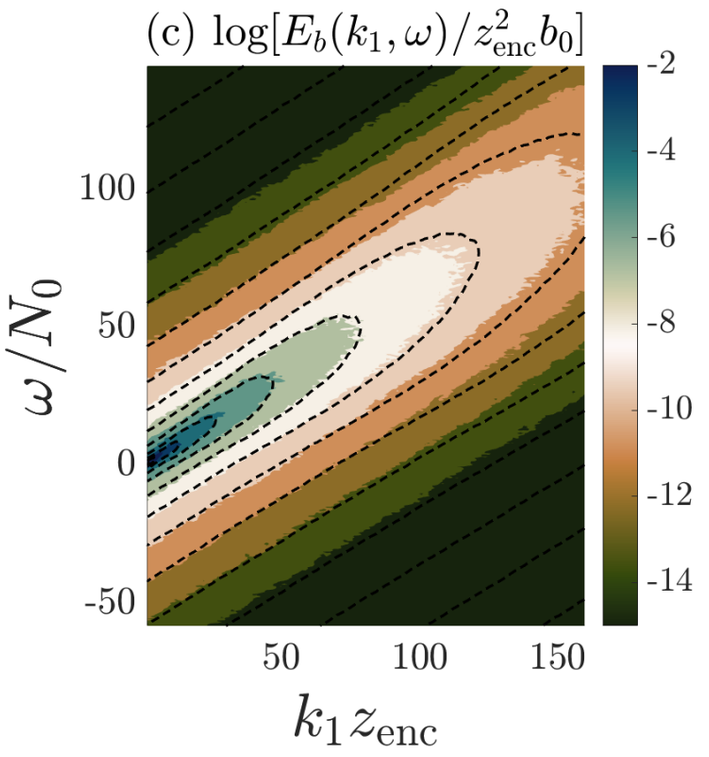
Streamwise Velocity

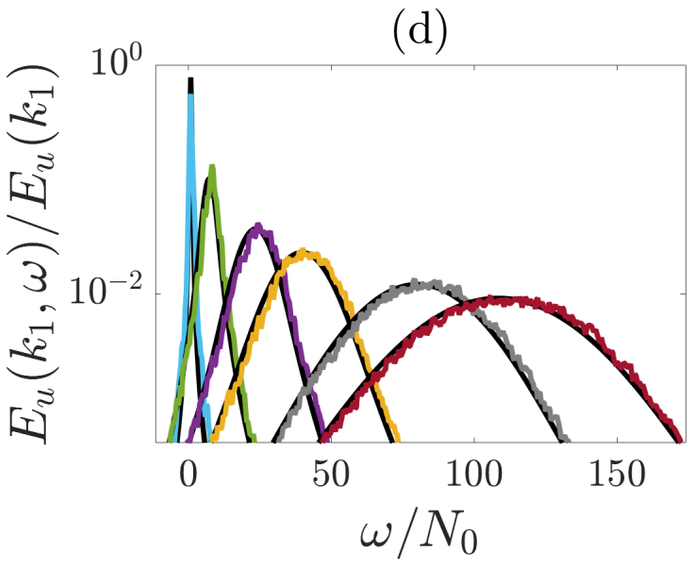


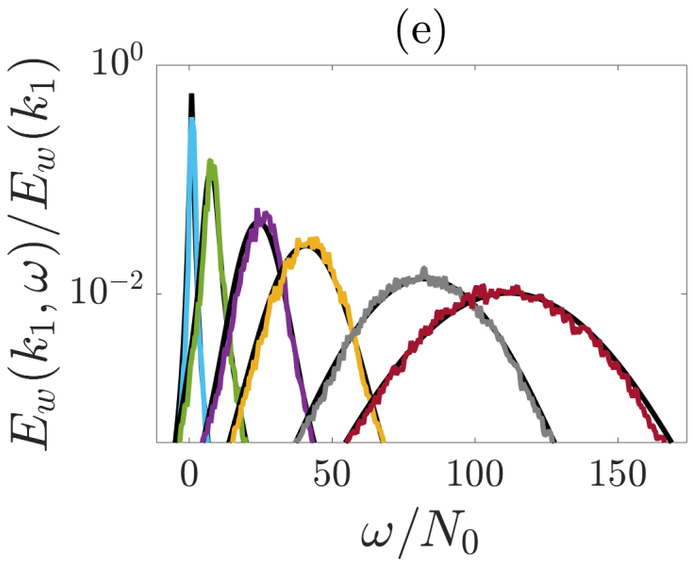
Vertical Velocity

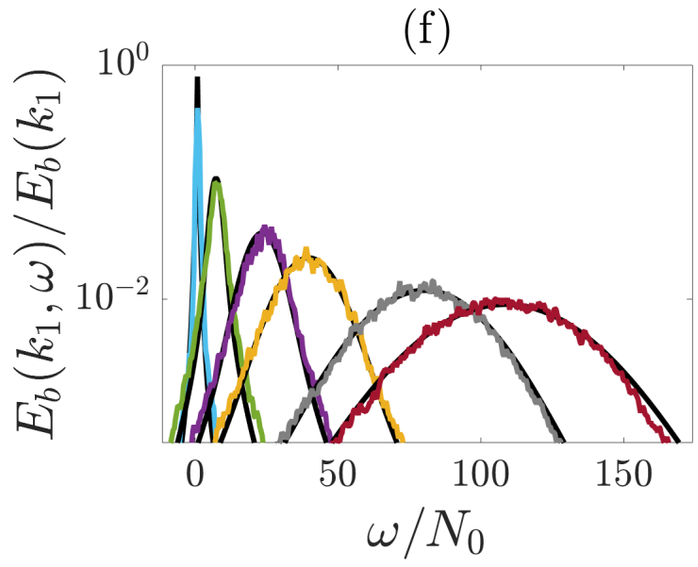


Buoyancy









Wavenumber Spectrum Model: von Kármán approach vs. DNS

$$E(k) = \frac{A_1\ (k/k_e)^4}{[1+(k/k_e)^2]^{17/6}},$$

$$\phi_{ij}(\boldsymbol{k}) = \frac{E(k)}{4\pi k^2}\left[\delta_{ij} - \frac{k_i k_j}{k^2}\right],$$

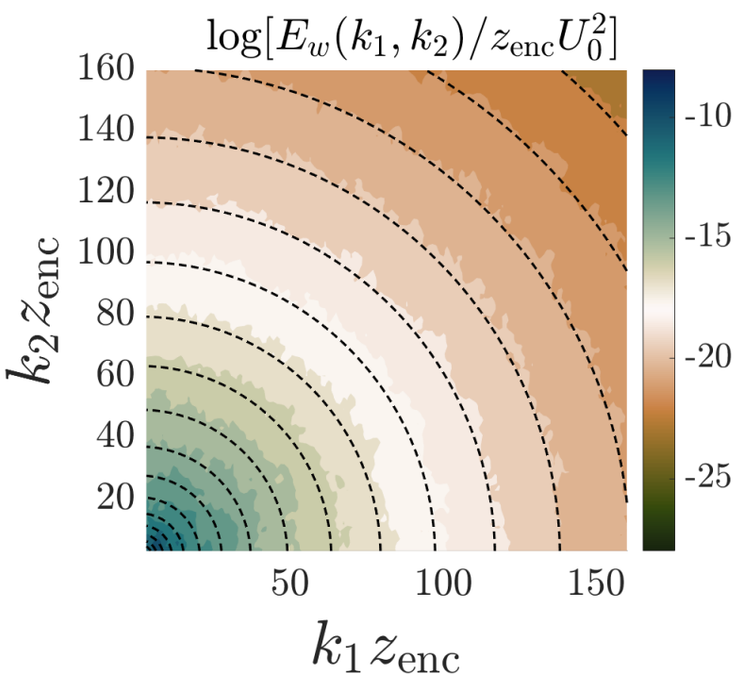
$$\int_{-\infty}^{\infty} \phi_{ij}\ dk_3.$$

$$E_w(k_1,k_2) = \frac{4}{9\pi}\frac{C_w w_*^2}{k_e^2}\frac{\left[\left(\frac{k_1}{k_e}\right)^2 + \left(\frac{k_2}{k_e}\right)^2\right]}{\left[1+\left(\frac{k_1}{k_e}\right)^2 + \left(\frac{k_2}{k_e}\right)^2\right]^{7/3}},$$

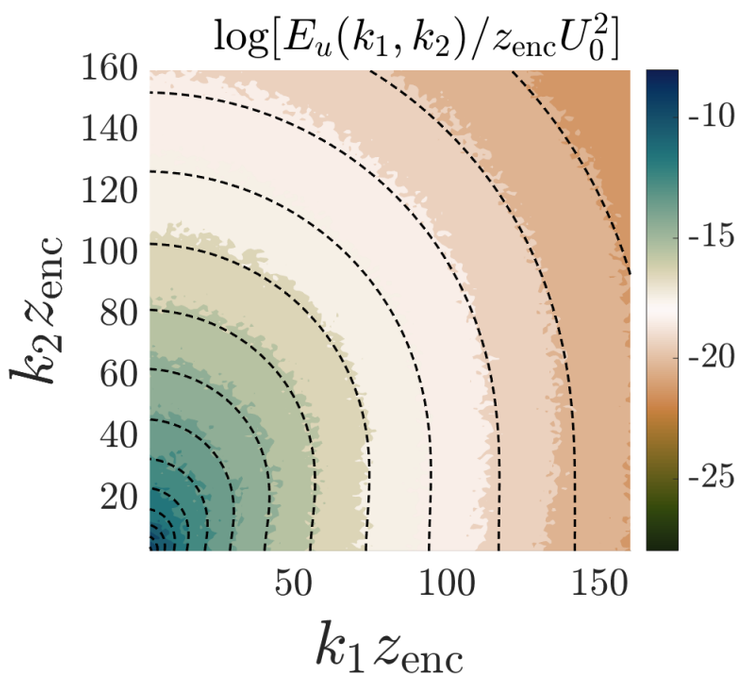
$E_u(k_1,k_2)$ ✓

$E_b(k_1,k_2)$ ✓

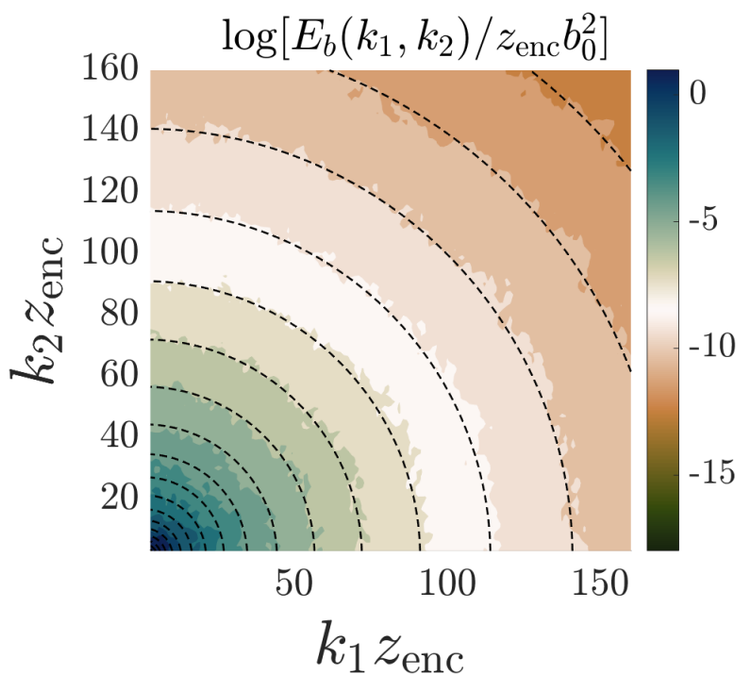
Vertical Velocity



Streamwise Velocity



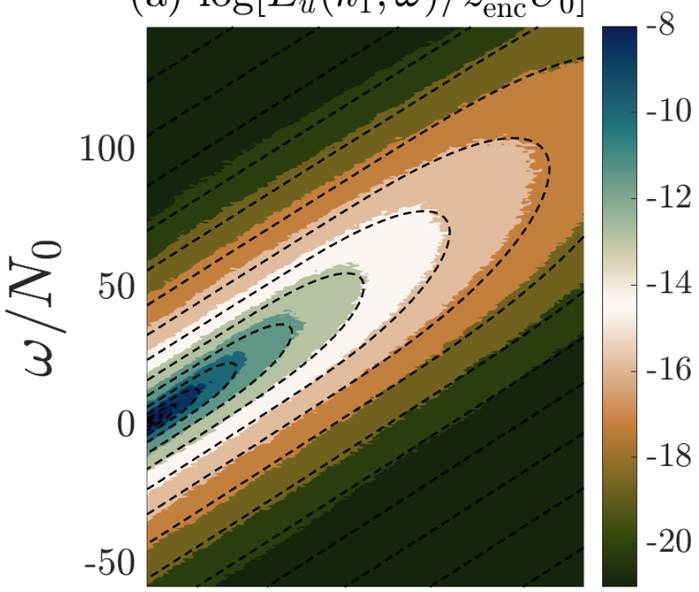
Buoyancy

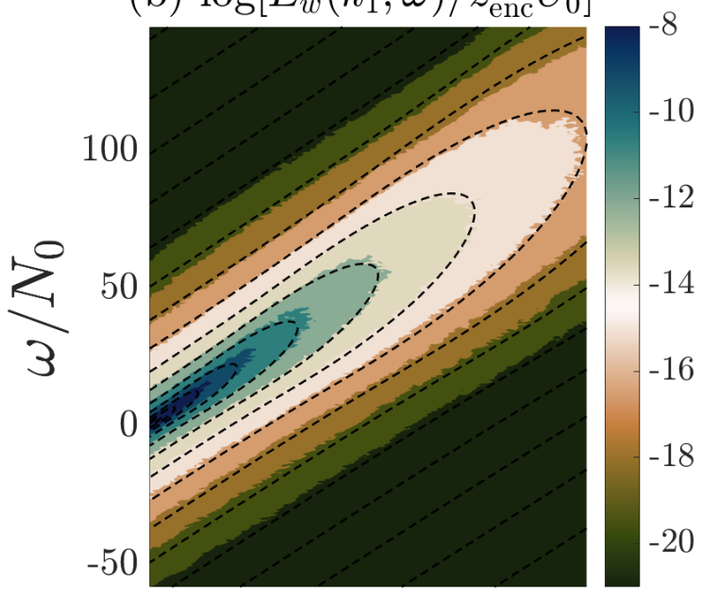


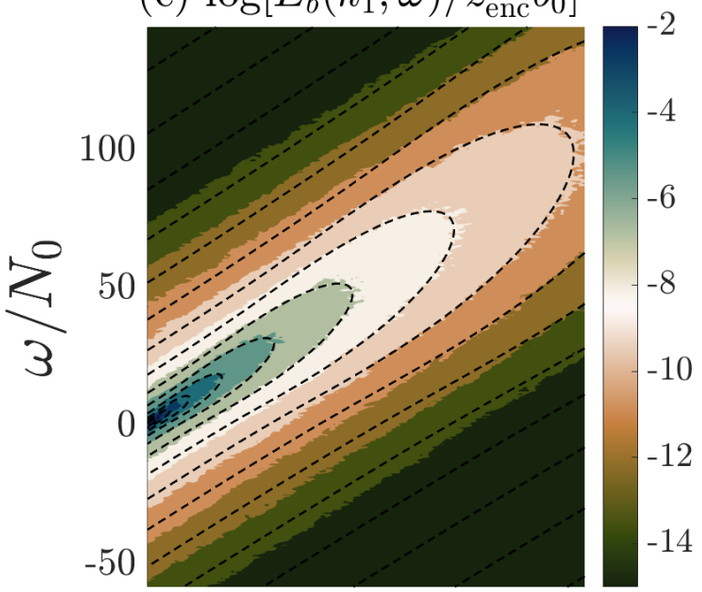
Wavenumber-Frequency Spectra: von Kármán-based LRAM vs. DNS

Streamwise Velocity | **Vertical Velocity** | **Buoyancy**

ML







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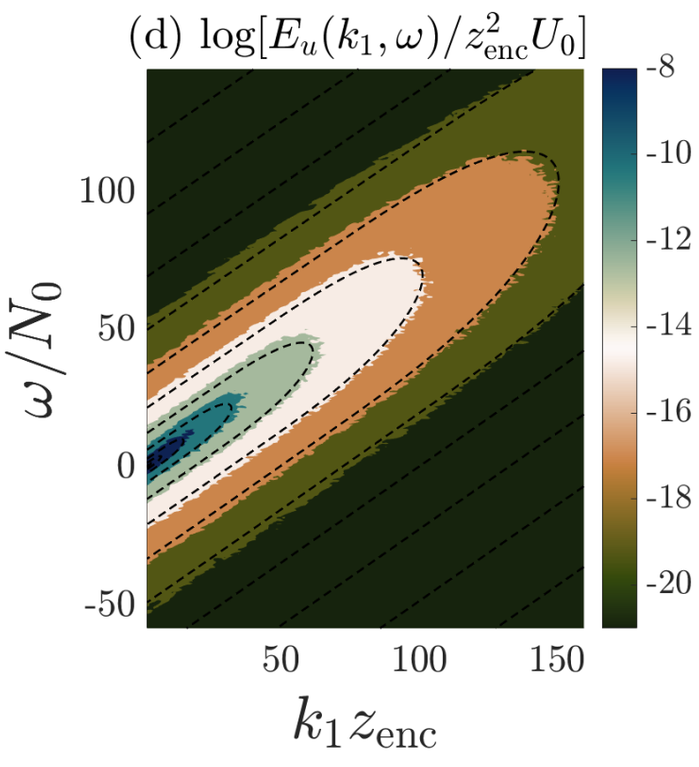

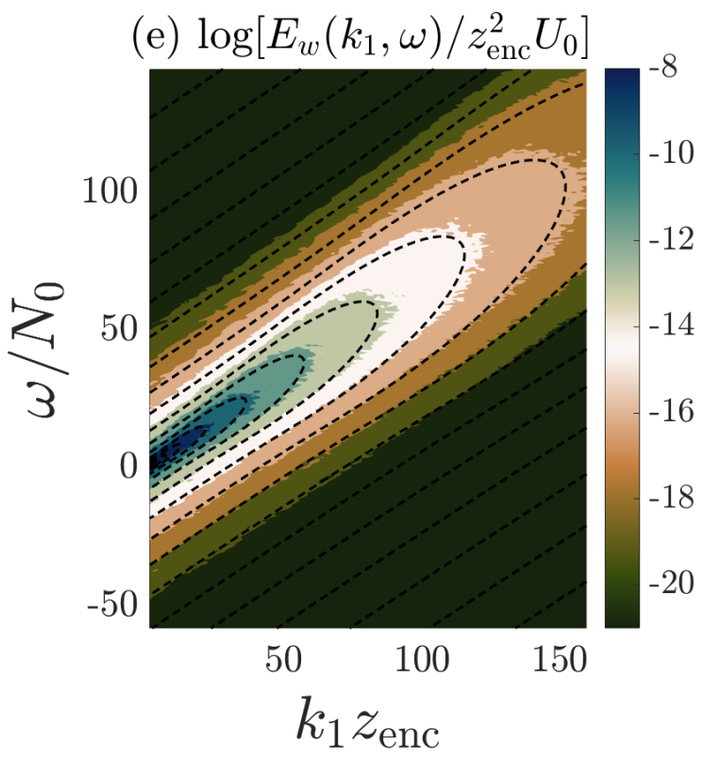

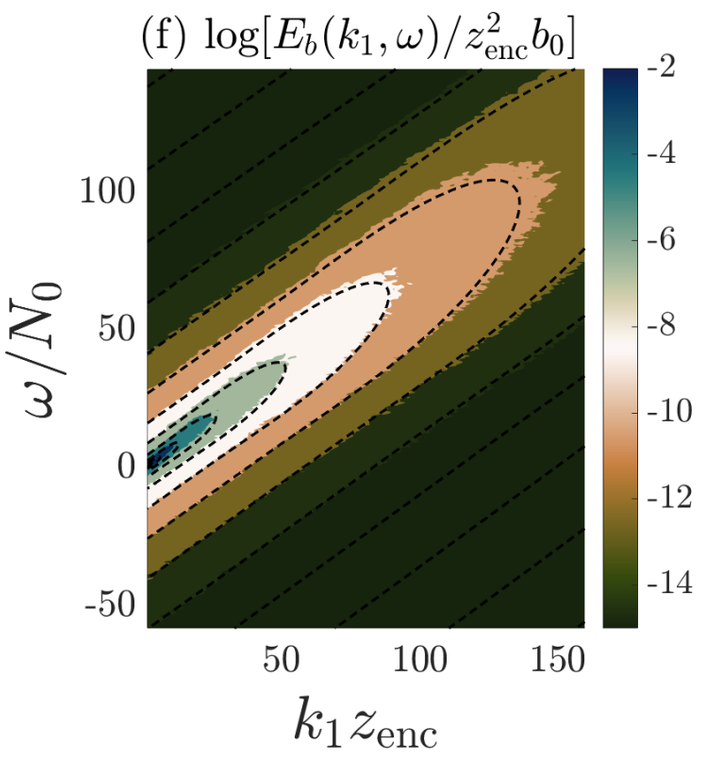

Conclusions

- We applied a linear random advection approach to model the wavenumber-frequency spectra for sheared CBL flows.

- We used a von Kármán spectrum to parameterize two-dimensional wavenumber spectra for velocity components and buoyancy.