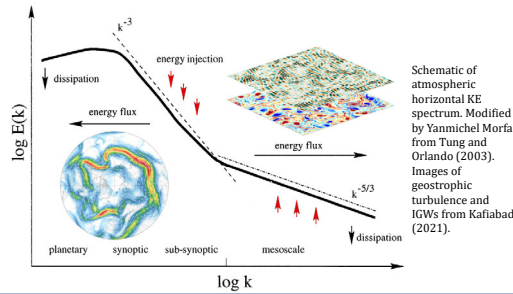


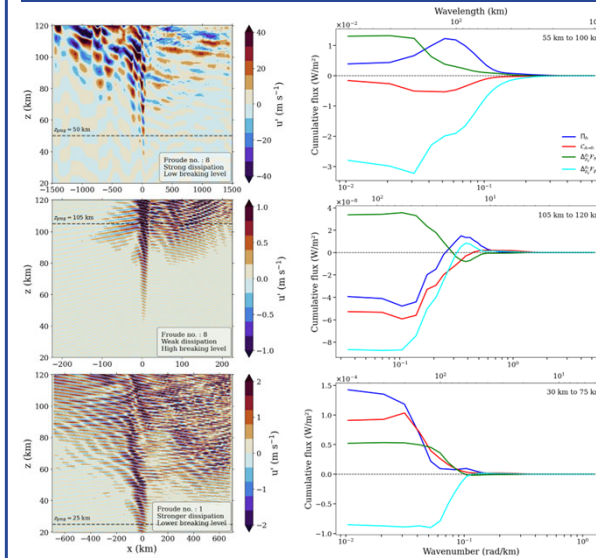


Mesoscale Ambiguity

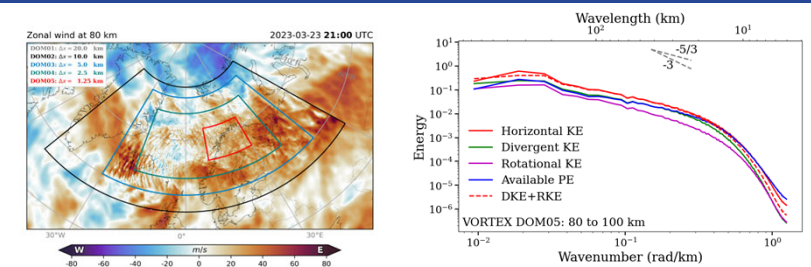
- Atmospheric motions span a vast range of scales. The distribution of energy across these scales follows distinct power laws, revealing the underlying physics.
- They show a consistent -5/3 slope at the mesoscale, but this slope alone does not allow identifying the underlying physics.
- Determining whether the dynamics is driven by turbulence or gravity waves is critical for atmospheric predictability and developing physically consistent model parametrizations.
- Traditional global spectra fail to resolve the spatial structure of energy fluxes.



Energy Budget of Idealized Mountain Waves

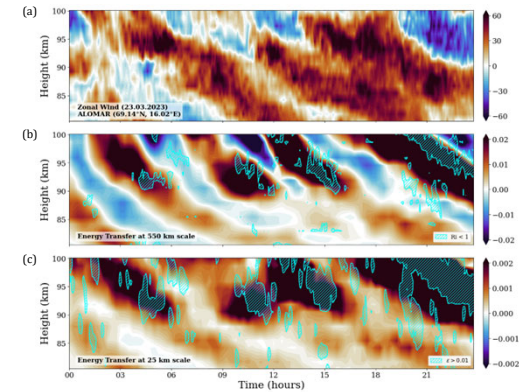
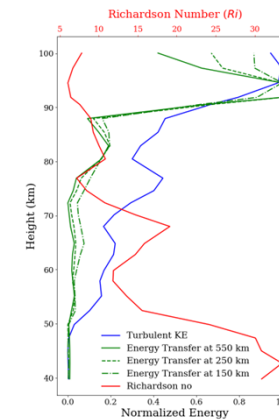
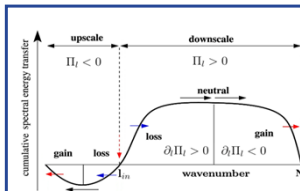


Mesoscale Energy Transfers in Realistic Simulations



Objectives

- Examine energy transfers in both spectral and physical space.
 - Spectral space:** To understand how energy moves across scales.
 - Physical space:** To pinpoint where energy is being exchanged.
- Formulate a full spectral budget for regional atmospheric domains and connect it to instantaneous energy transfers in physical space.
- Validate the framework on idealized simulations.
- Study interactions between waves, turbulence and mean-flow in regional UA-ICON simulations.



Methodology

- Spectral Space: A non-hydrostatic, discrete Fourier transform (DFT) based spectral energy budget (Peng et al, 2015).
- $$\frac{\partial}{\partial t} \mathcal{E}_h[k_h] = \Pi_h[k_h] + \partial_z \mathcal{F}_{pt}[k_h] + \mathcal{D}iv_h[k_h] + \partial_z \mathcal{F}_{pt}[k_h] + \mathcal{C}_{A-h}[k_h] + \mathcal{H}_h[k_h] + \mathcal{D}_h[k_h] + \mathcal{J}_h[k_h],$$
- ↓ nonlinear transfer ↓ momentum flux ↓ 3D divergence ↓ pressure flux ↓ APE conversion ↓ diabatic ↓ diffusion ↓ adiabatic
- Physical Space: Duchon-Robert framework to measure instantaneous energy transfers at specific spatial location and scale of interest (Duchon & Robert, 2000).

$$\frac{1}{2} \partial_t E + \varepsilon = -\frac{1}{4} \nabla_l \cdot \langle \delta \mathbf{u} (\delta \mathbf{u})^2 \rangle + \nu \nabla_l^2 E$$

Energy injection Energy transfer Viscous dissipation

$\mathcal{D}_l(\mathbf{u})$ represents the amount of energy transferred at the scale l , by inertial dissipation. For scales larger than Kolmogorov scale, this term provides most of the energy transfer (Faranda et al, 2018).

$$\mathcal{D}_l(\mathbf{u}) = \frac{1}{4\ell} \int_V d\mathbf{r} (\nabla G_\ell(\mathbf{r}) \cdot \delta \mathbf{u}(\mathbf{r}) |\delta \mathbf{u}(\mathbf{r})|^2)$$

Summary and Outlook

- UA-ICON successfully simulates a mesoscale -5/3 scaling in the mesosphere and lower thermosphere (MLT). However, the presence of this scaling alone does not uniquely identify the underlying dynamics. Multiple mesoscale processes can produce the same spectra.
- To address this ambiguity, we formulate a full spectral energy budget in parallel with energy transfers in physical space. These complementary diagnostics are first tested and validated on idealized mountain wave simulations where dominant mechanisms are known.
- Variability within the MLT is primarily governed by large-scale waves and tides, which govern the background dynamics. High downscale energy transfers are observed in mesoscale domains characterized by subcritical Richardson values, indicating shear dominated turbulence.
- The energy dissipation captured by subgrid-scale parametrizations aligns closely with resolved near-grid scale transfers, ensuring a physically consistent energy cascade.
- The application of our framework to UA-ICON simulations with regional refinement and combined with mesospheric observations, offers an opportunity to elucidate the mesoscale HKE spectrum in the MLT region.

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