Analysis of vertical scaling of horizontal wind kinetic energy spectra

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1. Introduction

Explicit simulation of convection requires grid spacing on the order of 100m [Bryan et al., 2003]. At these scales, turbulence is partially resolved breaking down the assumptions of planetary boundary layer (PBL) parameterizations. At coarser resolutions, increasing the model resolution or improving the cumulus scheme without considering the turbulence scheme does not necessarily result in better simulations, as the interactions among resolved and parameterized physics depend on flow and stability regimes and numerical implementation. Vertical motions deserve a special attention they are the key part of pollution transport and severe weather phenomena such as thunderstorms, hurricanes and fronts.

- The Weather and Research Forecasting (WRF) model can reproduce some of the observed mesoscale spectral features and classical spectral slope transition from -3 to -5/3 dependence .
- In the presence of strong convection, the spectral slope in the mesoscale approaches -5/3, representing the dominant turbulence regime.
- With no intense convection, steeper spectral slopes between -2 and -2.3 arise, representing a flow dominated by large gradients and underlying topography.

Here we look at two different analyses:

- Spectral analysis of moisture and wind field over the Andes Mountains (ANDES)
- Spectral analysis of horizontal wind field over Southern Appalachian Mountains (SAM)

2 Experimental design (ANDES Cases, SAM Cases)

- **ANDES Cases:**

1. Extremely dry environment (**EDRY**), starting on 20 July 2003 corresponding with austral winter time.
2. Strong synoptic forcing associated with South American Low Level Jet (**S_SALLJ**) in the rainy season of 2003 coinciding with austral summer.
3. Weak synoptic forcing case (**W_SALLJ**).

- **Model Configuration:**

WRF version of 3.4.1, Three nested domains with one-way coupling 18, 6, 1.2 km, Yonesi University (YSU) PBL scheme, Lin Microphysics scheme, Noah land surface model, Kain-Fritsch cumulus parameterization (two outer domains)

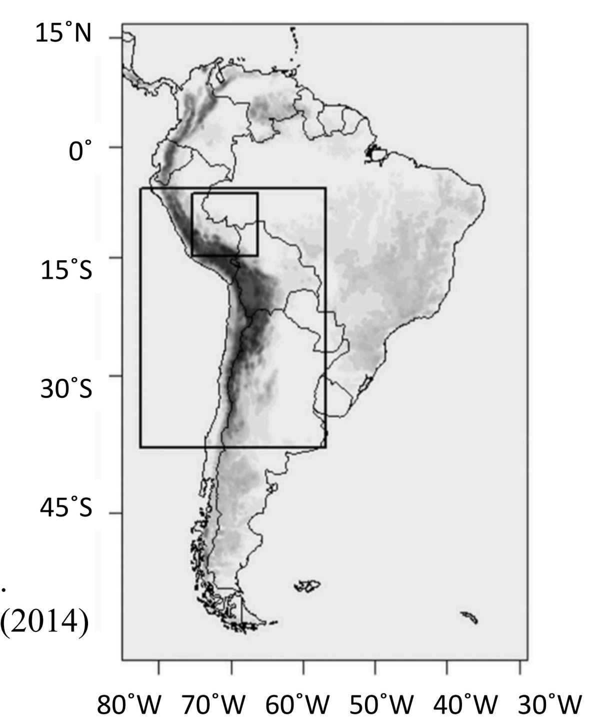


Fig 1. Model domains. Nogueira and Barros, (2014)

- **SAM Cases:**

1. Strong synoptic forcing during during May (4 days) - **FRONTAL**
2. Weak synoptic forcing during the early June (7 days) - **WSF**

- **Model Configuration:**

WRF version of 3.5.1 , Three nested domains with one-way coupling (WSF, 15, 5, 1.25 km; FRONTAL 9, 3, 1 km), Mellor-Yamada-Nakanishi and Niino (MYNN) PBL scheme Milbrandt and Yau microphysics, Kain-Fritsch cumulus scheme (in the domains with grid spacing higher than 3 km)

The data is used after 12 hours of simulation in the inner domain so that the spectra is fully developed.

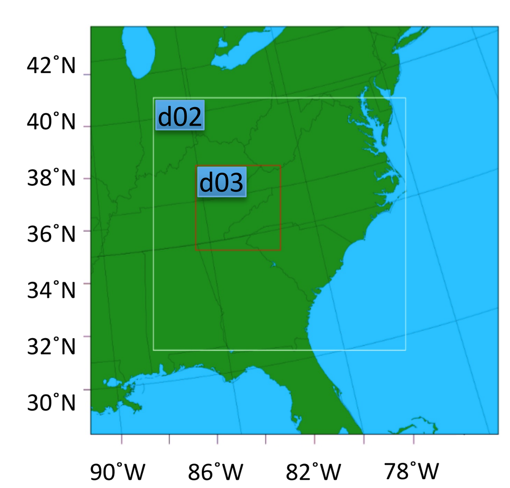


Fig 2. Model domains.

3.1 Convective/Nonconvective transition (ANDES)

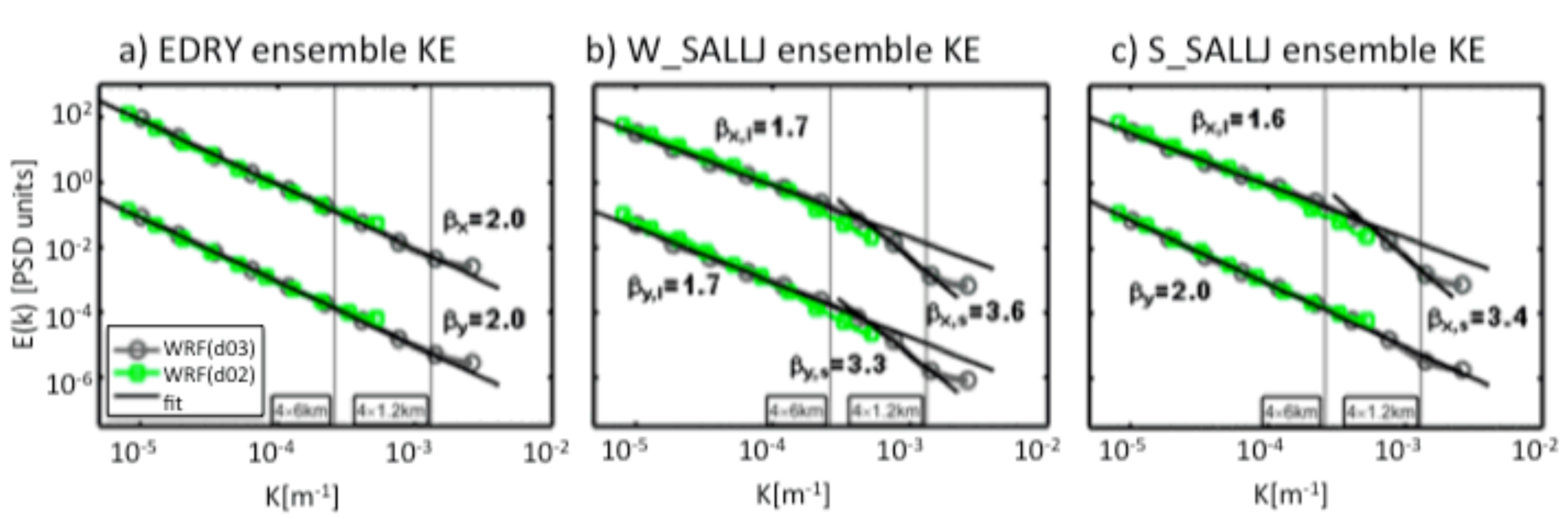


Fig 3. Ensemble Kinetic Energy (KE) spectra; Power Spectral Density (PSD) units W/Hz. Nogueira and Barros, (2014)

3.1 Convective/Nonconvective transition Cont. (ANDES)

Time-averaged ensemble kinetic energy spectra for seven constant height horizontal levels of the model between 6000 and 9000 over the high resolution and intermediate domains are shown.

a) In nonconvective environments, an isotropic **β=2.0** scaling behavior in both x and y directions is formed.

b, c) In moist environment under weak synoptic forcing, isotropic behavior with **β=1.7** scaling and a scaling break at about 12-13 km is observed. The steeper slopes of about **β=3.6** may be affected by numerical dissipation. In the presence of strong synoptic forcing, an anisotropic behavior occurs.

3.2 Scaling Analysis and Stability Condition (SAM, FRONTAL)

Here we adapt the following notation:

Meso-γ ~ 5-12.5 km, Meso-β3 ~ 12.5-50 km, Meso-β2 ~ 50-200 km, Meso-β1 ~ 150-350 km

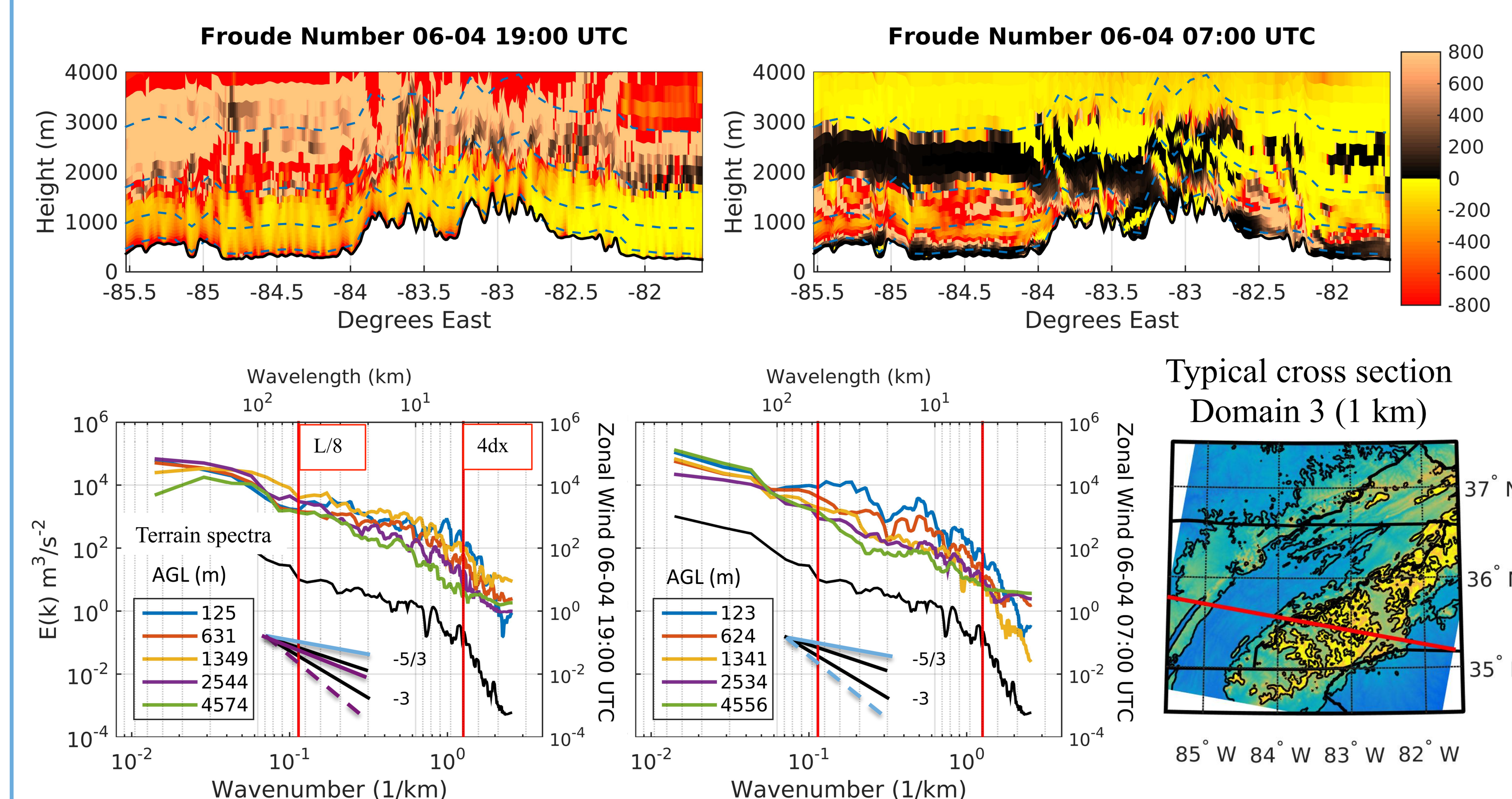
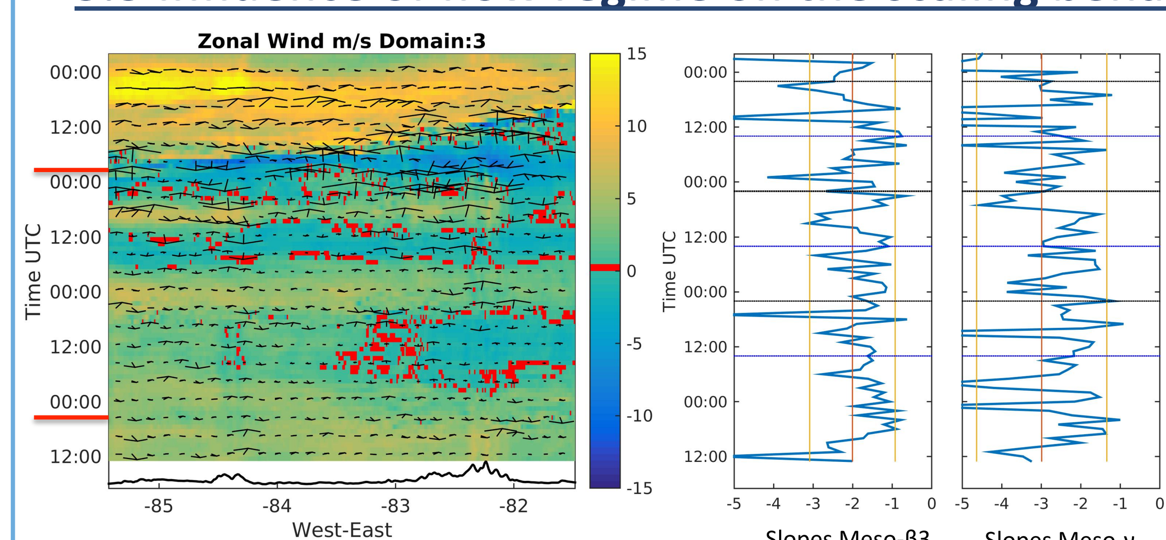


Fig 4. Froude number and instantaneous zonal wind spectra for a typical cross section of domain 3. The spectrum of the terrain is shown with a black line. The slopes are shown with their colors for comparison.

Mid-day: The first three layers (125, 631, 1349 m) that are approximately within the boundary layer, form flatter slopes about -5/3 suggesting an environment dominated by convective flow. The layers above are inside regions with more stable conditions showing a steeper slope. The spectra in the scales smaller than 4dx are affected by numerical dissipation and are not considered here.

Mid-night: The 123 m layer that is associated with the stable region near the surface shows abrupt changes in the spectral slopes through different ranges. The slopes generally steepens with increase in height and stability.

3.3 Influence of flow regime on the scaling behavior (SAM, FRONTAL)



Stronger downdrafts and updrafts result in higher variance in Meso-γ slopes. This variance, however, is not higher than the variance observed in the terrain spectral slopes. Flatter slopes may arise due to the gravity waves induced by the terrain, while steeper slopes may arise under the stable conditions when the flow follows the terrain slopes.

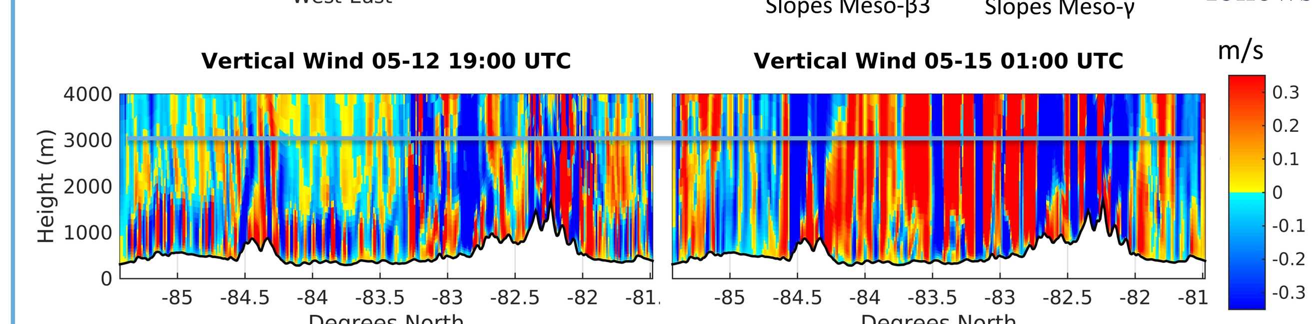


Fig 5. Hovmoller diagram and cross sections for wind fields.

3.4 Scale transition over height and length scale (SAM, WSF)

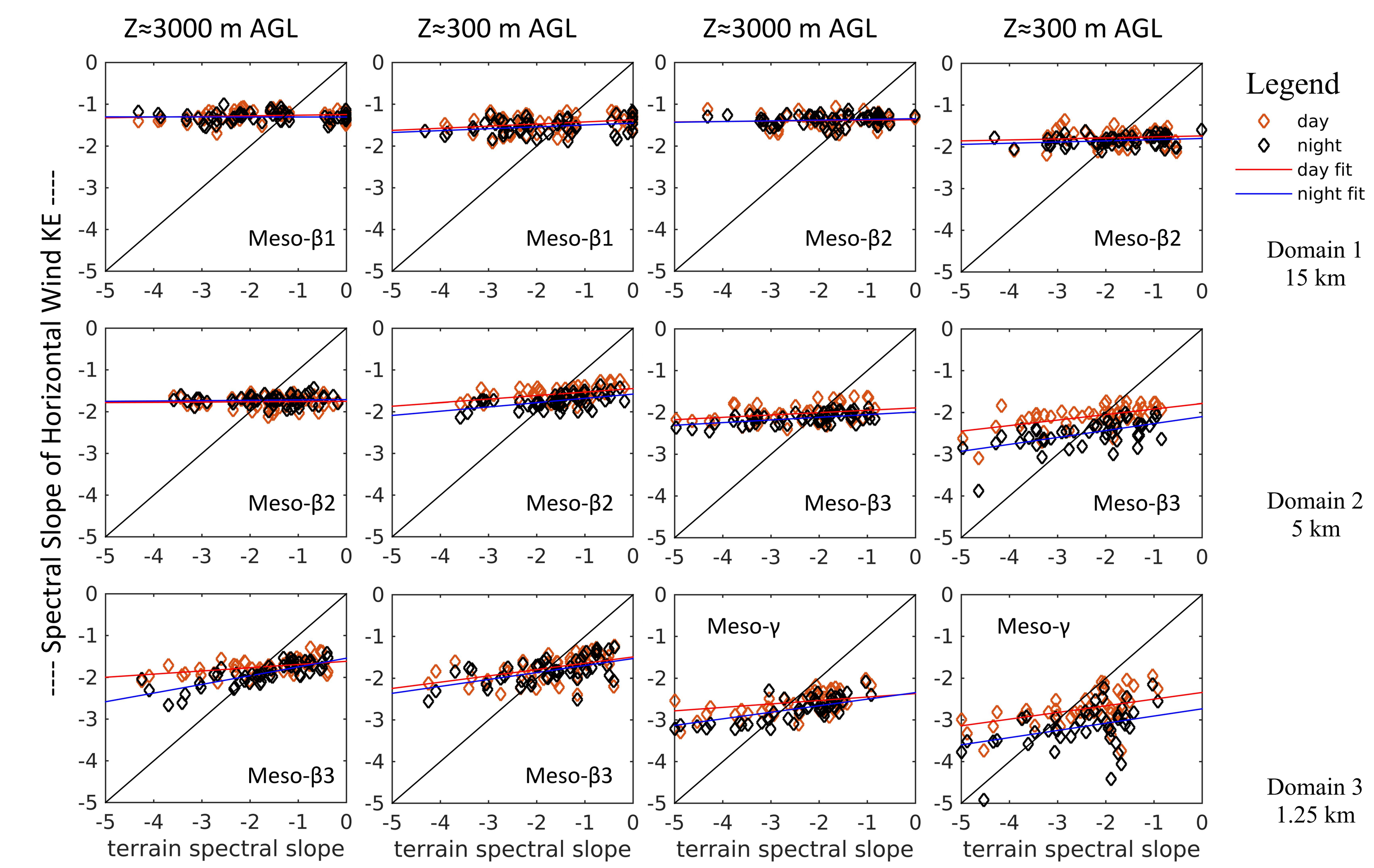


Fig 6. Scaling behavior of horizontal wind KE and terrain

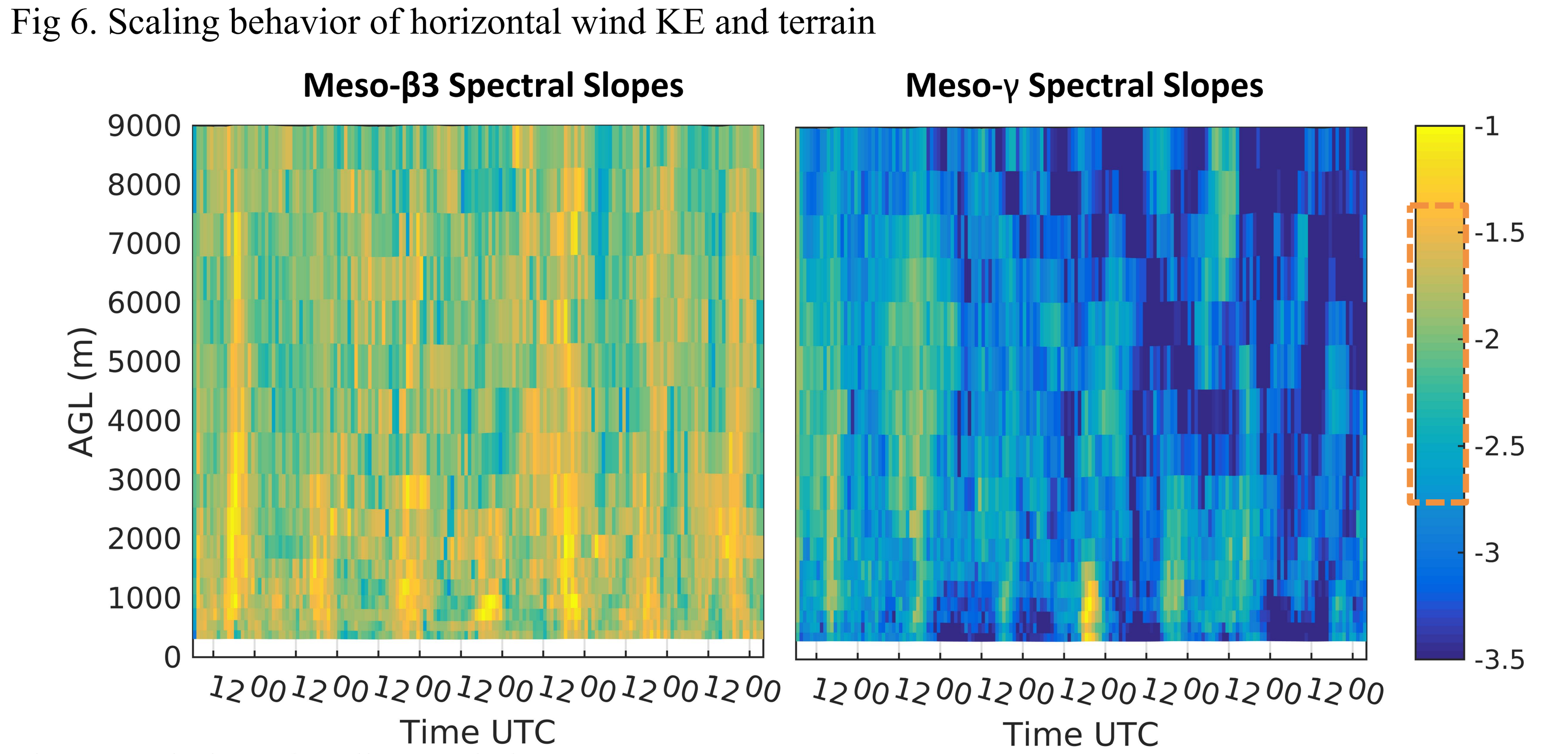


Fig 7. Evolution of scaling statistics.

4. Conclusions

- For Meso-γ scales and low levels (<3000 m), strong diurnal dependence and influence of the terrain is observed in the model spectral behavior. This may be contributed to phenomena such as potential flow, gravity waves and is tightly related to the topography, and the environmental condition. Also a scale break is observed in the stable flow regimes.
- Comparing Meso-β range and Meso-γ scales, a scale break is observed in stable environments even in the higher levels (3000-9000 m).
- The results are along each other in high elevation (ANDES) and lower elevation (SAM) mountains.

5. References

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