Spectral analysis of unstable flows: understanding the low frequency spreading of Kaimal's scaling

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Spectral scaling has been used to study the low frequency part of the velocity and temperature spectra, as well as co-spectra of heat and momentum over a flat surface in the 70's. Kaimal et al. (1972) showed that the low frequency spectral energy is driven mainly by stability in stable atmospheric conditions. In unstable conditions however, no explanation of the behavior of the low frequency region of spectra has been provided until now. The reason for this is that the analysis is based on Monin-Obukhov Similarity Theory (MOST), which is known to fail in describing unstable conditions even over flat terrain (especially for horizontal velocity variances). Since then, some refinements of MOST have been proposed like the approach of Panofsky et al. (1977) who derive laws for the scaled velocity variances including the mixed-layer height. More recently, Tong et al. (2015) used a so-called "Multi-point Monin-Obukhov similarity" where both the vertical and the horizontal length scales are important. However, these approaches are limited to flat terrains and are thus not applicable to the increasingly studied complex and mountainous terrains.

In the present work, we use data from 14 fields experiments, both over flat and complex terrains, in unstably stratified conditions. We show that turbulence anisotropy is the main factor able to characterize the spectral energy at low frequency for the horizontal velocity and the temperature spectra, as well as the momentum and heat flux co-spectra. Given that there exists a link between turbulence anisotropy and atmospheric stability, one might think that there is a bias linked to the repartition of turbulence anisotropy intensity within the stability range. Based on Stiperski et al. (2023) that relates scaled variances and dissipation rate with both turbulence anisotropy and atmospheric stability, we were able to separate the contribution of turbulence anisotropy from the one of stability alone. While clustering of spectra by stability conditions is not able to explain the spreading of low frequency, stability conditions are still a second order factor not negligible. Its impact increases as anisotropy decreases.

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