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Scalewise Universal Relaxation to Isotropy of Inhomogeneous Atmospheric Boundary Layer Turbulence

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The turbulent energy cascade is one of the most recognizable characteristics of turbulent flow. Still, representing this tendency of large-scale anisotropic eddies to redistribute their energy content with decreasing scale, a phenomenon referred to as return to isotropy, remains a recalcitrant problem in the physics of turbulence. Atmospheric turbulence is characterised by large scale separation between production and viscous destruction of turbulent kinetic energy making it suitable for exploring such scale-wise redistribution of energy among velocity components. Moreover, real-world atmospheric turbulence offers an unprecedentedly diverse source of inhomogeneity and large-scale anisotropy (caused by shear, buoyancy, terrain-induced pressure perturbations, closeness to the wall) while maintaining a high Reynolds number state. It may thus be assumed that relaxation through the energy cascade may be dependent on the anisotropy source, thus adding to the ways that atmospheric turbulence differs from canonical turbulent boundary-layers.

Here, we examine the scalewise return to isotropy for an unprecedented dataset of atmospheric turbulence measurements covering flat to mountainous terrain, stratification spanning convective to very stable conditions, surface roughness ranging over several orders of magnitude, various distances from the surface, and Reynolds numbers that far exceed the limits of direct numerical simulations and laboratory experiments. The results indicate that irrespective of the complexity of the dataset examined, the return-to-isotropy trajectories that start from specific initial anisotropy at large scales show surprising scalewise universality in their trajectories towards isotropy. This novel finding suggests that the effects of boundary conditions, once accounted for in the starting anisotropy of the trajectory in the cascade, cease to be important at much smaller scales. It can therefore be surmised that large-scale anisotropy encodes the relevant information provided by the boundary conditions, adding to the body of evidence that the information on anisotropy is a missing variable in understanding and modelling atmospheric turbulence [1-3].

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