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Turbulence- waves or quasi linear gravity waves in the atmosphere?

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We critically re-examine theories of turbulence in a stratified atmosphere arguing that the dynamics should be buoyancy driven rather than energy driven and that they should be scaling, but anisotropic, not isotropic. We compare the leading statistical theories of atmospheric stratification which are conveniently distinguished by the elliptical dimension D_s which quantifies their degree of the spatial stratification (in terms of the horizontal and vertical spectral exponents $E(k_x) \approx k_x^{-\beta x}$, $E(k_Z) \approx k_z^{-\beta z}$ we have D_s = 2+ (β_x-1)/(β_z-1)). This includes the mainstream isotropic 2D (large scales), isotropic 3D (small scales) theory but also the more recent linear gravity wave theories (D_s=7/3) and the classical fractionally integrated flux (FIF) 23/9D unified scaling model. In the latter, the horizontal wind has a $k_x^{-5/3}$ spectrum as a function of horizontal wavenumber determined by the energy flux and a $k_z^{-11/5}$ energy spectrum as a function of vertical wavenumber determined by the buoyancy force variance flux. We examine the relevant empirical evidence both from the literature, and using state-of-the-art lidar data covering over 3 orders of magnitude in scale for both horizontal-vertical and horizontal-temporal cross-sections (using aerosol backscatter as passive tracer surrogates).

The 23/9D FIF model is the most physically and empirically satisfying - being based

on turbulent fluxes. The FIF model is actually a vast family of scaling models broadly compatible with turbulent phenomenology and with the classical turbulent laws of Kolmogorov and Corrsin and Obukov. However, until now it has mostly been developed on the basis of structures localized in space-time. In this paper, we show how to construct extreme FIF models with wave-like structures which are spatially localized but unlocalized in space-time, as well as a continuous family of intermediate models which are akin to Lumley-Shur models in which some part of the localized turbulent energy "leaks" into unlocalized waves.

The key point is that the FIF requires two propagators (space-time Green's functions) which can be somewhat different. The first determines the space-time structure of the cascade of fluxes, this must be localized in space-time in order to satisfy the usual turbulence phenomenology. In contrast, the second propagator relates the turbulent fluxes to the observables, although the spatial part of the propagator is localized as before, in space-time it can be unlocalized (it is still localized in space, now in wave packets); the result is "turbulence waves". We display numerical simulations which demonstrate the requisite (anisotropic, multifractal) statistical properties as well as wave-like phenomenologies including nonlinear dispersion relations which may be quite close to (but not identical) to those obtained from the classical quasi-linear (Goldman-Taylor) gravity wave equations.