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Lidar data and anisotropic space-time generalizations of Corrsin-Obukov and Kolmogorov laws

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We use state-of-the-art lidar data of atmospheric aerosols (considered a passive tracer) in order to obtain a direct scale by scale characterization of atmospheric stratification. We analyzed 2D vertical-horizontal and 2D vertical-time cross section data sets spanning 3 orders of magnitude in scale in horizontal, vertical and time, finding for both cirrus and aerosols that the anisotropic, multifractal extensions of the Corrsin-Obukhov law accurately follow the theoretical (anisotropic) scalings predicted by the 23/9D atmospheric model proposed over 20 years ago. This model assumes that energy fluxes dominate in the horizontal (leading to Kolmogorov, $k_x^{-5/3}$ spectra), whereas buoyancy force variance fluxes dominate in the vertical (leading to Bolgiano-Obukhov $k_z^{-11/5}$ spectra).

In order to test the theory in arbitrary directions in (z, t) or (x, z) space, and in order to get more complete information about the underlying physical scale, we developed and applied a new Anisotropic Scaling Analysis Technique (ASAT) which is based on a nonlinear coordinate transformation. This transforms the original differential scaling into standard self-similar scaling; there remains only a "trivial" anisotropy. This method was used in real space on 2D structure functions as well as in fourier space on spectral densities. It was applied to both (z, t) and (x, z) data. Using the ASAT tech-

nique we verified the theory to within about 10% over more than 3 orders of magnitude of space-time scales in arbitrary directions in (x, z) and (z, t) spaces. By considering the high (and low) order structure functions, we verify the theory for both weak and strong structures (as predicted, their average anisotropies are apparently the same).

Putting together the results for (x, z) and (z, t) (and assuming that there is no overall stratification in the horizontal (x, y) plane), we find that the overall (x, y, z, t) space is found to have an "elliptical dimension" characterizing the overall space-time stratification equal to D_{st}=3.21±0.05 which is close to the theoretical value D_{st}=1+1+5/9+2/3=29/9=3.22… corresponding (in conditions with no mean wind) to $k_x^{-5/3}$, $k_y^{-5/3}$, $k_z^{-11/5}$ scaling in space and ω^{-2} scaling in time. The main competing theory is the scaling quasi-linear gravity wave theories which predicts the same horizontal spectrum ($k_x^{-5/3}$) but k_z^{-3} rather than $k_z^{-11/5}$ for the vertical spectrum. Thus, obtained results are incompatible with quasi-linear gravity waves.

Finally, we show how these scalings can be used to produce highly realistic multifractal simulations of clouds, including turbulence-wave phenomenologies.