STREAMWISE TURBULENT INTENSITY UNDER UNSTABLE ATMOSPHERIC STRATIFICATION EXPLAINED BY A SPECTRAL BUDGET

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Abstract Because of its non-conformity to Monin-Obukhov Similarity Theory (MOST), the effects of thermal stratification on scaling laws describing the stream-wise turbulent intensity σ_u normalized by the turbulent friction velocity (u_*) continues to draw research attention. The streamwise turbulent intensity happens to be of utmost importance as a direct measure of the intensity of turbulence and an analytical model able to predict its nature would be considered useful for a copious number of practical applications- ranging from industrial pipe flow to air pollution modeling among many. A spectral budget method used previously by [1] was demonstrated as a suitable workhorse to analytically explain the 'universal' logarithmic scaling law exhibited by σ_u^2/u_*^2 for neutral conditions as reported in different high Reynolds number experiments. In the present work [3], that theoretical framework has been expanded to assess the variability of σ_u/u_* under unstable atmospheric stratification. At least three different length scales- the distance from the ground (z), the height of the atmospheric boundary layer (δ), and the Obukhov length (L) are all found to be controlling parameters in the variation of σ_u/u_*. Analytical models have been developed and supported by experiments for two limiting conditions: $z/\delta < 0.02$, $-z/L < 0.5$ and $0.02 << z/\delta < 0.1$, $-z/L > 0.5$. Under the first constraint, the turbulent kinetic energy spectrum is predicted to follow three regimes: k^0, k^{-1} and $k^{-5/3}$ divided in the last two-regimes by a break-point at $kz = 1$, where k denotes wavenumber. The σ_u/u_* is shown to follow the much discussed logarithmic scaling reconciled to Townsend's attached eddy hypothesis $\sigma_u^2/u_*^2 = B_1 - A_1 log(z/\delta)$, where the coefficients B_1 and A_1 are modified by MOST for mildly unstable stratification. Under the second constraint, the turbulent energy spectrum tends to become quasi inertial, displaying a k^0 and a $k^{-5/3}$ with a breakpoint predicted to occur $0.3 < kz < 1$. However, the mechanism of this shift of spectral behavior in between the domains of the two aforementioned formulations is still unknown and will be explored in future by the help of Large Eddy Simulations (LES), although signatures of this interesting behavior can be observed in experimental data. This useful theoretical framework is also planned to be extended to include stable stratification [2]- although in the stable atmosphere, the buoyancy term will act as a sink of turbulent kinetic energy and the physics of the boundary layer is much more complicated. However, this work brings together well established but seemingly unrelated theories of turbulence such as Kolmogorov's hypothesis, Townsend's attached eddy hypothesis, MOST, and Heisenberg's eddy viscosity under a common framework.

References

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