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Self-protection and self-similarity of the stably-stratified geophysical turbulence

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Following Richardson (1920), the effect of stratification on the shear-generated geophysical turbulence is determined by the gradient Richardson number *Ri* = $(N/S)^2$, where $N$is the Brunt-Vaisala frequency, *S* = *dU/dz* is vertical shear of the mean wind/current velocity U, and z is vertical coordinate. The concept of Richardson-number similarity postulates that dimensionless characteristics of turbulence are universal functions of *Ri*.

Monin and Obukhov (1954) have proposed for the atmospheric surface layer a widely recognised *Monin-Obukhov similarity theory* (MOST). This theory postulates that dimensionless characteristics of turbulence are fully determined by the ratio z/L, where $L = -u_*^3/F_b$ is the Obukhov length scale, u_* is friction velocity and F_b is vertical turbulent flux of buoyancy. Nieuwstadt (1984) has employed local,z-dependent values of F_b and u_* instead of the surface values, and demonstrated applicability of such version of MOST to the almost entire stably stratified planetary boundary layer. MOST is consistent with the *Ri*-similarity: in the surface layer *Ri* is a monotonously increasing function of z/L and vice versa (e.g., Sorbjan, 2010). In the strongly unstable stratification, MOST and *Ri*-similarity fail because of the self-organisation of convective turbulence (Elperin et al., 2006; Zilitinkevich et al., 2006).

In this paper we employ the EFB turbulence closure theory (Zilitinkevich et al, 2013) together with available experimental, LES and DNS data to explain the most puzzling feature of the stably stratified geophysical turbulence, namely, its self-protection in very stable stratification, due to the counter-gradient heat-transfer mechanism missed in the traditional theory. We also explain the self-similarity of turbulence, due to the Kolmogorov's nature of dissipation for the turbulent kinetic energy (TKE), turbulent potential energy (TPE) and turbulent fluxes of heat and momentum.

In non-steady regimes, traditional similarity criteria, such as z/L, *Ri* or the flux Richardson number $Ri_f = -F_b/(u_*^2 S)$ are no longer justified. In numerical models, these criteria are determined diagnostically, which is why they become strongly variable and unreliable. To overtake these difficulties, we propose a concept of approximate similarity based on the "energy stratification criterion" Π ≡(TPE)/(TKE). In the steady state, Π is proportional to $Ri_f/(1 - Ri_f)$, so that the Π-similarity reduces to the traditional Ri_f- or *Ri*-similarities. In the imbalanced turbulence where traditional similarity concepts fail, the Π-similarity, based on prognostic, trustworthy values of turbulent energies, remains a reasonable approximation.