Inverse cascades and non-gradient turbulent fluxes in stratified turbulence: beyond the conventional paradigm

Sergej S. Zilitinkevich [1,2]
[1]Finnish Meteorological Institute; [2]University of Helsinki, Finland

Current vision and modelling of stratified geophysical turbulence are to a large extent based on conventional paradigm leaving no alternative to the forward cascades of kinetic energy and other properties of turbulence towards molecular dissipations, and the downgradient turbulent transports quantified via turbulent viscosity, heat conductivity and diffusivity. These concepts underlie turbulence-closure models, theory and modelling of turbulent diffusion, and famous Monin-Obukhov Similarity Theory (MOST) of the surface-layer turbulence.

In this framework, convective turbulence generated by buoyancy forces is considered as principally the same as mechanical turbulence generated by mean velocity shears and, thus, subjected to the forward cascades; and turbulence in super-critically stable stratifications typical of free atmosphere and ocean thermocline is considered as principally the same as in sub-critically stable boundary layers but just weaker due to strong static stability and weak velocity shears.

Recent observational evidences have disclosed principal failures of conventional theory of stratified turbulence and intolerable uncertainties in its modelling. Nevertheless, neither MOST nor traditional turbulence-closure / turbulent diffusion models have been seriously questioned. The failures root in the commonly recognised paradigm attributed to Kolmogorov (1941a,b; 1942). However, Kolmogorov considered the shear-generated turbulence in neutrally stratified flows where his major concepts:

- definitely forward energy cascade – from larger to smaller eddies, towards dissipation
- and definitely down-gradient turbulent fluxes,

serve as reasonable approximations. Moreover, Kolmogorov was not responsible for the extension of his paradigm to stratified turbulence. This was done without proof by his followers.

This talk demonstrates that conventional paradigm makes a Procrustean bed for the theory of turbulence in both unstable stratification (Zilitinkevich, 1973, 2013; Zilitinkevich at al., 2006) and strongly stable stratification (Zilitinkevich et al., 2008, 2013). We highlight its restrictive nature; demonstrates miscarriages of conventional theory as applied to essentially stratified flows; and outline new Energy- and Flux-Budget (EFB) turbulence-energetics and closure theory accounting for non-gradient turbulent fluxes in both stable and unstable stratifications, inverse energy cascades in convective turbulence, and PBL-scale self-organised convective motions just generated via inverse cascades.

References

Kolmogorov, A., (1941a), “The local structure of turbulence in incompressible viscous fluid for very large Reynolds number” (in Russian) *Dokl. Akad. Nauk SSSR*, 30, 301 (English translation, Friedlander, S. and Topper, L., Turbulence, Interscience, New York, 1961).

Kolmogorov, A., (1941b), “Dissipation of energy in locally isotropic turbulence”, *Dokl. Akad. Nauk SSSR*, 31, 538.

Kolmogorov, A., (1942), “Equations of turbulent motion of an incompressible turbulent fluid”, *Izv. Akad. Nauk SSSR Ser. Phys*. VI, No. l-2, p. 56.

Monin, A., and A. Obukhov, (1954), “Basic laws of turbulence mixing in the surface layer of the atmosphere”. *Trudy Geofiz. Inst. AN SSSR*, 24 (151), 163-187.

Zilitinkevich, S.S., (1973), “Shear convection”. *Boundary-Layer Meteorol*., 3, 416-423.

Zilitinkevich, S.S., Hunt J.C.R., Grachev A.A., Esau I.N., Lalas D.P., Akylas E., Tombrou M., Fairall C.W., Fernando H.J.S., Baklanov A., Joffre S.M., (2006), “The influence of large convective eddies on the surface layer turbulence”. *Quart. J. Roy. Met. Soc*., 132, 1423-1456.

Zilitinkevich S.S., (2013) “Atmospheric Turbulence and Planetary Boundary Layers”. Fizmatlit, M., 248 pp.

Zilitinkevich, S., Elperin T., Kleeorin N., Rogachevskii I., Esau I., (2013) “A hierarchy of energy- and flux-budget turbulence closure models for stably stratified geophysical flows”. *Boundary-Layer Meteorol*., 146, 341-373.