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A fluctuation-dissipation analogy for conveyance and mixing laws by turbulent eddies in hydrology, hydraulics, and micrometeorology

Gabriel Katul (1), Costantine Manes (2), and Dan Li (3)

(1) Duke University, Nicholas School of the Environment, Durham, United States (gaby@duke.edu), (2) Department of Environment, Land and Infrastructure Engineering, Politechnic of Turin, Turin, Italy, (3) Department of Earth and Environment, Boston University, 685 Commonwealth Avenue, Boston, MA 02215, USA

Around the turn from the 19th to the 20th century onwards, a large number of semi-empirical formulae have been independently introduced to describe turbulent flow properties in hydraulics and micrometeorology. These formulae remain the corner stone of textbooks and working professional tool-kits alike. Their success at packing a large corpus of experiments dealing with flow conveyance above gravel beds, pipes and channels, momentum and scalar mixing in stratified boundary layers (including evaporation) explains their wide usage in hydraulics, atmospheric and climate models today. They continue to serve as ’work-horse’ equations for flow and transport in natural systems operating at Reynolds numbers that are simply too large for direct numerical simulations. Despite all these successes, what is evidently missing is a link between these equations and the most prominent features of the flows they aim to describe: turbulent fluctuations and eddies. Establishing this link has been drawing significant research attention over the past 15 years and frames the scope of this presentation. To date, two approaches have been proposed that bridge turbulent energetics (or fluctuations) to bulk flow (or macroscopic) properties: the spectral link and the co-spectral budget model. These links connect facets of the universal properties of the turbulent energy distribution in eddies developed by Kolmogorov to bulk flow properties. The talk reviews the theoretical aspects associated with current spectral links and co-spectral budget models and highlights their prospects to offer derivations of commonly used expressions originating from experiments and observations. These approaches are beginning to delineate contours of a unified fluctuation-dissipation like relation that may describe conveyance and mixing laws by turbulence independently developed in disjointed disciplines. A practical outcome is that the many semi-empirical formulae now in use in hydraulics and micrometeorology may finally profit from developments and advances in turbulence theory.