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A Universal Scaling Law for Gas Transfer Velocities across Complex Interfaces

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Seminar Details

Friday, March 28, 2025
2:30pm – 4:00pm

UH Campus
Classroom & Business Building
Room CBB 108

Online via TEAMS
https://www.cive.uh.edu/research/seminars

ABSTRACT: Bulk mass exchange between an interface emitting or absorbing gas and a turbulent flow, represented by a gas transfer velocity, is commonly described as an empirical function of a mean velocity at some reference height. Such a representation, while of practical significance and continued use in large-scale climate models, misses the most important ingredient to the transfer process itself: turbulent eddies. A large corpus of field and laboratory experiments support the finding that transfer velocities at interfaces subject to turbulent eddies scale as $(\epsilon\nu)^{1/4}$; where ν is the kinematic viscosity and e is the mean turbulent kinetic energy dissipation rate of eddies. Originally predicted from surface renewal theory by Lamont and Scott (1970), this scaling appears to hold for marine and coastal systems, and across many other conditions including transfer of water vapor from rough surfaces into a turbulent atmosphere as shown by (a minor modification to) Brutsaert (1965). In arriving at these results, a number of assumptions were made regarding the surface renewal rate describing the contact durations between eddies and the evaporating or gas-exchanging interface, the diffusional mass transfer process from the surface into eddies, and the internal length scale of eddies. The working hypothesis explored here is that this universal scaling is a direct outcome of the Kolmogorov inertial subrange energy content in eddies modified to include viscous-cutoff thereby by-passing the need for a surface renewal assumption. The connection between energy content in eddies (i.e. a microscopic state) and gas transfer velocities (i.e., macroscopic outcome) may be viewed analogous to a fluctuation-dissipation relation but for turbulent flows. This analogy is further explored using super-statistics to show how variability and intermittency in the dissipation rate leads to variable similarity coefficients.

BIOGRAPHY: Gabriel G. Katul received his B.E. degree in 1988 at the American University of Beirut (Beirut, Lebanon), his M.S. degree in 1990 at Oregon State University (Corvallis, OR) and his Ph.D degree in 1993 at the University of California in Davis (Davis, CA). He currently holds a distinguished Professorship in Hydrology and Micrometeorology at the Department of Civil and Environmental Engineering at Duke University (Durham, NC). He received several honorary awards, including the inspirational teaching award by the students of the School of the Environment at Duke University (in 1994 and 1996), an honorary certificate by La Seccion de Agrofisica de la Sociedad Cubana de Fisica in Habana (in 1998), the Macelwane medal and became thereafter a fellow of the American Geophysical Union (in 2002), the editor's citation for excellence in refereeing from the American Geophysical Union (in 2008), the Hydrologic Science Award from the American Geophysical Union (in 2012), the John Dalton medal from the European Geosciences Union (in 2018), the Outstanding Achievements in Biometeorology Award from the American Meteorological Society (in 2021) and later became an elected fellow of the American Meteorological Society (in 2024), and the recipient of the American Meteorological Society hydrologic science medal (in 2025). Katul was elected to the National Academy of Engineering (in 2023) for his contributions in eco-hydrology and environmental fluid mechanics. His research focuses on micro-meteorology and near-surface hydrology with emphasis on heat, momentum, carbon dioxide, water vapor, ozone, particulate matter (including aerosols, pollen, and seeds) and water transport in the soil-plant-atmosphere system as well as their implications to a plethora of hydrological, ecological, atmospheric and climate change related problems.