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A Theoretical Model of Extended Power-Law Scaling

M. Siena (1,2), A. Guadagnini (1), M. Riva (1), and S.P. Neuman (3)

(1) Dipartimento di Ingegneria Idraulica, Ambientale, Infrastrutture Viarie e Rilevamento, Politecnico di Milano, Milano, Italy, (2) Dipartimento di Matematica e Informatica, Università di Trieste, Trieste, Italy, (3) Department of Hydrology and Water Resources, University of Arizona, Tucson, Arizona, USA

Order q sample structure functions $S^q(s)$ of many variables scale as a power $\zeta(q)$ of the separation scale or lag s. In many cases $\zeta(q)$ varies in a nonlinear fashion with q, a behavior commonly attributed in the literature to multifractals. Power-law scaling tends to break down outside some intermediate range of separation scales, which is often quite narrow. In this latter case $\zeta(q)$ may be difficult to identify unambiguously by standard methods. Fortunately, it is often possible to broaden the range of power-law scaling by a method known as extended self similarity (ESS). If $\zeta(q)$ can be determined with reasonable accuracy by a standard (say moment) method for some (usually low) order q, ESS allows evaluating it with improved accuracy for all remaining orders. No clear explanation for the phenomenon of extended power-law scaling has so far been given outside a narrow domain of Burger's equation. We demonstrate theoretically and on experimental log permeability data that the phenomenon is consistent, at all separation scales, with truncated (self-affine, monofractal) fractional Brownian motion (tfBm). Since in theory the scaling exponents of tfBm vary linearly with q we conclude that nonlinear scaling in this case is not an indication of multifractality but an artifact of sampling. We end by demonstrating how this allows one to identify the functional form and estimate all parameters of the corresponding tfBm based on sample structure functions of first and second orders.