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Biophysical coupling in benthic ecosystems: scales, hydrodynamic equations, double-averaging methodology

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Biophysical coupling in aquatic benthic ecosystems mainly relates to two types of inter-connected processes: (i) physical interactions between flow and organisms (e.g., due to drag forces); and (ii) ecologically relevant mass-transfer-uptake processes (e.g., due to molecular and turbulent diffusion). These processes occur in a wide range of scales and depend on how physical scales match biological scales such as organism dimensions, patch/community dimensions, life cycles, and others. This multi-scale property together with physical and biological complexity of boundary conditions in benthic ecosystems often makes the conventional methodologies impracticable and therefore new approaches are required. One of such approaches, the double-averaging (in time and in spatial domains) methodology, is discussed with particular focus on flows over biologically-modified beds. The double-averaging procedure gives the continuity, momentum, advection-diffusion, energy, and other high-order equations, which are averaged in both time (ensemble) and space (in the plane parallel to the mean bed) domains. This methodology allows scale decomposition (or separation of scales) and can be also viewed as a scaling-up procedure that changes the scale of consideration from one level in time-space-probability domain to another level. It represents a platform for coupling biological, physical, and geochemical descriptions and provides a natural way for integrating small-scale bio-physico-geochemical processes into larger–scale behavior. An example related to mass-transfer-uptake processes in benthic periphyton community is presented.