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Anisotropic turbulent flow in flows within emergent rigid vegetation

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Emergent vegetation covering floodplains and wetlands has an important role in fluvial ecosystems, not only for flood protection purposes but also to promote high standards of water quality and habitat diversity within good landscape design practices. Natural systems are generally not homogeneous. Often, stems are arranged in alternating patches of lower and higher stem densities. The flow within stem arrays is thus influenced by several space scales, determined by the number-density of stems and its spatial modulation.

To characterize flow phenomena in vegetated streams, similar conditions to those found in nature were reproduced in laboratory where vegetation were simulated by dense arrays of vertical emergent stems. The key feature of spatial patchiness in the spatial distribution of the stems was simulated by imposing a periodic longitudinal variation of the stem density. Within a multiple-averaged paradigm for flow characterization, effects of patchiness are formally expressed as interaction between different spatial scales. Such interaction should affect flow spatial heterogeneity and turbulent anisotropy, both influenced by the integral scales.

This work is thus aimed at characterizing flow anisotropy, flow spatial heterogeneity and the interaction of spatial scales, represented by different stem densities and respective modulation.. The data treatment is performed in order to allow for a detailed characterization of the flow structure featuring instantaneous, time-averaged and double-averaged velocities, spectral estimators and anisotropy estimators based on the anisotropy tensor. A new measure of spatial heterogeneity, based on the concept of spatial anisotropy is proposed..

To achieve these goals, three experimental tests were carried out in the 12.5 m long and 40.8 cm wide tilting recirculation flume of the Laboratory of Hydraulics at IST featuring i) a uniform stem density of 400 stems/m2, ii) a uniform stem density of 1600 stems/m2 and, ii) a gradually varying stem density with minimum and maximum densities of 400 stems/m2 and 1600 stems/m2, separated by a fixed wavelength of 0.5 m. In all tests, stems were placed at irregularly over a horizontal gravel-sand bed and the discharge was kept constant. Velocity measurements were carried out with a 532 nm, 30 mJ 2D Particle Image Velocimetry (PIV) system, which allows for obtaining instantaneous velocity maps.

This study shows an impact of alternating patches with different densities in energy cascading in the sense of Kolmogorov. Velocity power spectra analysis shows that in this type of flows, scale modulation destroys the coherent vorticity produced around the stems. Moreover, the flow seems to have an inertial scale corresponding to the distance between those alternating patches. Normal longitudinal form-induced stresses are the main expression of flow heterogeneity and contribute to a expansion axisymetric spatial anisotropy. Turbulence is mainly conditioned by the local integral sale, revealing a strong tendency to isotropy.

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