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Cross-correlation between time scales in open-channel river flows

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In natural river flows different length scales coexist simultaneously including grain scale (e.g. grain roughness), meso-scale (e.g. bed forms, bank forms and vegetation patches or elements) and morphological scale (e.g. channel configuration, bends, braiding, etc.). These length scales have an impression on time scales and, consequently, a wide range of time-scales co-exists as well which may be analyzed in an Euleurian frame. Several authors argue that these scales are not independent thus interaction is expected across energy spectra of instantaneous velocities signals between different but specific scales. A formal theoretical framework to account for the interaction between scales of these flows acquires additional complexity when compared to time-averaged approaches applied to turbulent river flows. In the present research we study the importance of the cross-correlation between time coherent motions at different scales and how can this be included in conservation equations. This analysis is based on 15 instantaneous 3D velocities profiles measured in an armoured gravel-bed river by means of an Acoustic Doppler Velocity Profiler. 3D instantaneous velocity profiles were measured with a vertical resolution of 5 mm in a 0.30x0.40 m^2 horizontal grid for 3.5 min each with an acquisition frequency of 26 Hz. With a water depth of 0.20 m and the bed material composed of coarse round gravel with a D_{50} of 68 mm, the riverbed is hydraulically rough and the flow has relative submergence of 2.9 (ratio of the water depth by D_{50}). Previous work using the present data concerned the identification of coherent structures existing within narrow reaches of the flow energy spectra by means of wavelet decomposition. We identified and reconstructed a low-frequency oscillation in the streamwise velocity as well, corresponding to large-scale regions of velocity alternating higher or lower than the mean using Empirical Mode Decomposition to isolate the oscillation and phase averaging techniques based on a Hilbert transform of the velocity signal to reconstruct them. Here a multiple-scale analysis is carried out where the interaction between different scale bands becomes evident and can be characterized and quantified. Conditional sampling techniques and wavelet multilevel decomposition of single point instantaneous velocity measurements are used to isolate the signal corresponding to a particular scale (the most energetic scale, in the present case). Subsequently, cross-correlation between the sampled data and the residual signal is analyzed and discussed. The global contribution of a particular scale to total normal stresses and also to local stresses within one coherent structure phase cycle is examined. The present results constitute an attempt to quantify the interaction between different scales within the flow turbulent structure. A decomposition of the instantaneous velocity signal accounting for several scales is proposed and the implication of this in conservation equations (namely momentum equations) is assessed. For time-averaged quantities, cross-moments between energetic scales and residual signal are insignificant and negligible. However, for individual coherent events, these crossed interactions acquire importance for the local flow energy. Cross-moments are never higher than 0.2 of the total signal energy. The results show the importance of the averaging window for each flow analysis and indicate that further sampling and correlation techniques have to be applied to determine the interaction between scales. In the future, the formal introduction of multiple-scale decomposition into transport equations, with the development of new terms accounting for interaction between scales, is envisaged.

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