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Detection and reconstruction of large scale flow structures in a river by means of empirical mode decomposition combined with Hilbert transform

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The occurrence of large scale flow structures (LSFS) coherently organized throughout the flow depth has been reported in field and laboratory experiments of flows over gravel beds, especially under low relative submergence conditions. In these, the instantaneous velocity is synchronized over the whole vertical profile oscillating at a low frequency above or below the time-averaged value.

The detection of large scale coherently organized regions in the flow field is often difficult since it requires detailed simultaneous observations of the flow velocities at several levels. The present research avoids the detection problem by using an Acoustic Doppler Velocity Profiler (ADVP), which permits measuring three-dimensional velocities quasi-simultaneously over the full water column. Empirical mode decomposition (EMD) combined with the application of the Hilbert transform is then applied to the instantaneous velocity data to detect and isolate LSFS.

The present research was carried out in a Swiss river with low relative submergence of 2.9, herein defined as h/D_{50}, (where h is the mean flow depth and D_{50} the bed grain size diameter for which 50% of the grains have smaller diameters). 3D ADVP instantaneous velocity measurements were made on a 3x5 rectangular horizontal grid (x-y). Fifteen velocity profiles were equally spaced in the spanwise direction with a distance of 10 cm, and in the streamwise direction with a distance of 15 cm. The vertical resolution of the measurements is roughly 0.5 cm. A measuring grid covering a 3D control volume was defined. The instantaneous velocity profiles were measured for 3.5 min with a sampling frequency of 26 Hz.

Oscillating LSFS are detected and isolated in the instantaneous velocity signal of the 15 measured profiles. Their 3D cycle geometry is reconstructed and investigated through phase averaging based on the identification of the instantaneous signal phase (related to the Hilbert transform) applied to the original raw signal. Results for all the profiles are consistent and indicate clearly the presence of LSFS throughout the flow depth with impact on the three components of the velocity profile and on the bed friction velocity. A high correlation of the movement is found throughout the flow depth, thus corroborating the hypothesis of large-scale coherent motion evolving over the whole water depth. These latter are characterized in terms of period, horizontal scale and geometry.

The high spatial and temporal resolution of our ADVP was crucial for obtaining comprehensive results on coherent structures dynamics. EMD combined with the Hilbert transform have previously been successfully applied to geophysical flow studies. Here we show that this method can also be used for the analysis of river dynamics. In particular, we demonstrate that a clean, well-behaved intrinsic mode function can be obtained from a noisy velocity time series that allowed a precise determination of the vertical structure of the coherent structures. The phase unwrapping of the UMR and the identification of the phase related velocity components brings new insight into the flow dynamics

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