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Effect of dispersive water waves on non-contact surface Doppler spectra in shallow river flows

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Radar and acoustic Doppler methods are being widely used for measuring the surface velocity of rivers and open channels remotely. Although the relation between the Doppler spectra and the water surface shape and dynamics have been well characterised for oceanographic applications, little is known about the behaviour of the spectra in shallow river flows. In rivers, turbulent currents and shallow-depth effects are much stronger, whereas wind effects are weak. In this work, the statistics of the free surface, and the Doppler spectra of airborne ultrasound were compared and analysed for a set of turbulent free surface flows over a rough bed. Measurements of the spectra in a laboratory flume were combined with numerical simulations based on a Kirchhoff model of scattering and a first-order free surface model. In the more typical backscattering configuration, the shape of the Doppler spectra was found changing strongly with the flow conditions. At low Froude numbers, the Doppler velocity was uniquely identified from a single peak of the spectra. At intermediate and high Froude numbers, capillary waves that propagate relative to the mean flow in both directions, though mostly upstream, produced a more complex multi-peak spectrum. The amplitude of the different spectral peaks makes the identification of a single representative surface velocity difficult, possibly explaining the previously observed higher uncertainty of radar and acoustic Doppler velocity measurements in very rough channels. Compared with backscattering, the forward scattered (or bistatic) Doppler spectra are more stable and behave more predictably across the same range of flow conditions, with a weaker effect of nonlinearities becoming visible only for higher Froude numbers. The width of the main spectral peak was found to increase linearly with the surface velocity for all measured flow conditions. It is suggested that forward scattering Doppler could provide a more robust alternative than backscattering for non-contact river surface velocity measurements.