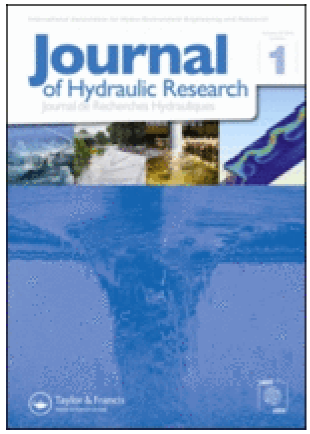

``A Lagrangian drifter for surveys of water surface roughness in streams'', by Christian Noss et al.

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Discussion

"A Lagrangian drifter for surveys of water surface roughness in streams", by Christian Noss et al.

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"A Lagrangian drifter for surveys of water surface roughness in streams", by Christian Noss et al.

The Discussers congratulate the Authors for developing an instrument capable of accurately measuring the water surface roughness of free surface turbulent flows in a Lagrangian frame, and for using the instrument to collect data to empirically develop a set of relations between the water surface standard deviation and some hydraulic parameters of the flow. The Authors highlighted the need for further experiments in order to clarify the physical mechanisms behind these relations, however we believe that a deeper insight into such processes (and a further validation of their experimental results) can already be extracted from their data, as discussed below.

The existing validation of the experimental results in the paper is based on a comparison with a simple theoretical model developed by Nichols, Tait, Horoshenkov, and Shepherd (2016). The model presented by Nichols et al. (2016) represents the surface roughness in terms of localized disturbances that fluctuate vertically at a characteristic frequency f while being advected at the flow velocity. According to Nichols et al. (2016), the origins of the localized disturbances appeared to be related to turbulent bursting events. This conceptualization was inspired by earlier observations of the fluctuating spatio-temporal correlation of the surface roughness reported by Horoshenkov, Nichols, Tait, and Maximov (2013). In this paper, the comparison with the model by Nichols et al. (2016) yielded values of the depth of influence factor N that varied much more strongly among different tests than observed by Nichols et al. (2016) in flume experiments with similar bulk flow characteristics.

An alternative interpretation of the fluctuating surface correlations was provided by Dolcetti, Horoshenkov, Krynkin, and Tait (2016) and Dolcetti and García Nava (2019). While the surface roughness of open channel flows presents a combination of non-dispersive deformations and gravity-capillary waves with various wavelengths and orientations, the characteristic spatial scale of such surfaces matches the wavelength λ_0 of the stationary gravity-capillary waves oriented against the flow (Dolcetti et al., 2016). Neglecting the effects of shear for simplicity (these are considered by Dolcetti et al. (2016)), the radian frequency of gravity-capillary waves propagating over a flow with speed U and depth D is

$$\Omega(k,\theta) = kU\cos(\theta) \pm \left[\left(g + \frac{\gamma}{\rho}k^2\right) k \tanh(kD)\right]^{1/2}, \tag{1}$$

where $k = 2\pi/\lambda$ is the surface wavenumber, θ is the direction of propagation of a wave relative to the flow direction, g is the gravitational acceleration, γ is the surface tension coefficient, and ρ is the water density. The wavelength of the stationary waves $\lambda_0 = 2\pi/k_0$ is found numerically from the solution of

$$k_0^2U^2 = \omega_i^2(k_0) = \left(g + \frac{\gamma}{\rho}k_0^2\right) k_0 \tanh(k_0D), \tag{2}$$

where $\omega_i(k_0)$ is the intrinsic frequency of the waves with wavenumber k_0 in still water. Non-dimensionalizing in terms of the Froude $\mathsf{F} = U/(gD)^{1/2}$ and Bond $\mathsf{B} = \rho g D^2/\gamma$ numbers,

$$k_0d = \frac{\omega_i(k_0)U}{\mathsf{F}^2 g} = \left(1 + \frac{k_0^2D^2}{\mathsf{B}}\right)\frac{\tanh(k_0D)}{\mathsf{F}^2}. \tag{3}$$

According to Dolcetti and García Nava (2019), the water surface roughness of a shallow open channel flow over a rough bed can be modelled as a first approximation by a distribution of waves with wavenumber k_0 that propagate in all directions. An hypothesis about the formation of this distribution has been advanced by Dolcetti and García Nava (2019), although stronger experimental and theoretical evidence is required to clearly demonstrate the origin of the distribution. The model is described by (Dolcetti and García Nava (2019), Eq. (21))

$$z(x, y, t) = \frac{1}{2}\int_{-\pi}^{\pi} \hat{z}(\theta) \exp\left\{\mathrm{i}k_0\left[x\cos(\theta) + y\sin(\theta)\right] - \mathrm{i}\Omega(k_0, \theta)t\right\} \mathrm{d}\theta + \text{ c.c. }, \tag{4}$$

where c.c. indicates the complex conjugate, and $\hat{z}(\theta)$ is a complex random function of the surface angular spectrum at the wavenumber k_0. In the frame of reference of an ideal drifter, $x = x_0 + Ut$, $y = y_0$, assuming $x_0 = y_0 = 0$ without loss of generality, Eq. (4) can be written as

$$z(Ut, 0, t) = A\cos\left[\omega_i(k_0)t + \phi\right], \tag{5}$$

where A and ϕ are random real numbers that depend on the integral of $\hat{z}(\theta)$.

According to Eq. (5), the drifter would experience a sinusoidal vertical fluctuation while it moves along the flow, with the frequency

$$f = \frac{\omega_i(k_0)}{2\pi}, \tag{6}$$

that can be calculated from Eq. (2) or Eq. (3) based on the flow speed and depth. As shown in Fig. 4 by the Authors, the actual behavior of the drifter appears to be more complex, possibly because of the presence of waves with different wavelength, although the observed narrow-band spectra suggest that Eq. (5) can provide a reasonable approximation of their measurements.

Figure 1 shows a comparison between the peak frequencies measured by the Authors both in the flume and in the field, and the characteristic frequencies predicted by Eq. (6). The agreement appears high for most flume and field data, with deviations < 12 % for all experiments except flume experiment 10 and the field rippled flow (RF) experiment. Note that results for the SBT section are not included, as this flow had a velocity < 0.23 m s^{-1}, which precluded the formation of stationary waves. It is suggested that the lack of stationary waves could partially explain the different results observed by the Authors for this experiment. In the RF section, the Authors observed a broad spectrum (1–4 Hz) without marked peaks, while Eq. (6) predicts a frequency of 5.8 Hz. According to Eq. (3), the characteristic wavelength for that experiment was only 52 mm. It is suggested that these short and fast waves may have been outside of the range of measurement capability of the drifter, which had a diameter of 28 mm. Considering experiment 10, the expected peak frequency for this experiment was 0.63 Hz, which is lower than the preprocessing filter cutoff. This instrument feature may explain the much poorer correspondence observed in this test than in the other laboratory tests.

In conclusion, the peak frequencies observed by the Authors appear to be in good agreement with the analytical model described by Dolcetti and García Nava (2019) and results of this models also provide an explanation for experiments in which good agreement was not obtained. The model by Dolcetti and García Nava (2019) is described by a single spatial and temporal scale, which correspond to the wavelength and intrinsic frequency of the stationary gravity-capillary waves oriented against the flow. It is interesting to note that the data from the drifter indicates that stationary waves still seem to represent the dominant free-surface features even for the large water depths reported in this study. These waves are believed to originate from the interaction with the rough static bed. This may explain the strong correlation between the water surface standard deviation and the shear velocity observed by the Authors. The match between the data and the model by Dolcetti and García Nava (2019) gives more confidence on the fact that the drifter could be deployed in a range of situations (subject to the small- and large-wavelength restrictions) and collect high quality data that may help to clarify the nature and characteristics of the water surface roughness in small rivers and open channels.

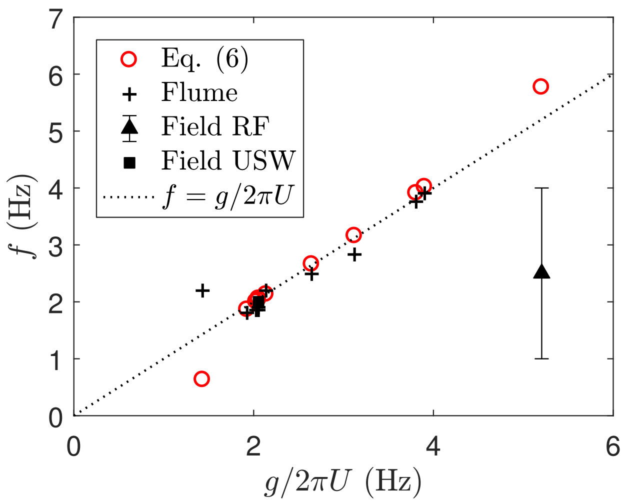

Figure 1 Peak frequency of measured drifter fluctuations in the flume (crosses) and in the field (square, triangle), compared with the intrinsic frequency of stationary waves, Eq. (6) (red circles). Dotted line: $f = g/2\pi U$, which corresponds to Eq. (6) for $\mathsf{B}/k_0^2D^2 \to \infty$, $k_0D \to \infty$. Note that finite depth generally decreases the frequency (small $g/2\pi U$), while surface tension increases it (large $g/2\pi U$).

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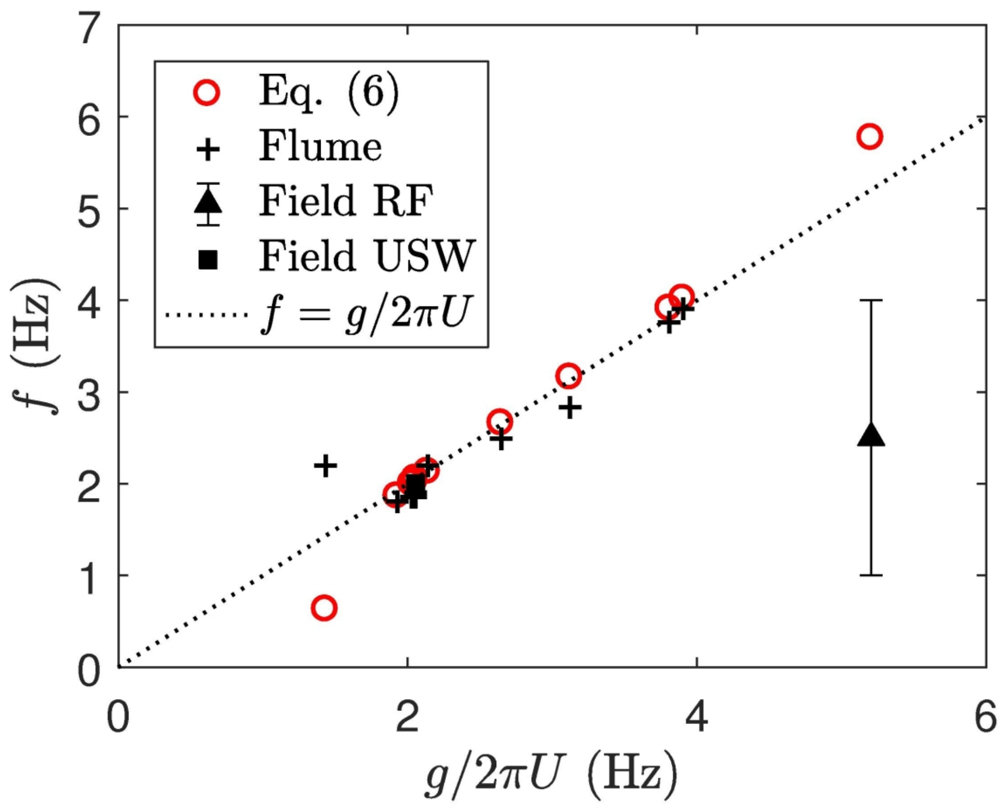

Peak frequency of measured drifter fluctuations in the flume (crosses) and in the field (square, triangle), compared with the intrinsic frequency of stationary waves, Eq. (6). Dotted line: $f = g/2\pi U$, which corresponds to Eq. (6) for $B/k_0^2D^2 \to \infty$, $k_0D \to \infty$. Note that finite depth generally decreases the frequency (small $g/2\pi U$), while surface tension increases it (large $g/2\pi U$).

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