An acoustic technique to measure the velocity of shallow turbulent flows remotely

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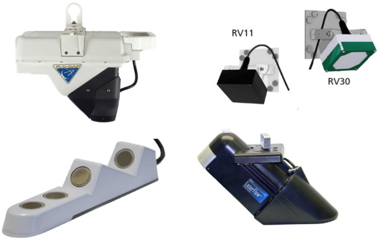
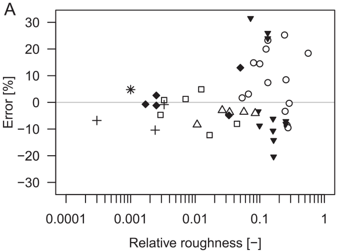
Remote monitoring of shallow turbulent flows based on Doppler



Remote measurements:

- Lower cost.
- Safer access.
- Less risk of fouling.
- Reliable?



(Welber *et al.*, 2016 WRR)

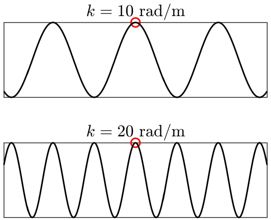
Free surface patterns in shallow flows


(Brocchini and Peregrine, 2001 JFM)


(Chanson, 2000 WRR)

- Turbulent 'boils'.
- Gravity-capillary waves.

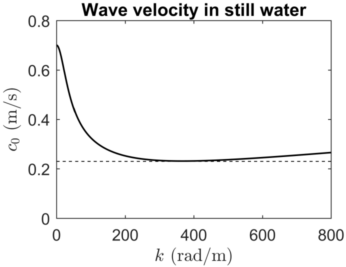
Gravity-capillary waves

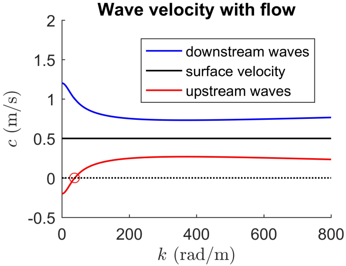


Wavenumber: $k = 2\pi/\lambda$

Frequency: $f = kc/2\pi$

Mean surface velocity: U_0

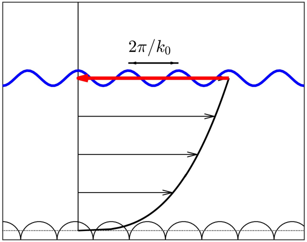




Downstream waves: $c \approx U_0 + c_0$

Upstream waves: $c \approx U_0 - c_0$

Stationary waves



$$U(z) = (z/H)^n$$

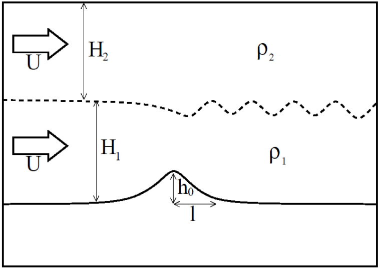
$$k_0 \frac{I_{-1/2-n}(k_0 H)}{I_{1/2-n}(k_0 H)} = \frac{g + \frac{\gamma}{\rho} k_0^2}{U_0^2}$$

k_0: wavenumber of stationary waves
H: mean depth
U_0: mean surface velocity
n: velocity profile exponent
γ: surface tension
ρ: density

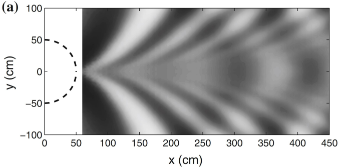
(Burns, 1953 MPCam; Fenton, 1976 IMA JAM)

Isolated bed topography - stationary wake

Isolated roughness element

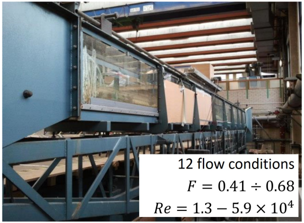


(Teixeira *et al.*, 2017 JAtSc)



(Lacaze *et al.*, 2013 ExpF)

Experiments in a laboratory flume



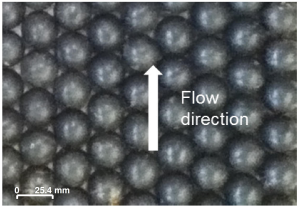
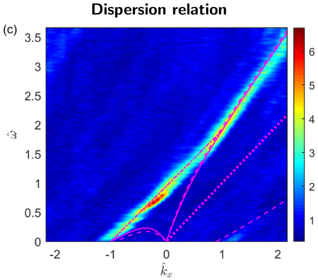


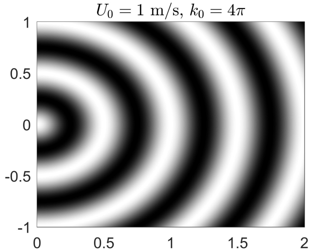
Figure 4.2: A photograph of the flume bed.

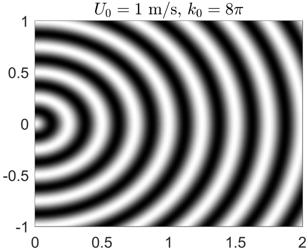


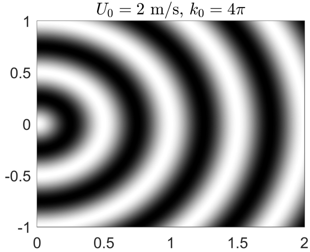
(Dolcetti *et al.*, 2016 PoF)

Waves in all directions with same wavenumber k_0.
But different amplitude

Radial pattern of waves

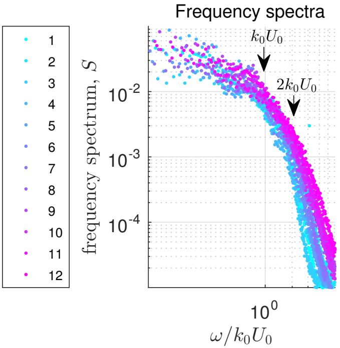


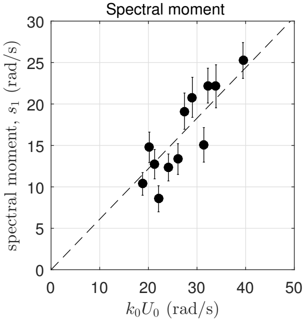




Upstream: $f = 0$
Transverse: $f = k_0 U_0 / 2\pi$
Downstream: $f = 2 k_0 U_0 / 2\pi$

Surface frequency spectra





12 flow conditions

$F = 0.41 - 0.68,\ Re = 1.3 - 5.9 \times 10^4$

First moment (average frequency):

$$s_1 = \frac{\int \omega S(\omega) d\omega}{\int S(\omega) d\omega}$$

Velocity estimation procedure

1. Calibration (linear fitting):

$$s_1 = m k_0 U_0$$

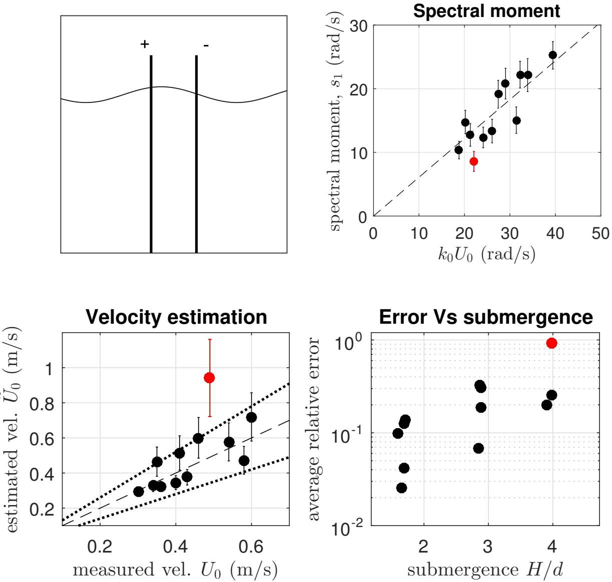
2. Calculation of k_0:

$$\begin{cases} k_0 U_0 = \frac{s_1}{m} \\ k_0^2 U_0^2 \frac{I_{-1/2-n}(k_0 H)}{I_{1/2-n}(k_0 H)} = \left(g + \frac{\gamma}{\rho} k_0^2\right) k_0 \end{cases} \rightarrow k_0$$

3. Estimation of U_0:

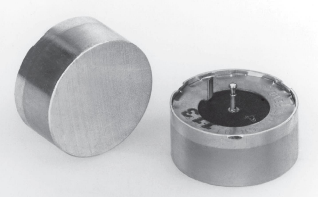
$$\rightarrow \tilde{U}_0 = \frac{s_1}{m k_0}$$

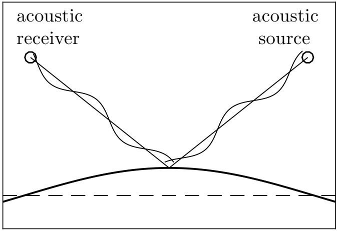
Applications - Conductance wave probe

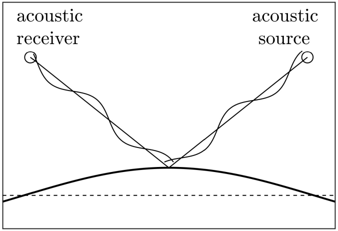


Applications - Acoustic measurements

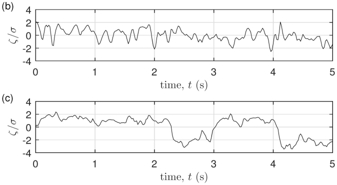
Acoustic transducers, 39 kHz





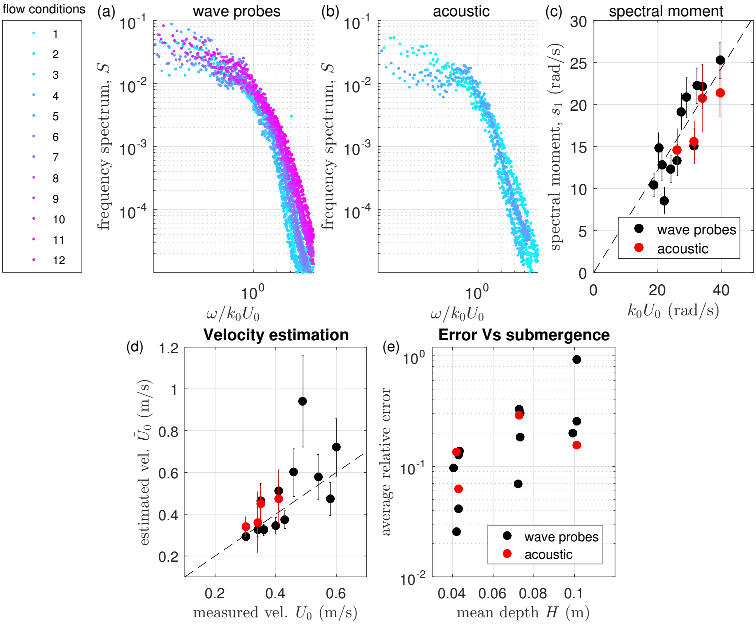


Surface measurement



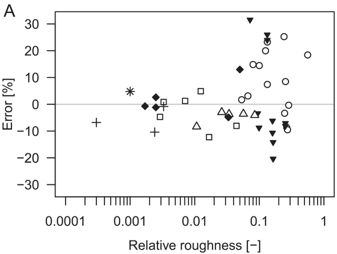
$$F = 0.45 - 0.52$$
$$Re = 1.3 - 4.1 \times 10^4$$

Acoustic measurement of the surface velocity



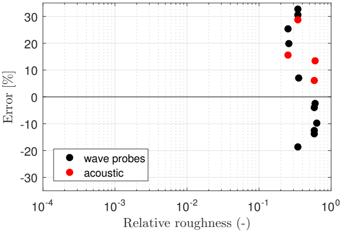
Accuracy

Microwave/Radar Doppler



(Welber *et al.*, 2016 WRR)

Acoustics



Accuracy comparable to alternative remote measurement techniques, superior at low submergences.

Thank you.