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Momentum balance under plunging breakers: the role of advection on sediment mobilization and transport

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Background & Motivation

- Pressure gradients important for sediment mobilization and transport [Madsen 1976; Foster et al. 2006].
- Acceleration used as proxy [Drake & Calantoni 2001; Hoefel & Elgar 2003] .
- But poor correlation between the total force and the local acceleration inside the surf /swash region [e.g., Puleo et al. 2007; [Pedrozo-Acuña et al. 2010].
- Aim: refine analysis to evaluate role of other terms and implications on sediment transport.

Present work

Model: COBRAS [Lin & Liu 1998] VOF, 2DV Reynolds-Averaged Navier-Stokes equations.

Topography: Steep impermeable (1:12) slope. Reference frame oriented parallel to bed [e.g., Puleo et al. 2007; Zhang & Liu 2008].

Waves: Monochromatic cnoidal: H=0.12m; T=2s. Waves are generated using source function

Bed-parallel momentum terms taken directly from the model. Total force (I) compared against the following contributions:

(II) Total acceleration+viscous/Reynolds stresses;

(III) Local acceleration.

(IV) Advective terms.

(V) Reynolds/viscous stresses.

Sediment transport: Pressure gradients and bottom shear stresses give Sleath and Shields parameters, - normalized by the plug, S=0.29, and sheet-flow, θ=0.8, values [Foster et al., 2006].

$$\underbrace{-\frac{1}{\langle\rho\rangle}\frac{\partial\langle p\rangle}{\partial x'}+g_x}_{I}=\overbrace{\underbrace{\frac{\partial\langle u\rangle}{\partial t}}_{III}+\underbrace{\langle u\rangle\frac{\partial\langle u\rangle}{\partial x'}+\langle w\rangle\frac{\partial\langle u\rangle}{\partial z'}}_{IV}-\underbrace{\frac{1}{\langle\rho\rangle}\left(\frac{\partial\langle\tau_{xx}\rangle}{\partial x'}+\frac{\partial\langle\tau_{xz}\rangle}{\partial z'}\right)}_{V}}^{II}$$

(1)

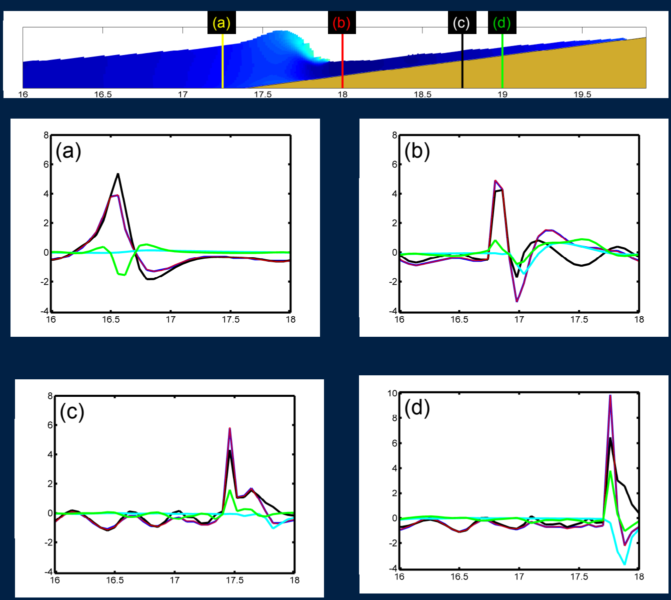

FIGURE 1.- Temporal evolution of momentum balance terms at a) pre-breaking, b) breaking point, and c)-d) post-breaking. The different curves corresponds to terms: I, II, III, IV, and V in Equation (1). The different cross-shore locations are depicted in the upper panel.

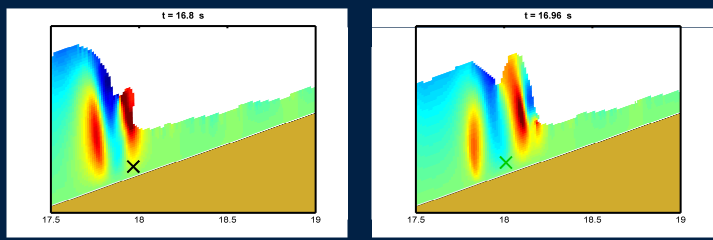

FIGURE 2.- Snapshots of the bed-normal velocity field during the wave impinge. Positive velocities at both sides of the jet produces a quasi-symmetric pressure gradient evolution at x=18m. Crosses depict the near-bed cell location of time series in Figures 1(b) and 3(b).

Simulation Results

The spatial variation of the momentum balance at different locations on the beach slope are presented in Figure 1. As expected, the RHS of (1) explains the total force evolution (Fig 1a-d).

Fig 1(a) Under a near-breaking wave the total force (blue line) is approx. in balance with the local acceleration term (black line). Advection and Reynolds/viscous stresses are negligible. Thus pressure gradient can be explained in terms of the local acceleration only (e.g. Hoefel and Elgar, 2003).

Fig 1(b) As wave impinges on the fluid a sharper spike observed. After impact local acceleration deviates from pressure gradient. Not possible to identify a church-roof profile, because wave-impact occurs up in the water column. Negative peak due to jet disturbance (see Figure 2) .

Fig 1(c) similar, but smaller magnitude spike. Momentum balance associated with turbulent bore passage, supported by observed increase in Reynolds/viscous stresses term (turbulence). Agrees with e.g. Puleo et al 2006.

Figure 1(d) Further onshore, big spike on the pressure gradient curve associated with another wave-impact in a region closer to the bed [see Pedrozo-Acuña et al, 2008].

Figure 3 Time evolution of normalized Sleath and Shields parameters for locations (a) and (b). Figure 3(a) pressure gradient and bottom shear stresses act in concert for sediment transport under near-breaking waves. However at the point of impingement, pressure gradient is more important in sediment mobilization.

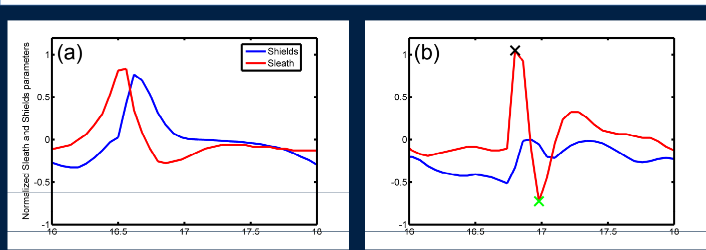

FIGURE 3.- Sleath and Shields parameters (normalized by the plug and sheet-flow thresholds) time-evolution at two different cross-shore locations.

Conclusions

- Numerical results show local acceleration alone cannot be used as proxy for pressure gradients under plunging breakers.
- The contribution of wave-impacts from plunging breakers to the momentum balance in the fluid is clearly revealed. Local acceleration does not completely explain the pressure gradient and the contribution of the advective terms cannot be neglected [e.g. Puleo et al., 2007; Pedrozo-Acuña et al., 2010].
- Spatial variability of the momentum balance under plunging breakers indicates a complex structure.

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