Swash Morphodynamics and Its Relation to Tsunamis

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Swash zone morphodynamics

1. On steep beaches swash defined as the distance from point of bore collapse (max. run-down) to max. run-up.
2. Large amounts of sediment transport occur on uprush and backwash. Net transport is the difference (often small) between two large quantities.
3. Erosion / Deposition highly dynamic

Physical effects

1. Bed shear stress.
2. Turbulence / acceleration (bores)
3. Pre-suspended sediment
4. Lag effects
5. In/exfiltration
6. Pore-pressure gradients (see Tonkin et al)

A Simple Morphodynamical Model of the Swash

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Depth-integrated (NSWE) (including in/exfiltration) + Sediment Conservation & advection diffusion equation.

$$
\begin{aligned}
&d_t + (dU)_x + (dV)_y = -w \\
&(dU)_t + \left(dU^2 + \frac{gd^2}{2} \right)_x + (dUV)_y = gdh_x - \frac{f_w}{2} U|\vec{U}| - Uw \\
&(dV)_t + (dUV)_x + \left(dV^2 + \frac{gd^2}{2} \right)_y = gdh_y - \frac{f_w}{2} V|\vec{U}| - Vw \\
&B_t + \xi \vec{\nabla}.\vec{q} + C_t = 0 \\
&C_t + \vec{U}.\vec{\nabla}C - w_s C_b - \mu_v C_{zb} = \vec{\nabla}.\left(\mu_h \vec{\nabla}C\right) - B_{st}
\end{aligned}
$$

$$\frac{1}{1-n} = \xi$$

Where free slip condition applied $B_t + \vec{U}.\vec{\nabla}B - W = w$ at $z = B(\vec{x}, t)$

Timescales

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Traditional morphodynamical models decouple hydro- and morphodynamic timescales. In the swash flows are transcritical, so this is not possible. $T_m \approx T_h$

So, for tsunami simulations models must be fully coupled

A Simpler Morphodynamical Model of the Swash

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$$d_t + (dU)_x + (dV)_y = -w$$
$$(dU)_t + \left(dU^2 + \frac{gd^2}{2} \right)_x + (dUV)_y = gdh_x - \frac{f_w}{2} U|\vec{U}| - Uw$$
$$(dV)_t + (dUV)_x + \left(dV^2 + \frac{gd^2}{2} \right)_y = gdh_y - \frac{f_w}{2} V|\vec{U}| - Vw$$
$$B_t + \xi \vec{\nabla}.\vec{q} = 0$$

$$\frac{1}{1-n} = \xi$$

NSWE (including infiltration) + Sediment Conservation equation.

Where $\vec{q} = A|\vec{U}|^2 \vec{U} - \frac{1}{\tan\phi} |\vec{q}^*| \vec{\nabla} b$ Writing $A|\vec{U}|^2 \vec{U} = \alpha \vec{U}$

these can be combined to give

$$B_t \left(1 + \xi \frac{\alpha}{d} \right) = -\xi d\vec{U}.\vec{\nabla} \frac{\alpha}{d} + \xi \frac{\alpha}{d} (\eta_t + w) + \xi \vec{\nabla}.\left(\frac{\alpha}{\tan\phi} |\vec{U}| \vec{\nabla} b \right)$$

Physical Processes

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Flow divergence: increasing depth (convergence) => deposition

Infiltration => deposition

$$B_t\left(1+\xi\frac{\alpha}{d}\right) = -\xi d\vec{U}.\vec{\nabla}\left(\frac{\alpha}{d}\right)+\xi\frac{\alpha}{d}\left(\eta_t + w\right)+\xi\vec{\nabla}.\left(\frac{\alpha}{\tan\phi}|\vec{U}|\vec{\nabla}b\right)$$

Flow picks up / drops based on local concentration gradient

Diffusion (smoothing): opposes bed growth

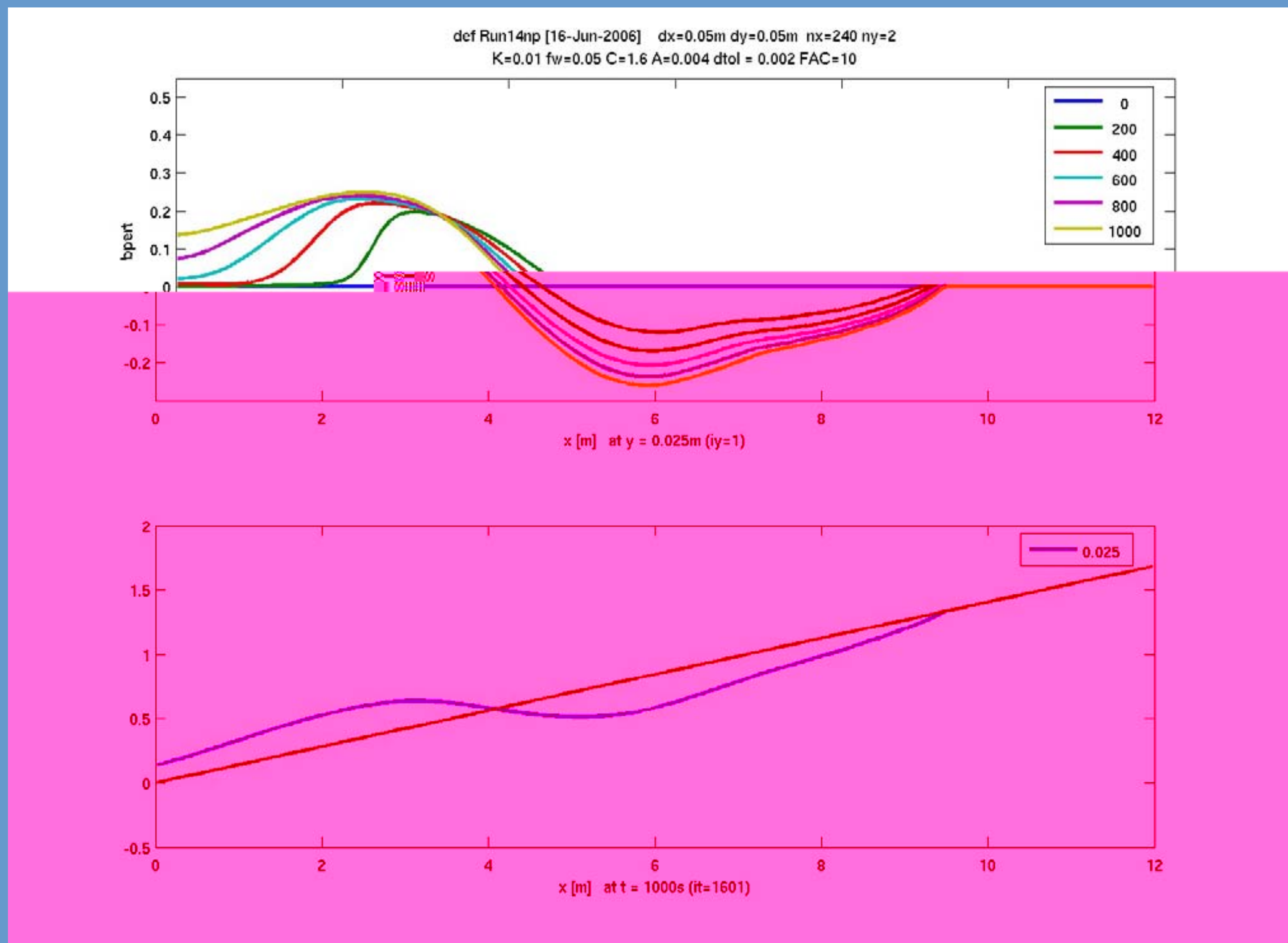
Cross-shore swash profile evolution

Impermeable & permeable beaches

Simulations on a steep (1:7) beach, with initially nearly non-breaking, 5s waves

Cross-shore swash profile evolution

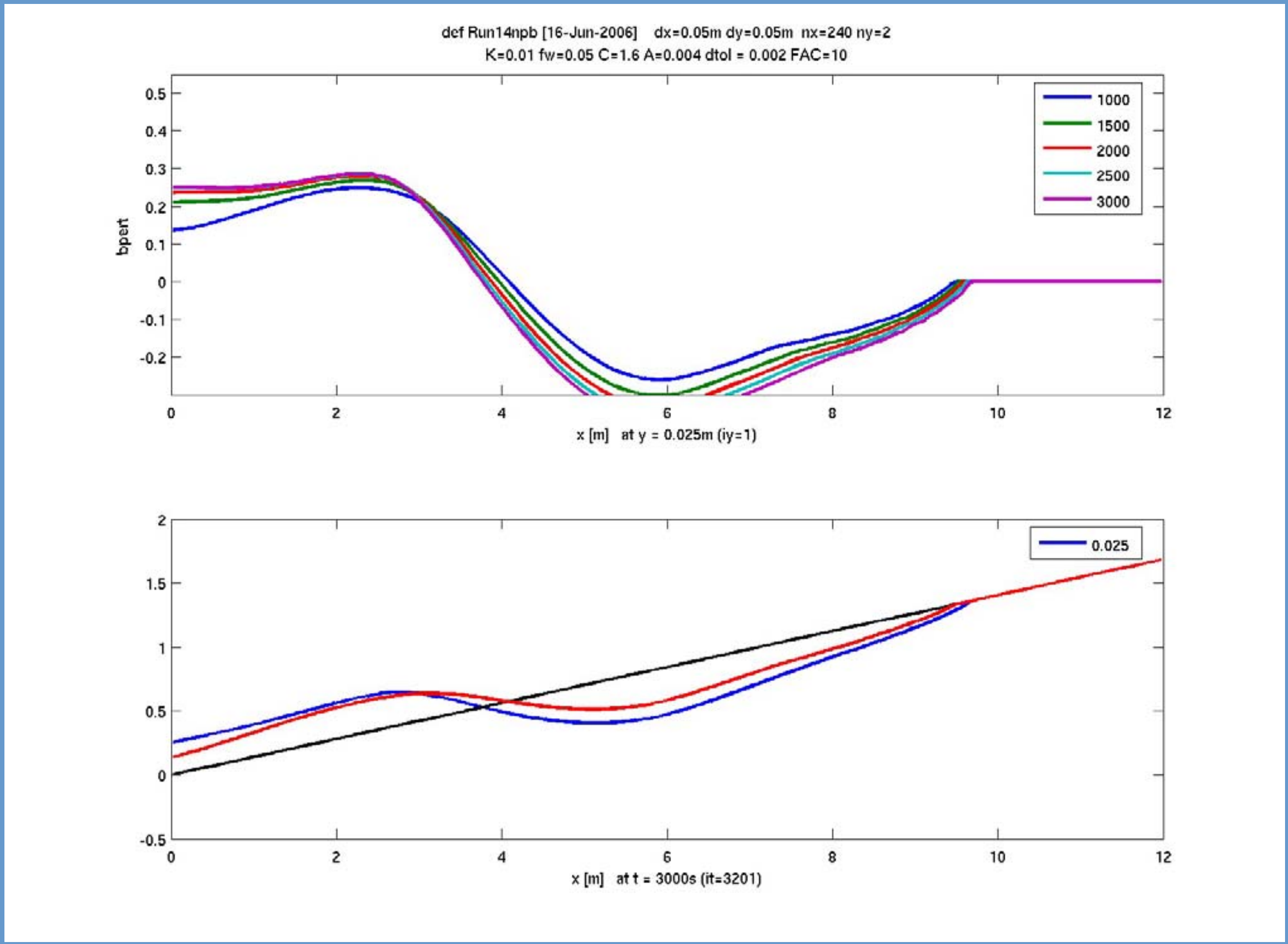
Impermeable beach



0-1000s

Cross-shore swash profile evolution

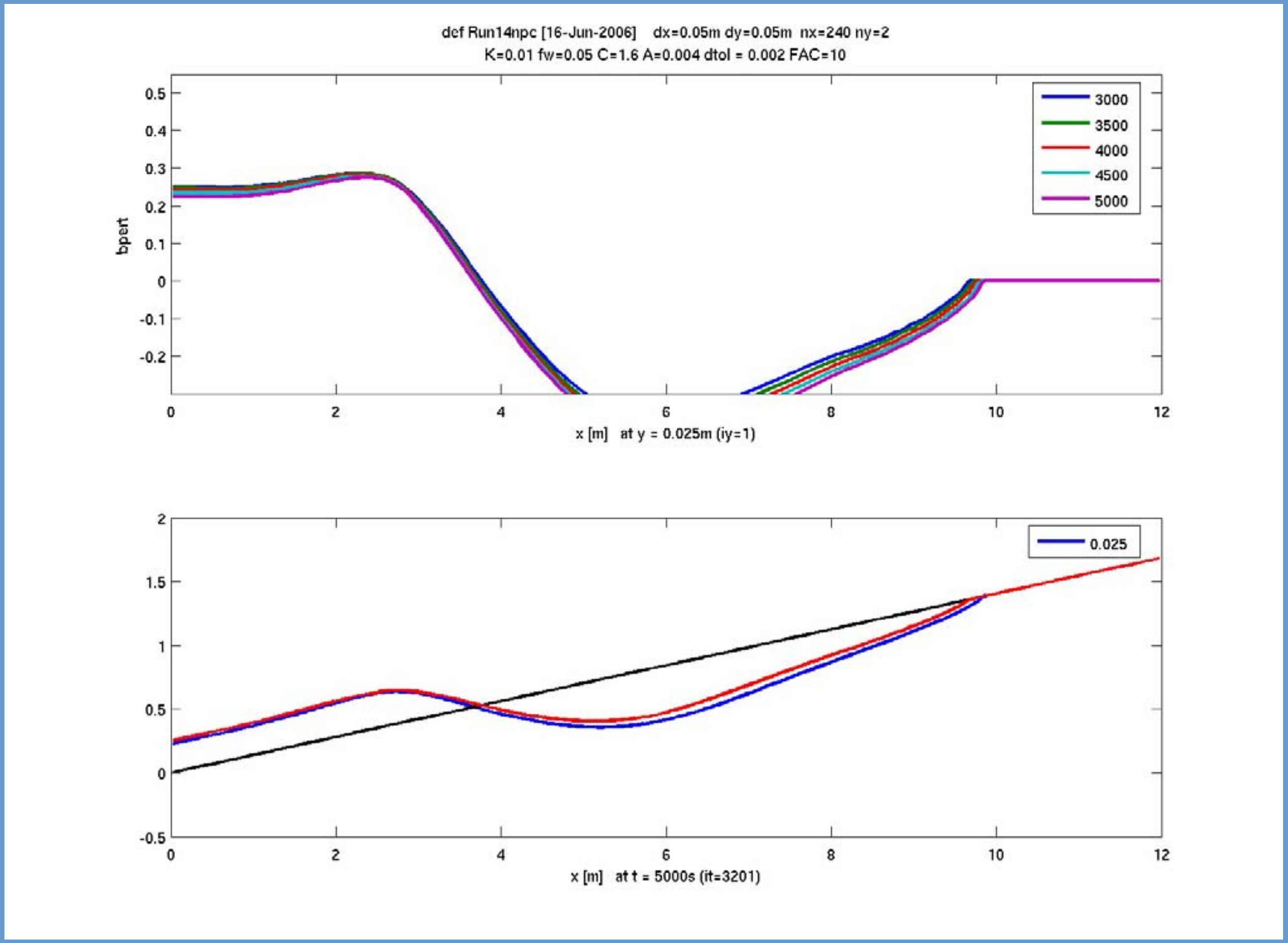
Impermeable beach



1000-3000s

Cross-shore swash profile evolution

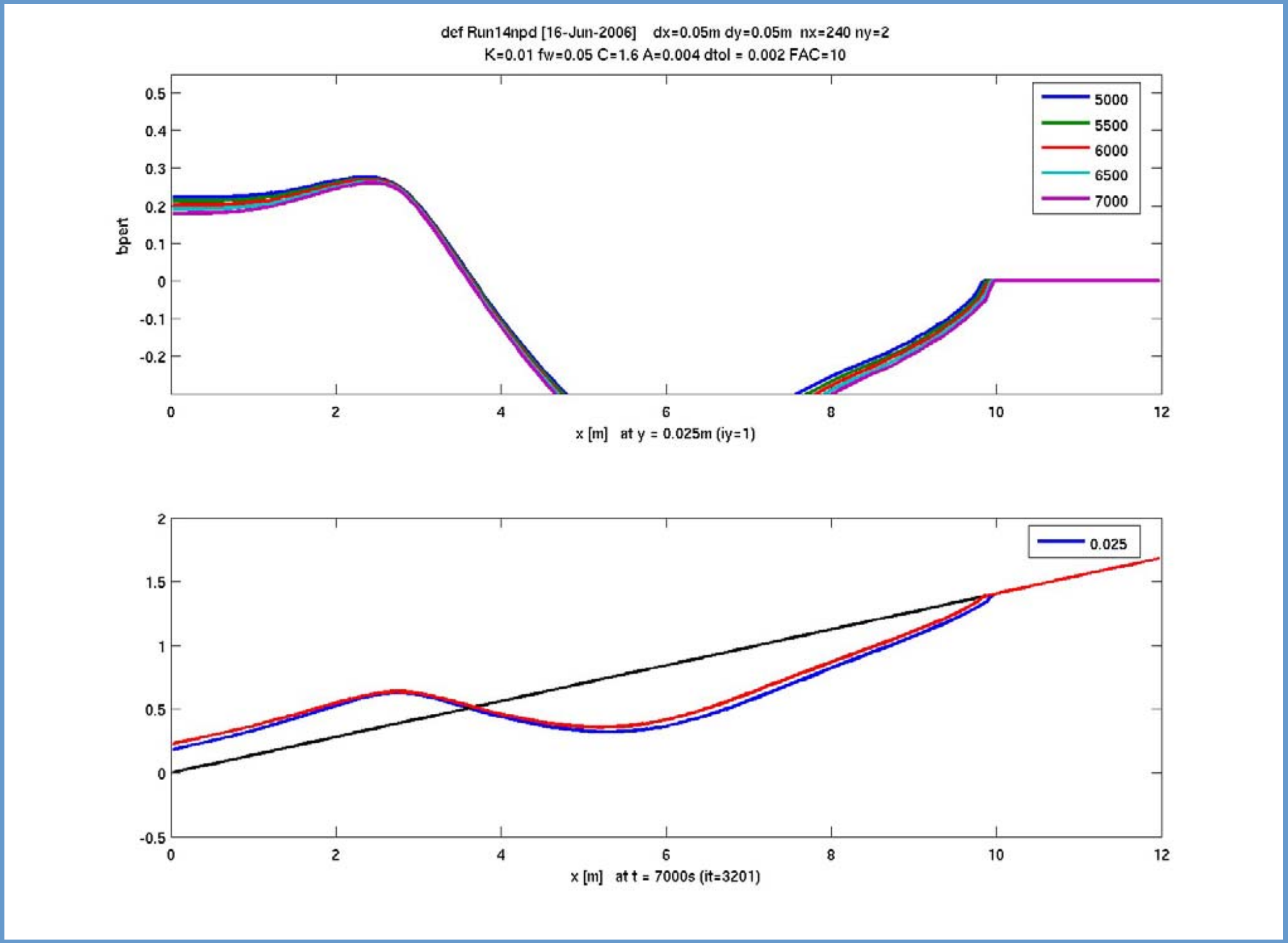
Impermeable beach



3000-5000s

Cross-shore swash profile evolution

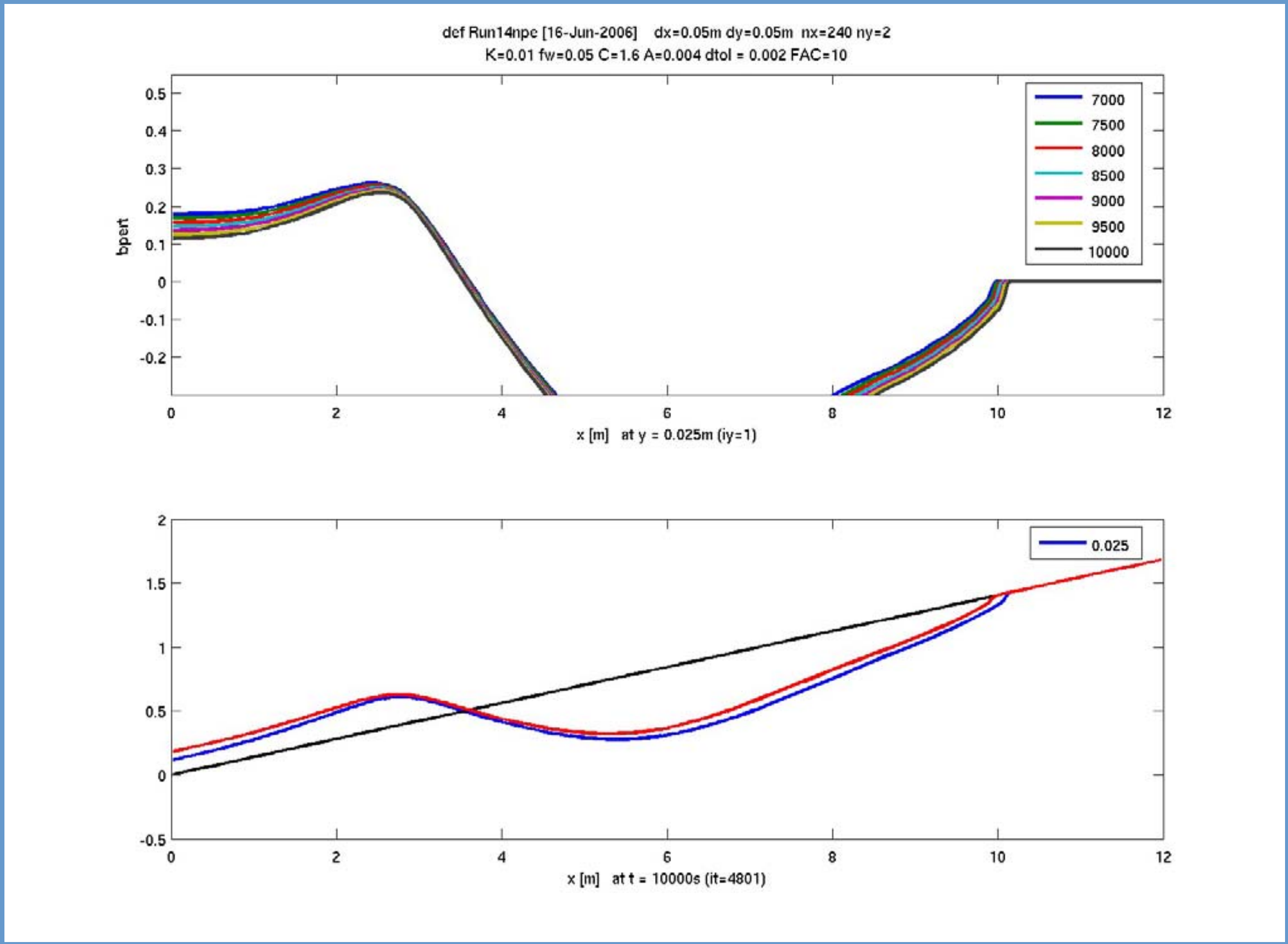
Impermeable beach



5000-7000s

Cross-shore swash profile evolution

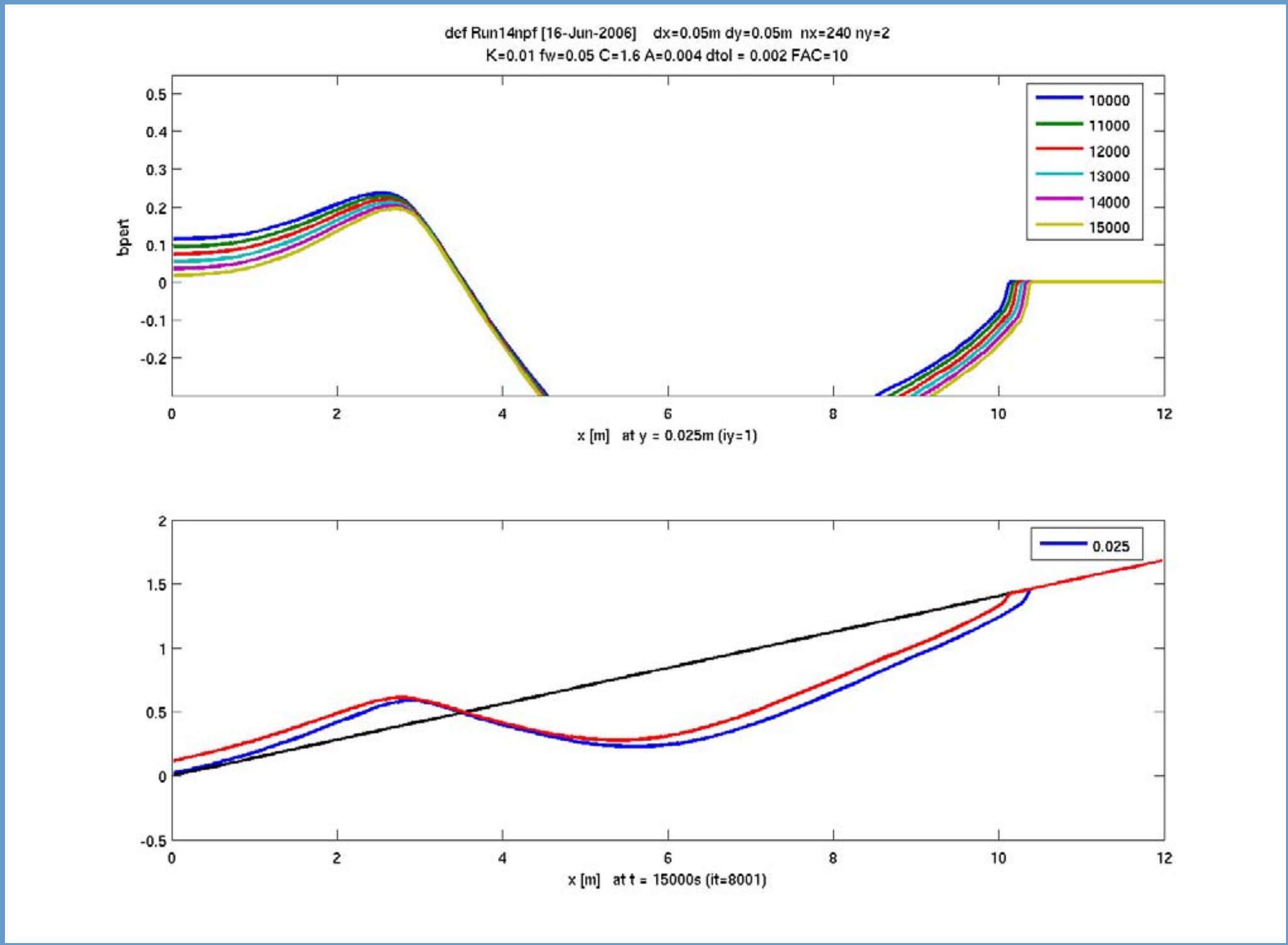
Impermeable beach



7000-10000s

Cross-shore swash profile evolution

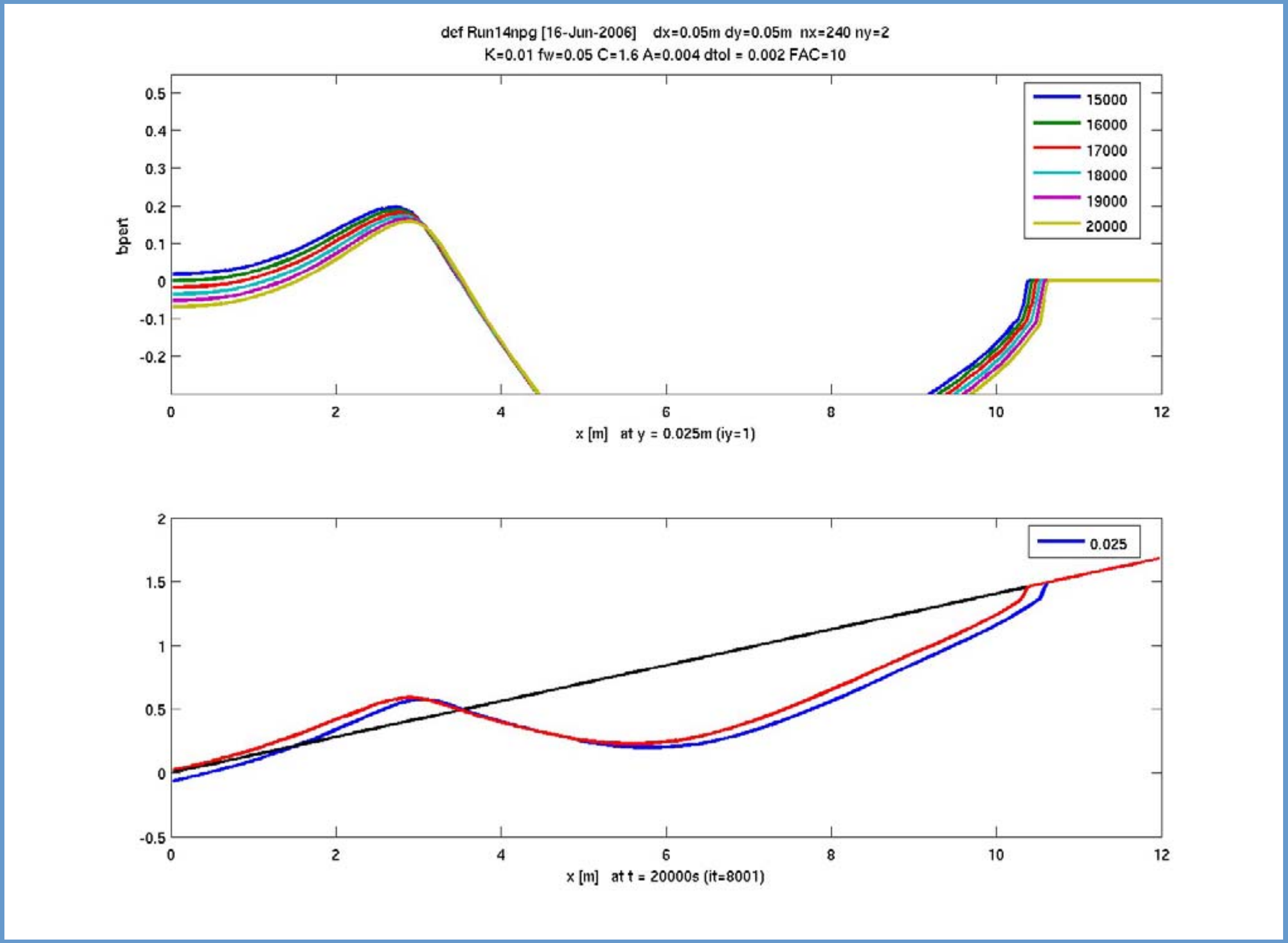
Impermeable beach



10000-15000s

Cross-shore swash profile evolution

Impermeable beach



15000-20000s

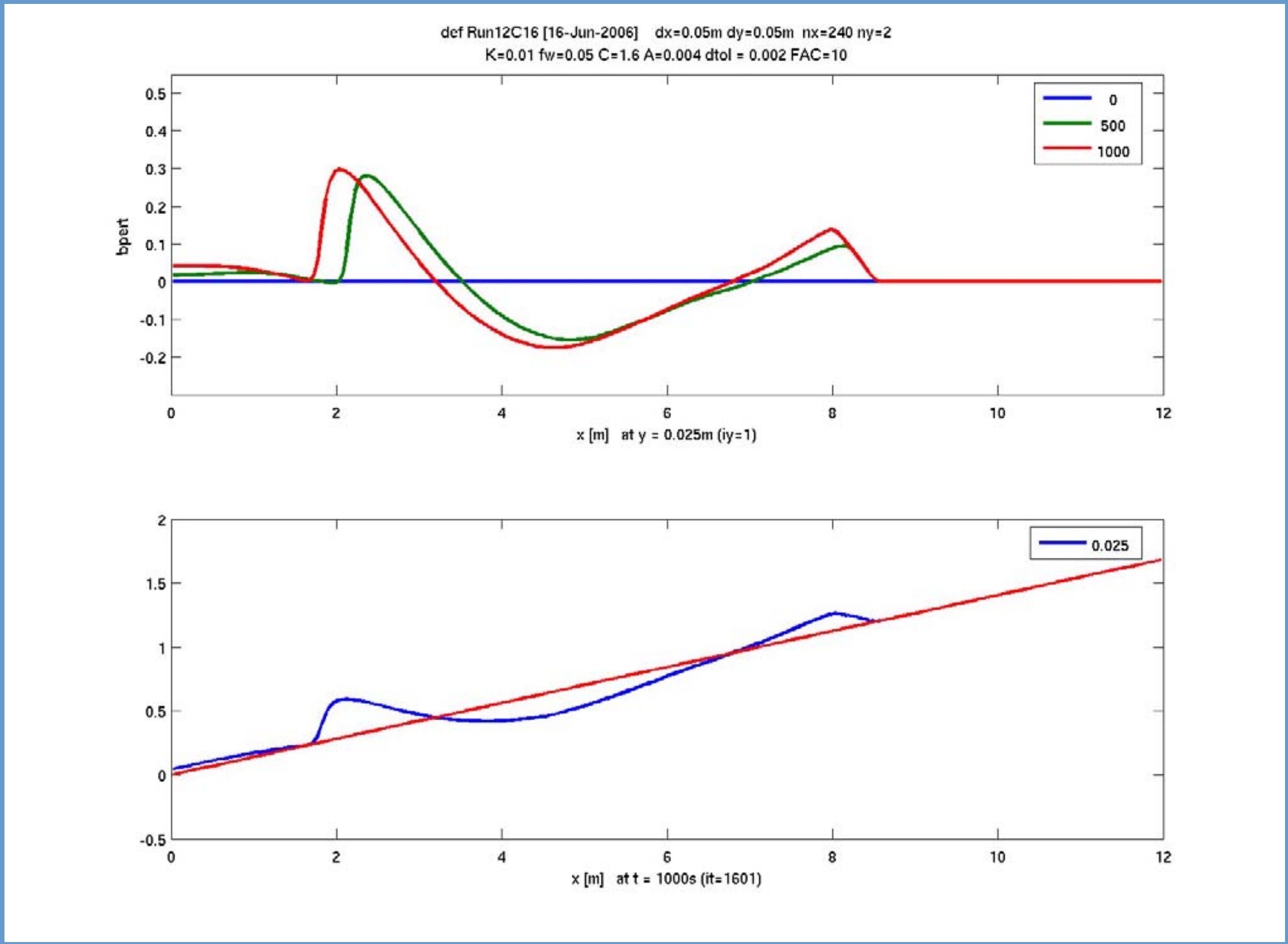
Cross-shore swash profile evolution

Impermeable & permeable beaches

Simulations on a steep (1:7) beach, with initially nearly non-breaking, 5s waves

Cross-shore swash profile evolution

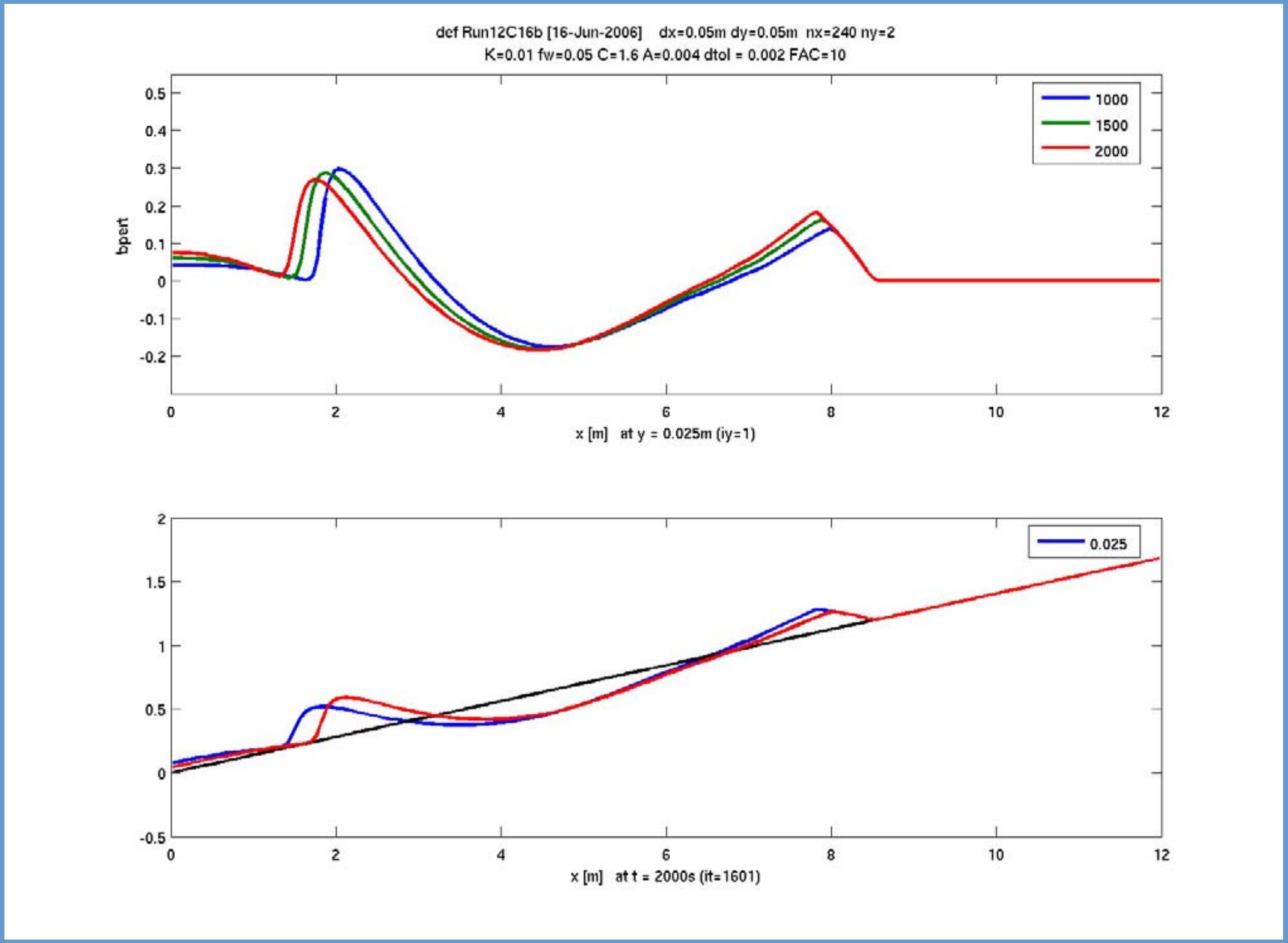
Permeable beach



0-1000s

Cross-shore swash profile evolution

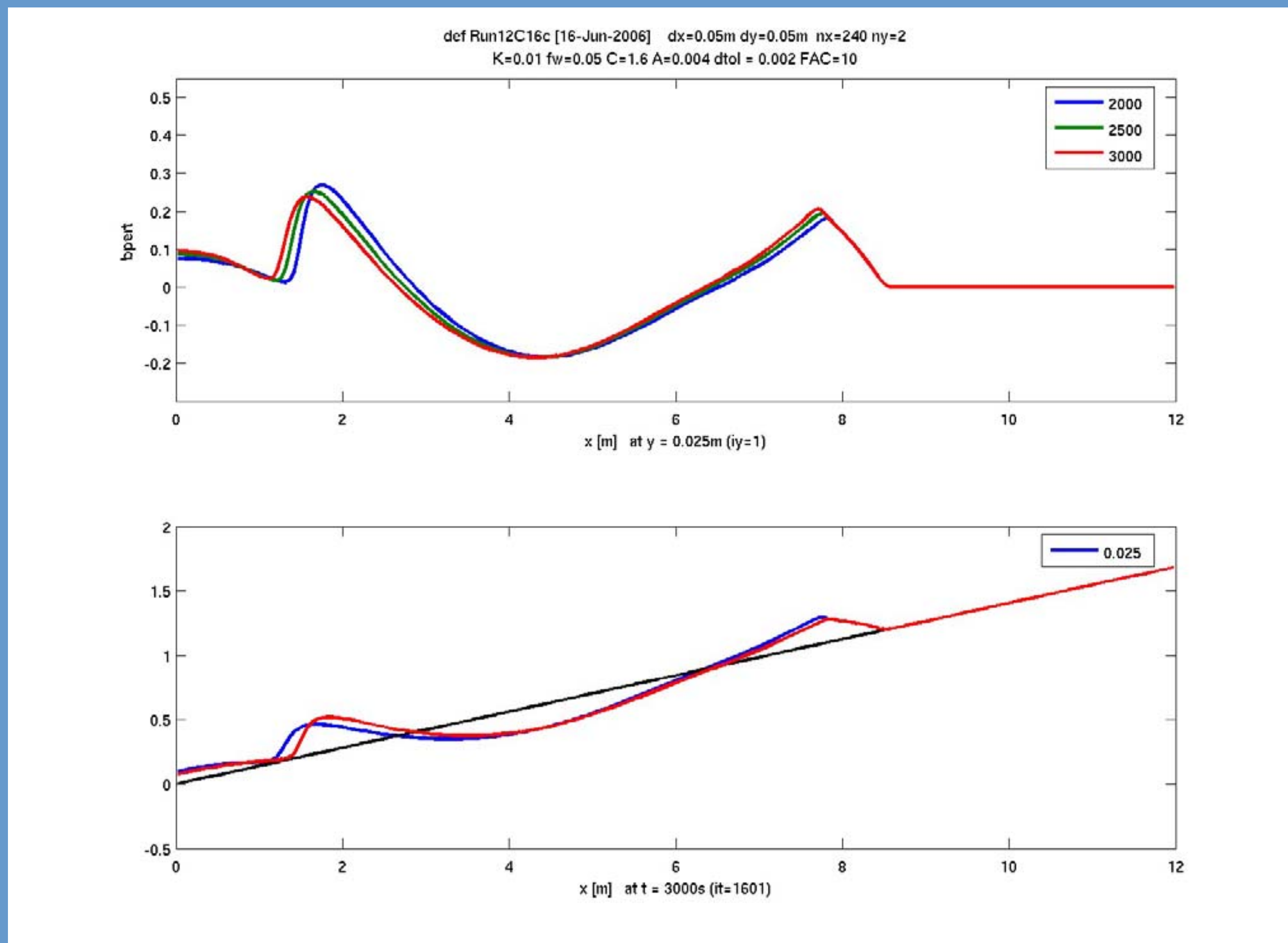
Permeable beach



1000-2000s

Cross-shore swash profile evolution

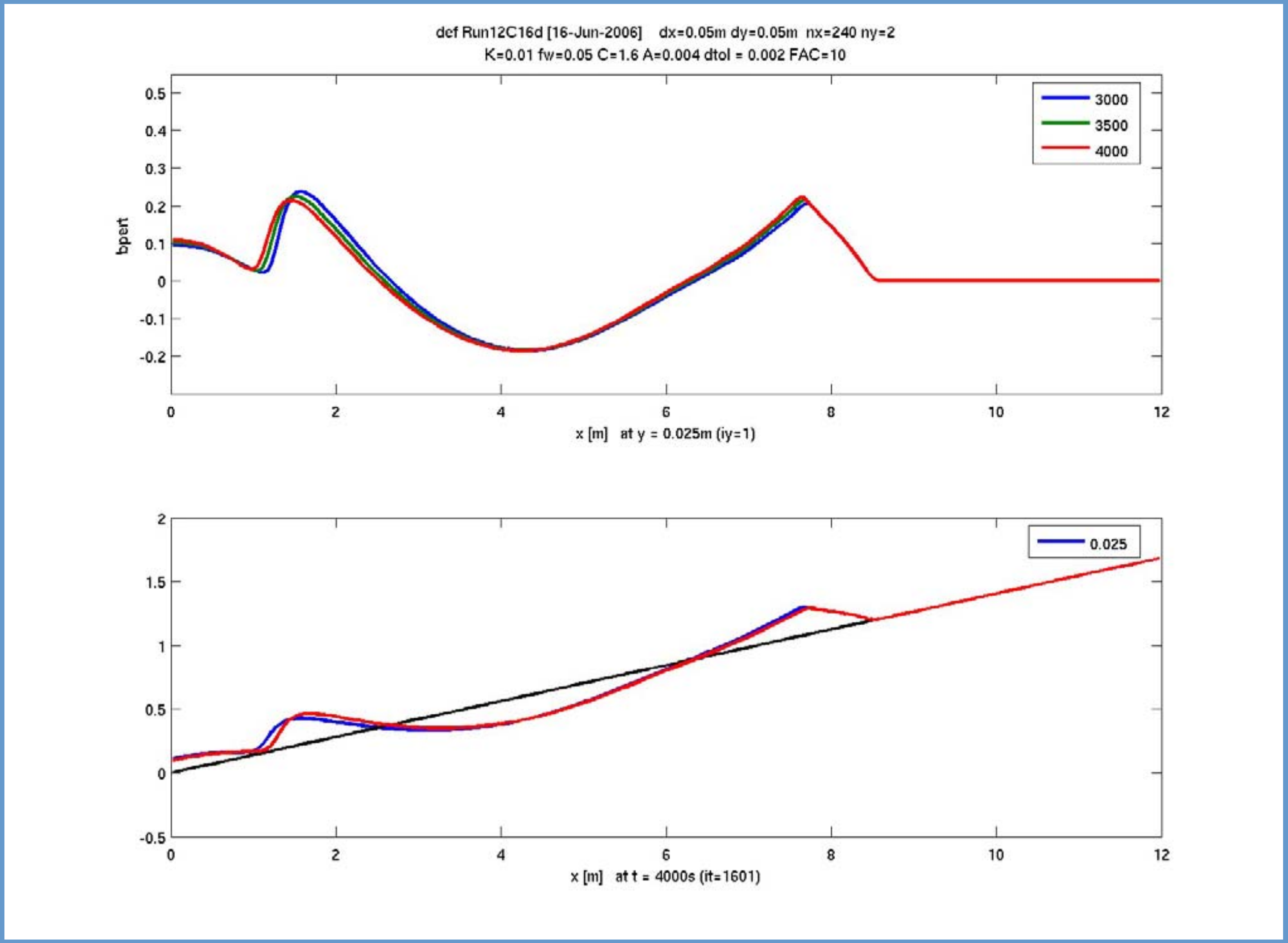
Permeable beach



2000-3000s

Cross-shore swash profile evolution

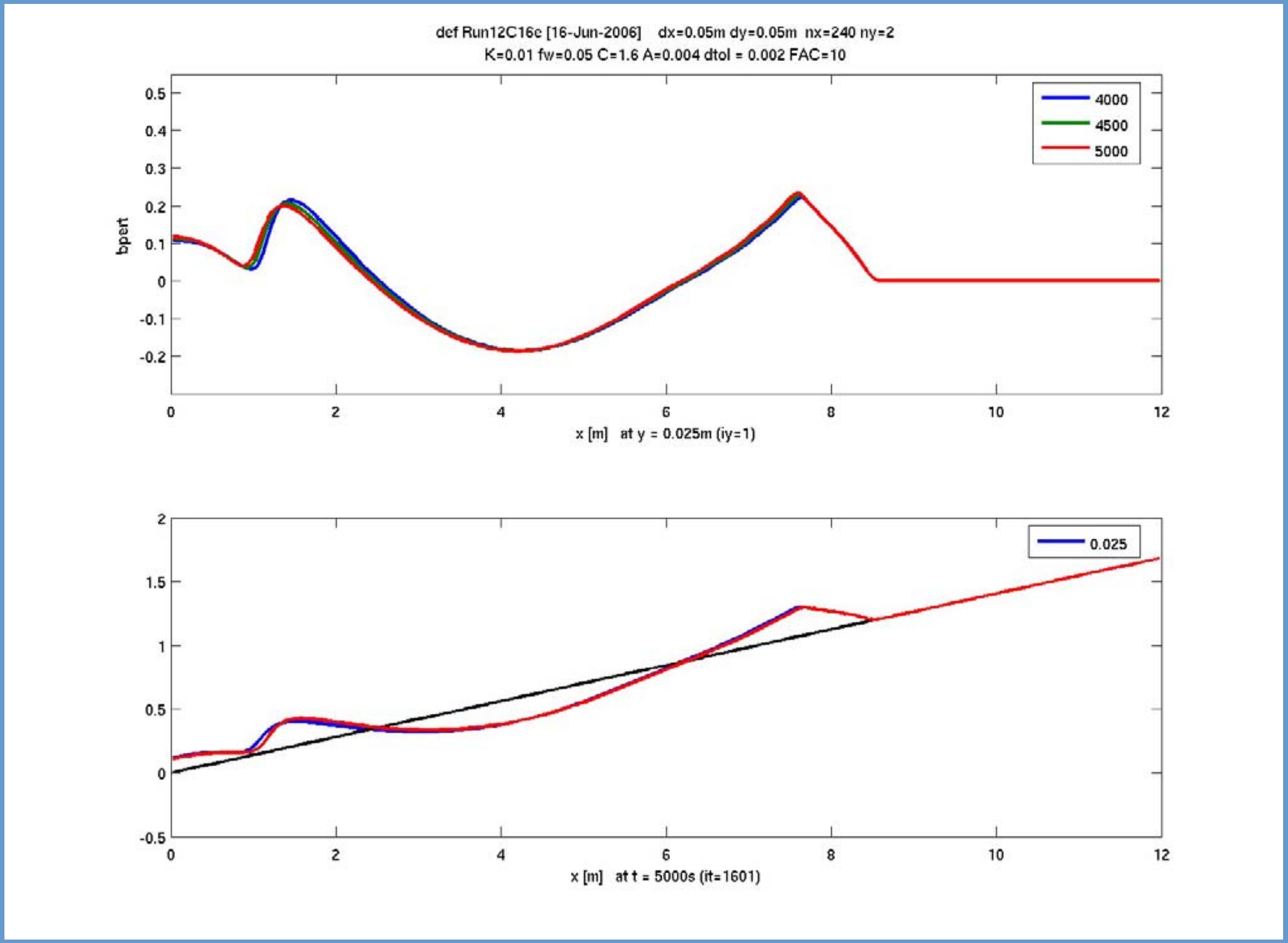
Permeable beach



3000-4000s

Cross-shore swash profile evolution

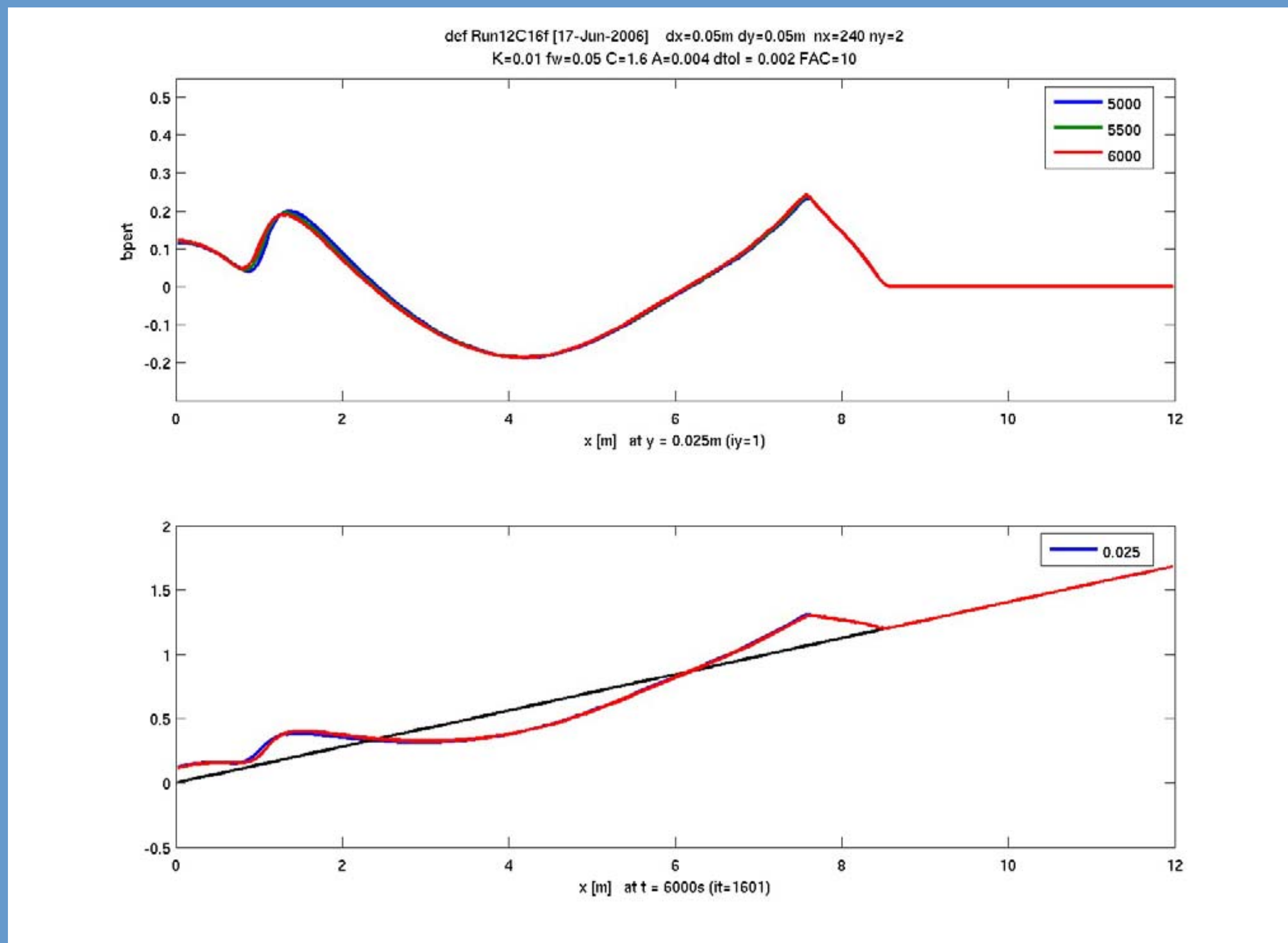
Permeable beach



4000-5000s

Cross-shore swash profile evolution

Permeable beach



5000-6000s

Erosion / Deposition

1. Duration
    1. Backwash dominant in lower swash
    2. Uprush & Backwash equal in upper swash on impermeable beach—infiltration favours Uprush.
2. Uprush
    1. Erosion in lower swash (concentration gradient); deposition in upper swash (flow convergence)
3. Backwash
    1. Erosion from upper swash (flow divergence); deposition in lower swash (concentration gradient)

• These simulations are for strictly periodic waves. Phasing of tsunamis important.

•Form of tsunami at 'bore collapse' will affect subsequent depths, velocities and therefore sediment transport (e.g.Guard et al, 2006)

•Where is the upper / lower swash during a tsunami event?

Stage of tide important in determining what happens to beach

2DH Effects

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An incipient ‘bump’ in the upper swash will experience almost full uprush but a diminished backwash, and therefore deposition. Areas adjacent to it will experience enhanced erosion.

Infiltration will favour deposition regardless of location

- Morphological features (sand dunes) in the ‘lower swash’ of tsunami eroded and transported onshore.
- Lower regions in lee of morpholgical features might lead to weiring (accelerating flow; localised scour).

- Inundation mapping highly dependent on accurate surveying and roughness

- A lot might be learned from overtopping, fluvial flooding and dam break community