Impact of wave energy arrays on beach processes

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Abstract

Due to depth-induced wave breaking, sand bars protect our coastlines from the impact of storm waves. Since the wave climate between an offshore wave energy converter (WEC) array and the coast will likely be modified by large-scale energy extraction, this could disrupt the natural process which maintains sand bars, possibly affecting coastal erosion and flooding. Here, we investigate this hypothesised impact through application of a one-dimensional cross-shore wave and sediment transport model.

Introduction

The need for wave energy

To reduce greenhouse gas emissions and aid sustainable development, there is an urgent need to support our electricity generating capacity through the development of low carbon technologies, particularly those generated from renewable sources (Bahaj, 2011). The ocean is a vast and largely untapped energy resource, which could be exploited by a range of technologies, including tidal and wave energy converters. The practically extractable worldwide wave energy resource has been estimated in the range 2000-4000 TWh/year, and so wave energy has been highlighted as a key contributor to the future global energy mix.

The impacts of wave energy exploitation

Any large-scale offshore wave energy converter (WEC) array has the potential to alter the wave climate between the array and the coast (Shields et al., 2009). Within this region, sand bars remove energy from storm waves, and so have an important role in natural coastal protection due to depth-induced wave breaking (Wijnberg & Kroon, 2002). Sand bars typically move shoreward when wave energy is low, and move offshore when waves are more energetic (Gallagher et al., 1998). Since WEC array operation could modify the nearshore wave climate, and hence disrupt the natural process which maintains sand bars, WEC operation could have a role in coastal protection due to changes in the location of depth-induced wave breaking.

Case study

To test this hypothesised impact of WEC array operation on nearshore morphodynamics, a case study was examined in southwest Wales, UK, a location suitable for exploiting the wave energy resource. The cross-shore profile includes a sand bar in water depth of around 8 m relative to mean sea level (Fig. 1).

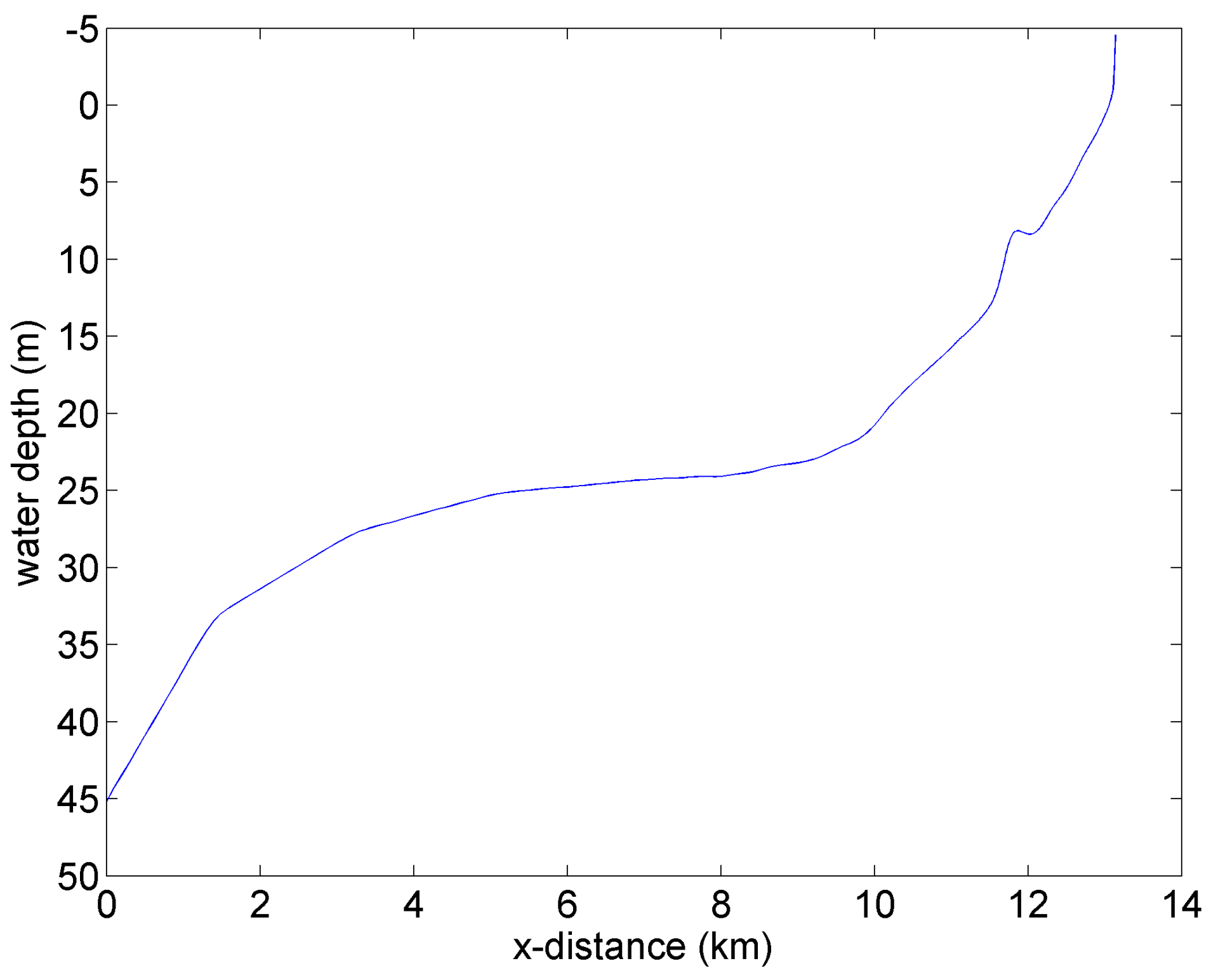


Fig. 1. Cross-shore bathymetry profile. Water depth is relative to mean sea level.

References

Bahaj (2011) Generating electricity from the oceans. Renew. Sust. Energ. Rev. 15, 3399-3416.

Gallagher at al. (1998) Observations of sand bar evolution on a natural beach. J. Geophys. Res. 103, 3203-3215.

Shields et al. (2009) Marine renewable energy: The ecological implications of altering the hydrodynamics of the marine environment. Ocean Coast. Manage. 54, 2-9.

Wijnberg & Kroon (2002) Barred beaches. Geomorphology 48, 103-120.

Cross-shore profile model

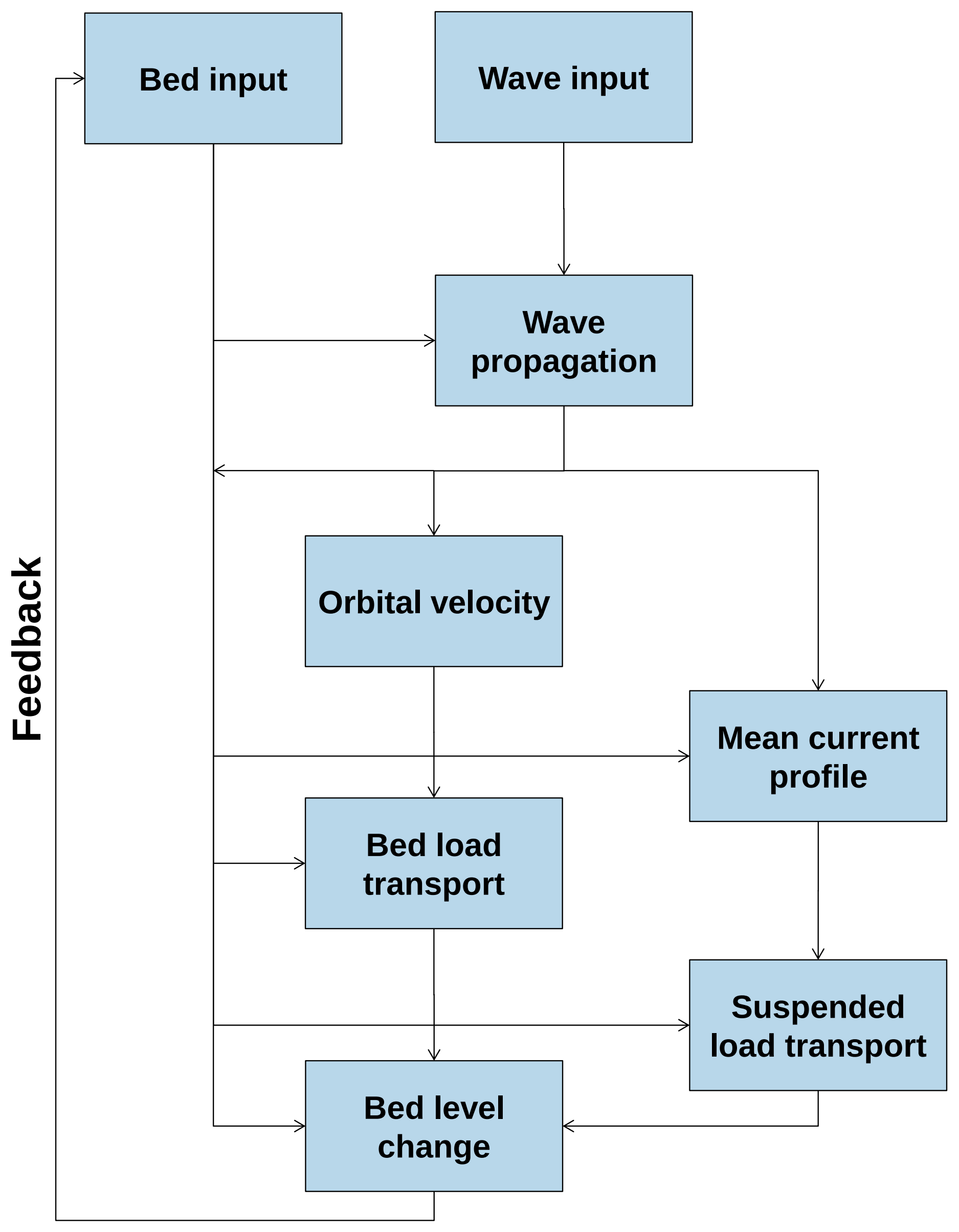
The cross-shore profile model, UNIBEST-TC, contains a wave propagation model (Fig. 2) which calculates wave energy decay along a profile, including the effects of shoaling, refraction and energy dissipation

$$\frac{\partial}{\partial x}(EC_g \cos\theta) = -D_w - D_f$$

where E is wave energy, C_g is group velocity, θ is the angle of incidence of the wave field, D_w is the dissipation of wave energy due to breaking, and D_f the dissipation due to bottom friction. After calculating the orbital velocity and mean current profile, bed load and suspended load are calculated, allowing the change in bed level z to be calculated using the depth-integrated mass balance equation

$$\frac{\partial z}{\partial t} + \frac{\partial q_{bed+sus}}{\partial x} = 0$$

The model includes feedback between the evolving bathymetry and the hydrodynamics.



Bed input
Wave input
Wave propagation
Orbital velocity
Mean current profile
Bed load transport
Suspended load transport
Bed level change
Feedback

Fig. 2. Overview of the cross-shore wave and sediment transport model, UNIBEST-TC.

Hydrodynamic impact

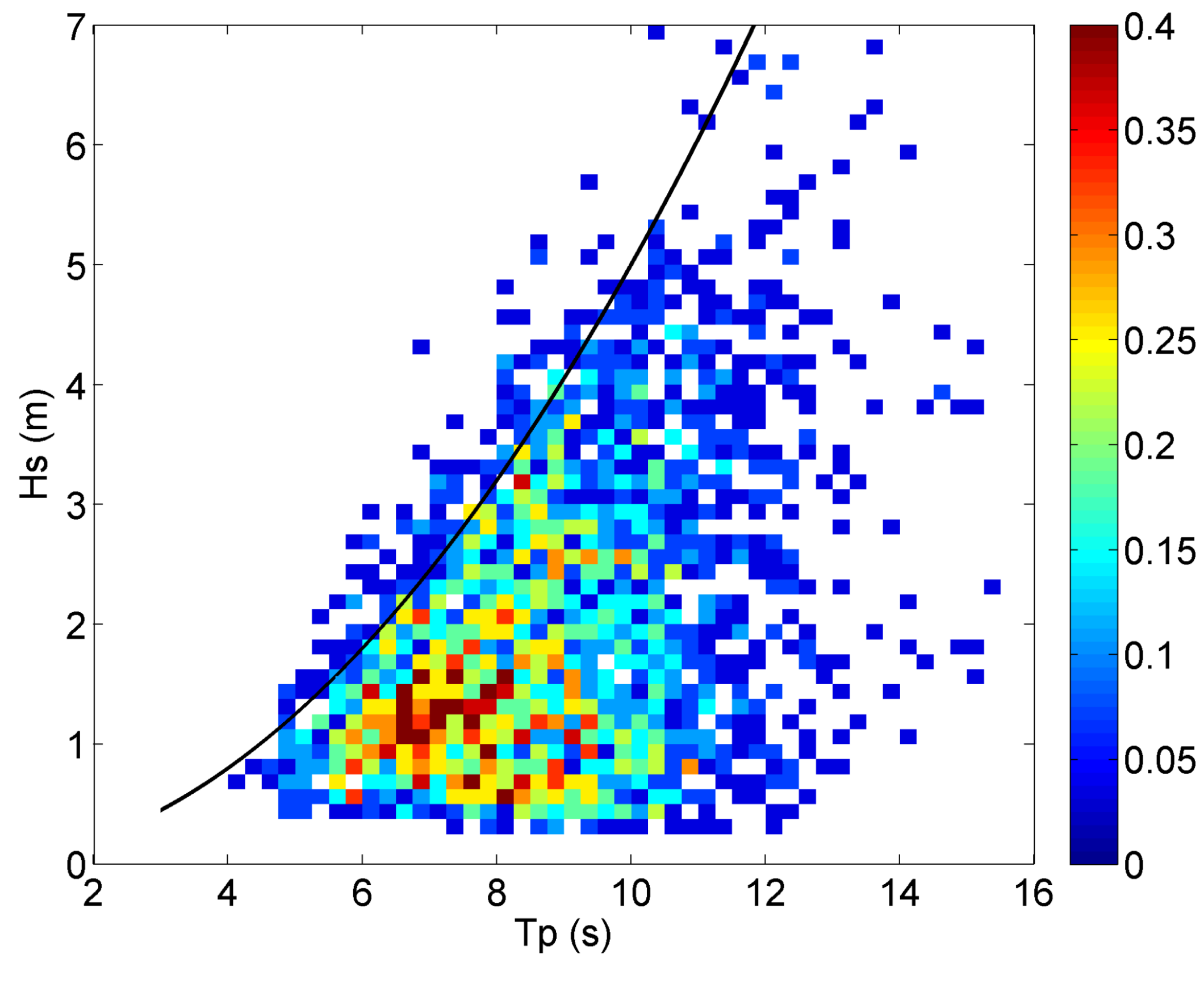


Fig. 3. Percentage joint distribution of *Tp* and *Hs* for one year of wave buoy data collected near the offshore model boundary. The curve shows the theoretical relationship for a deep-water wave steepness of 1/20. Energy was extracted from the model boundary by using this curve to reduce *Tp* and *Hs* in relative proportions to account for 10% reduction in wave energy due to WEC array operation.

Acknowledgements

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Results

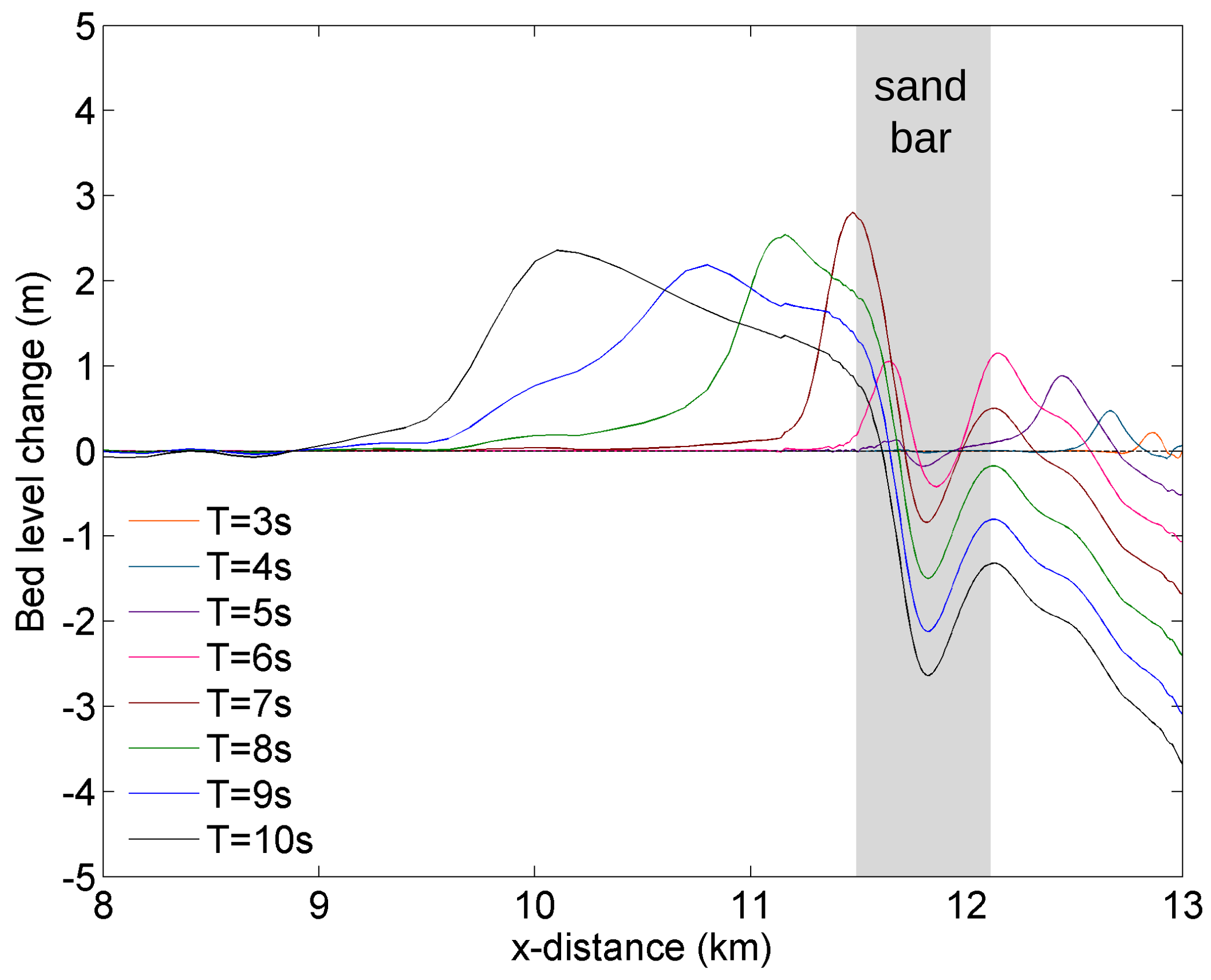

Fig. 4. Natural change in bed level after 6 months of simulation.

For the 'natural' simulations, generally the sand bar migrated offshore when $Tp \geq 7$s (Fig. 4). Subsequently, the simulations were repeated with 10% wave energy extracted at the model boundary using the methodology outlined in Fig. 3. Typical outputs are shown in Fig. 5 for a range of wave conditions. Generally, WEC array operation led to enhanced deposition at the bar and erosion of the bed seaward of the bar, when $Tp \geq 7$s. More details for Tp=7s are shown in Fig. 6.

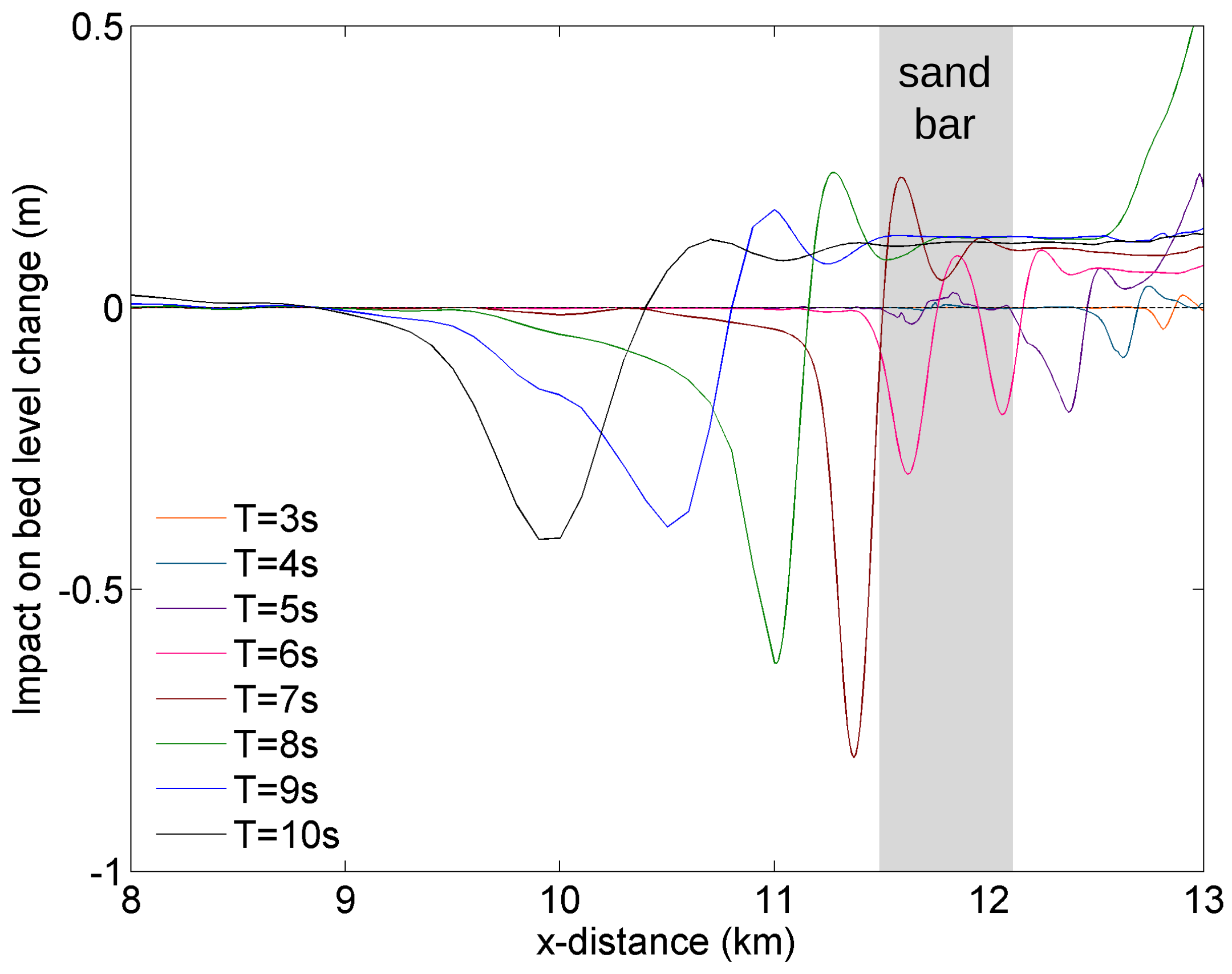

Fig. 5. Impact of 10% energy extraction on bed level change after 6 months of simulation.

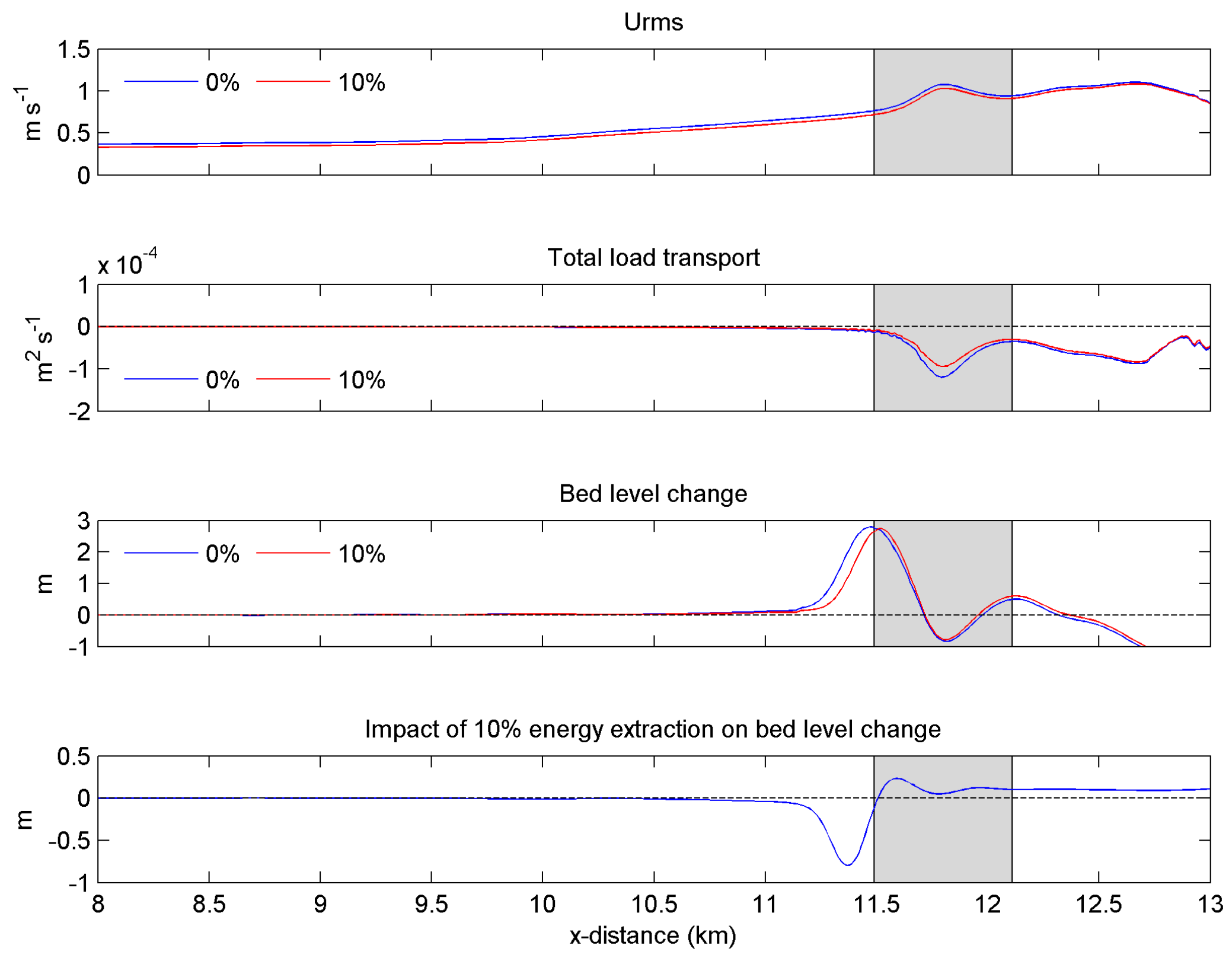

Fig. 6. Impact of 10% energy extraction after 6 months of simulation for *Tp*=7s. *Urms* is root-mean-square wave orbital velocity at the bed.

Conclusions

Under certain conditions, WEC array operation can lead to enhanced sand bar formation. Since reduced water depth over the bar enhances depth-induced wave breaking, WEC array operation could provide enhanced coastal protection from storm waves. However, this hypothesis remains to be tested for variable wave forcing over seasonal timescales, and for more realistic WEC array energy extraction scenarios.