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Discussion

Reply to discussion of "On the transport of suspended sediment by a swash event on a plane beach" [Coastal Engineering 52 (2005) 1–23]

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1. Introduction

We would like to thank Dr Baldock and Dr Alsina for their interest in the original paper (Pritchard and Hogg, 2005; hereafter PH05). They have identified a number of minor errors, and we supply the corrections below; their discussion also raises some important points on which we will also comment.

2. Errata

Baldock and Alsina (2005) (hereafter BA05) identified two separate errors in PH05: both errors were introduced when the paper was being written rather than when the computations were carried out, and we are confident that they do not affect the other results which we present.

Firstly, in the plots of the concentration field $c(x,t)$ in Figs. 5, 6 and 9, the 'snapshots' are incorrectly labelled: in all these figures, snapshots are taken at intervals of 0.36, with the first snapshot being taken at $t=0.2$. Correctly labelled versions of these figures are given below.

Secondly, there is an error in Eq. (29) of PH05. In the first line $c_{\mathrm{L}}^{\mathrm{pr}}(t;\xi)$ should read simply $c_{\mathrm{L}}(t;\xi)$: the expansion given is for the full solution rather than just for the component representing pre-suspended sediment. This error is responsible for a slight confusion: BA05 point out correctly that c^{pr} should be independent of q_{e}, since the concentration of presuspended sediment evolves solely by advection and deposition. For clarity, we give the expansion for the presuspended component here as

$$c_{\mathrm{L}}^{\mathrm{pr}}(t;\xi) = c_0(\xi)\left[1 - E\int_{t_0(\xi)}^{t}\frac{\mathrm{d}t'}{h_{\mathrm{L}}(t';\xi)} + \mathcal{O}\left(E^2\right)\right]. \qquad (1)$$

3. Discussion of key points

3.1. Sensitivity and calibration

BA05 made a very important point when they discussed the likely uncertainties involved in fitting model predictions to field data, and they provided an instructive comparison of the relative errors introduced by uncertainties in the measurement position relative to the point of bore collapse and those introduced by uncertainties in the grain size (and thus in the parameter E). It is arguably a useful feature of simple analytical models that they can be used to carry out such sensitivity tests, especially in environments such as the swash zone which provide serious challenges to measurement techniques. (Indeed, it may never be possible to calibrate predictive models beyond a certain accuracy, although in many situations there is undoubtedly room for improvement. We note that Eidsvik (2004) has estimated that typical errors in sediment transport predictions may be of the order of a factor of 2–5 or even larger: the hope for progress in understanding sedimentary systems therefore has to rest on obtaining results and principles which are robust to such errors.)

In relation to this point, it is worth correcting a possible misunderstanding. BA05 comment that when applying our results directly, the reference concentration $\hat{C}$ is unknown a

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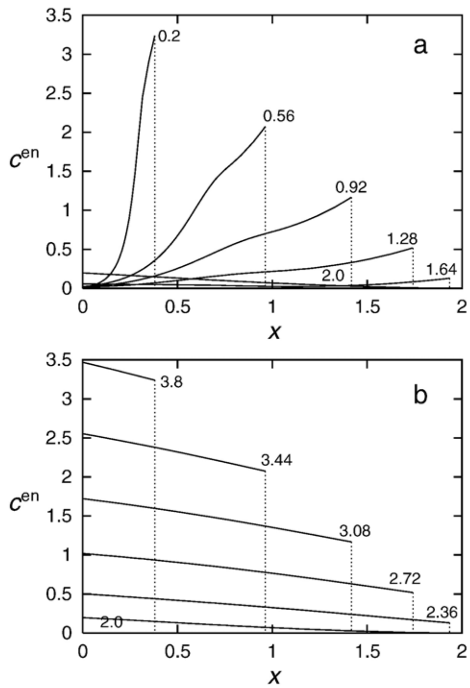

Fig. 5. Non-dimensional concentration fields $c^{en}(x,t)$ plotted at regular intervals in t: (a) $t=0.2$ to (shoreline advancing); (b) $t=2-3.8$ (shoreline retreating). Parameters throughout are $E=0.3$ and $q_e=u^2$; boundary condition $c=0$ imposed at $x=0$. Labels indicate the value of t for each 'snapshot' of the concentration field, and the fine dotted lines indicate the instantaneous shoreline position for each value of t.

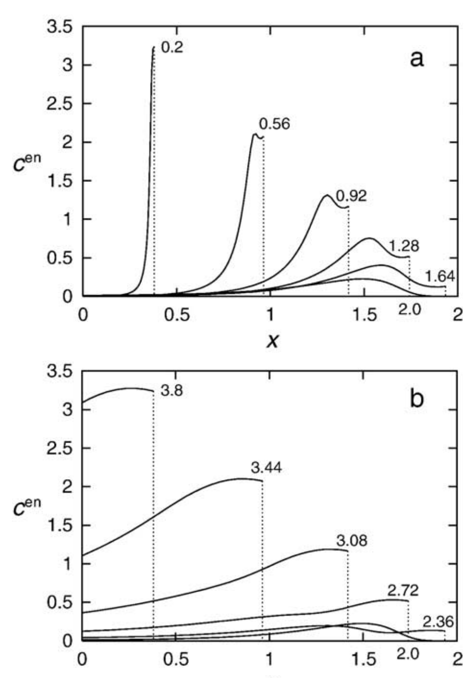

Fig. 6. Non-dimensional concentration fields $c^{en}(x,t)$ plotted at regular intervals in t: (a) t=0.2 to (shoreline advancing); (b) $t=2$ to 3.8 (shoreline retreating). Parameters throughout are $E=0.01$ and q_e=u^2; boundary condition $c=0$ imposed at $x=0$. Labels indicate the value of t for each 'snapshot' of the concentration field, and the fine dotted lines indicate the instantaneous shoreline position for each value of t.

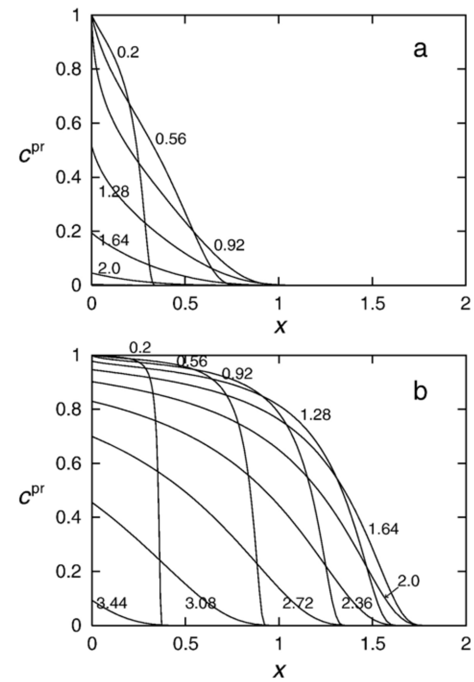

Fig. 9. Non-dimensional concentration fields $c^{pr}(x,t)$ plotted at regular intervals in t: (a) $E=0.3$; (b) $E=0.01$.The boundary condition $c=1$ is imposed at $x=0$ during the inflow ($t<1$). Labels indicate the value of t for each 'snapshot' of the concentration field.

priori and must be estimated from measurements because we do not specify the mass erosion rate parameter $\hat{m}_e$. This is correct, but it is not a intrinsic feature of our model that $\hat{C}$ must be fitted to data in this way; rather, it occurs because, in the absence of direct measurements of erosion rates under swash,we have left $\hat{m}_e$ unspecified for generality. The emphasis in our results, then, has not been so much on calculating the magnitudes of net transport but on predicting and understanding the patterns of cross-shore transport and how it varies with the fundamental parameter E.

We reiterate that our modelling approach provides a framework in which any dimensional form of the mass erosion rate $\hat{m}_e q_e(\bar{u}, \hat{h})$ can be considered. Once a form for $\hat{m}_e q_e$ has been chosen, the reference concentration is fully specified, and is no longer available as a fitting parameter. Equally, in principle a model such as ours could be used inversely to estimate $\hat{m}_e$ from measured concentrations; in the light of BA05's comments on sensitivity, however, it is likely that the results would not be very well constrained.

3.2. Depth dependence and the inaccuracy of the Shen-Meyer model

No sediment transport model is likely to be better than the hydrodynamic model which determines transport. It is therefore of great interest that Baldock et al. (2005; hereafter B05) find that the solutions of Shen and Meyer (1963) and Peregrine and Williams (2001) may substantially underestimate water depths under swash (as well as making a smaller, but possibly significant, difference to the predicted velocities).

BA05's first comment on this point may be slightly misleading: they interpret the results show in Figs. 2 and 7 as showing that 'a simple equilibrium transport model of the form $q = c_{\mathrm{eq}}uh$ radically alters the calculated net sediment flux in the swash zone in comparison to models of the form $q = |u^n|u\ldots$ noting the change of scales'. It is important to note that the non-dimensional scales here are not directly comparable. For the equilibrium transport model (Fig. 2a–c) and the full suspended load model (Fig. 7), concentrations and thus fluxes have been non-dimensionalised using typical scales for the velocity, water depth and concentration. In the Bailard model used for Fig. 2d, there is no equivalent of the 'reference concentration', and the fluid depth is irrelevant: the fluxes here have implicitly been nondimensionalised with respect to a scale given by the dimensional prefactor of the Bailard flux. Consequently, the scale on Fig. 2d cannot be directly compared with that on the other figures. What is relevant is the distribution of the flux across the swash zone, and while this does differ under the Bailard and depth-dependent total-load models, the difference is perhaps not as substantial as BA05 suggest.

To illustrate this, we consider the dimensional forms of the total-load formula given by PH05's suspended-load model in the quasi-steady limit $E \to \infty$ and the Bailard model for suspended load. The former is given by

$$\hat{q}_{\mathrm{PH05}} = \bar{u}\hat{h}\hat{c}_{\mathrm{eq}} = \frac{\hat{m}_{\mathrm{e}}}{\hat{w}_{\mathrm{s}}} \frac{\left(\hat{g}\hat{A}^3\right)^{1/2}}{\cos\theta} uhq_{\mathrm{e}}(u) = \left[\frac{\hat{C}\left(\hat{g}\hat{A}^3\right)^{1/2}}{\cos\theta}\right] uhq_{\mathrm{e}}(u), \tag{2}$$

so to redimensionalise the axes of Figs. 2a–c we should multiply them by the term in the square brackets. Meanwhile, the Bailard formula for the mass transport rate is given approximately (see Bailard, 1981, Eq. (9)) by

$$\hat{q}_{\mathrm{B81}} = \frac{\hat{\rho}}{(\hat{\rho}_{\mathrm{s}} - \hat{\rho})\hat{g}} \hat{\rho} c_{\mathrm{D}} |\bar{u}|^3 \epsilon_{\mathrm{s}} \frac{\bar{u}}{\hat{w}_{\mathrm{s}}} + \mathcal{O}\left(\epsilon_{\mathrm{s}}^2\right), \tag{3}$$

where $\hat{\rho}_{\mathrm{s}}$ is the density of the sediment and $\epsilon_{\mathrm{s}} \ll 1$ is an efficiency factor. This may be written in terms of our non-dimensional variables as

$$\hat{q}_{\mathrm{B81}} \approx \left[c_{\mathrm{D}}\epsilon_{\mathrm{s}} \frac{\hat{\rho}^2\hat{g}^2\hat{A}^2}{(\hat{\rho}_{\mathrm{s}} - \hat{\rho})\hat{w}_{\mathrm{s}}}\right] |u|^3 u, \tag{4}$$

where the redimensionalisation factor is again enclosed in square brackets.

If we take representative values of $\epsilon_{\mathrm{s}} = 0.025$ (Bailard, 1981), $c_{\mathrm{D}} = 0.002$ (Conley and Griffin, 2004), $\hat{w}_{\mathrm{s}} = 10^{-2}$ ms^{-1}, $(\hat{g}\hat{A})^{1/2} = 1$ ms^{-1}, $\tan\theta = 0.1$ and $\hat{C} = 100$ kg m^{-3} (PH05) and the typical sand density $\hat{\rho}_{\mathrm{s}} = 2650$ kg m^{-3}, the redimensionalisation factors are then given by

$$\frac{\hat{C}\sqrt{\hat{g}\hat{A}^3}}{\cos\theta} \approx 10\ \mathrm{kg\ m^{-1}s^{-1}} \text{ and } c_{\mathrm{D}}\epsilon_{\mathrm{s}} \frac{\hat{\rho}^2\hat{g}\hat{A}^2}{(\hat{\rho} - \hat{\rho})\hat{w}_{\mathrm{s}}} \approx 0.2\ \mathrm{kg\ m^{-1}s^{-1}}. \tag{5}$$

This factor of 50 difference in the redimensionalisation factors accounts for much, though not all, of the difference in the scales of the graphs in Fig. 2. This is not, however, to belittle the importance of representing the depth of water accurately when calculating suspended load. Without carrying out a detailed study of suspended sediment transport under B05's empirical model, it is difficult to predict how it would alter the transport patterns; however, we can make some general remarks.

Most obviously, increasing the water depth without significantly changing the velocity field would tend to increase the transport predicted by a depth-dependent instantaneous total-load model (or, equivalently, by our suspended-load model in the limit $E \to \infty$). It is not obvious, though, that the transport predicted by the full suspended-load model (i.e. with finite values of E) would increase in the same way. In a model which considers only the swash flow, the amount of pre-suspended sediment is an input to the model and may be assumed to be independent of the hydrodynamics within the swash zone; meanwhile, because q_{e} is a function only of u, the amount of sediment which is entrained within the swash zone does not depend directly on h. The differences to transport which may be expected will therefore depend essentially on how the deposition of sediment is affected by the greater depths. Essentially, the effect of increasing h is similar to the effect of decreasing E, as it leads to longer settling times and a slower sediment response. We can therefore expect that under B05's empirical model:

(i) Pre-suspended sediment will be more effectively transported up the beach, but may also remain in suspension longer on the backwash. The effect on the net flux of sediment is not obvious a priori although it seems likely that the 'active' region of the swash zone will extend further up the beach under these conditions (cf. Fig. 10a and b of PH05).

(ii) Sediment entrained within the swash zone will be more effectively transported up the beach and also more effectively exported. Comparing Figs. 7b and 8b of PH05, we may hypothesise that this will again lead to more sediment activity higher up the beach, but the effect on the magnitude of net transport is again not obvious a priori because of likely cancellation effects.

As a final point, the different distribution of fluid depth with position under the empirical model will undoubtedly have some effect, but this is impossible to predict meaningfully without carrying out explicit calculations. This appears likely to be a fruitful direction for future research.

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