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Geoscientific Model Development Discussions

Interactive comment on "A lattice-automaton bioturbation simulator for the coupled physics, chemistry, and biology of marine sediments (eLABS v0.1)" *by* Yoshiki Kanzaki et al.

Anonymous Referee #1

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Kanzaki and co-authors present a bioturbation simulator that is based on the LABS model, originally presented in Boudreau et al. 2001 and Choi et al. 2002. They expand that model to include the simulation of water flow, O2 and organic matter distributions. The main motivation is to establish a framework that has a mechanistic foundation to interpret the geologic record of trace fossils and provide an explanation for empirical relationships observed in the modern ocean between bioturbation and sediment properties. The manuscript is well written and organized, and the consistent presentation of the results across the 3 sets of figures make it easy for the reader to follow. They authors provide interesting results and shows some feedbacks (e.g. page 13, line 10) that illustrate the usefulness of the modeling approach, which I consider suitable for

GMD. There are, however, also a few shortcomings.

Validation: The model presentation introduces features that generally make sense, such as behavior tied to the presence of O2 or the reactivity of organic matter. However, what is lacking is a rigorous validation of the results, which of course is rather challenging. A key concern is the limited discussion what organisms the model represents. LABS was a novel way of looking at organisms that move sediment around. Are these the same organisms that govern the distribution of O2? Arguably, the most pronounced impacts on O2 in contemporary sediments are not caused by moving around sediment blocks but by the flushing of burrows, injection of fluid into the subsurface or similar activities. Thus, organisms other than the ones studied with eLABS, or other activities (e.g. pumping, rather than directional movement of infauna) by the organism studied may set the O2 distribution. Under these conditions, feedbacks other than that between movement and oxygenation considered in eLABS (which in the applications shown here possibly represents the 'simple small deposit feeders, resembling capitellids' referred to in Choi et al. 2002) may be dominant, and limit the ability of the model to capture the connections between food, air and organism.

Implementation: The calculation of the oxygen concentration is conducted on a grid that is occupied by water/organism particles with a general advection-diffusion-reaction equation (e.g., Boudreau, 1997) (EQ. 2). This is necessary as in the model there is no O2 in the (zero porosity) in the solid cells, yet no organic matter (M) in the fluid phase. However, nothing is stated what the size of this large scale grid is that represents average solid and fluid concentrations, or how exactly u and D are computed in the sediment.

Results: How robust are the findings, shown for example in Figure 7? What is the uncertainty in the stochastic default simulation? This is particularly important as results are shown in several panels relative to the default. For example, Fig11b shows an increase in Db at depth relative to the default, at a depth where Db is small. Is this consistently found for multiple realizations of the default simulation? If not, consider establishing uncertainty estimates. And is any of the patterns seen an effect of the boundaries (i.e. too small domain size)? On page 12, at the end of the first paragraph, it is stated that "When we remove the advective flow from the calculations, i.e., simulation (f), the resultant oxygen profiles, fluxes, burrow geometry and biodiffusion coefficient are generally similar to those with the default settings (panels (a) and (f) of Figs. 4, 5, 6, 7). Accordingly, with the assumptions adopted in the present study, advective water flow has only insignificant influences on bioturbation." If one follows the bioturbation definition of Kristensen et al. 2012, MEPS ("all transport processes carried out by animals that directly or indirectly affect sediment matrices.") I'd agree that at the low velocities resulting from with the movement of macrofauna, fluid flow is not important for solid phase distribution. However, there is ample observational evidence (documented in several of the papers cited) that shows the importance of bioadvective flow for solute distributions (O2 profiles) and fluxes.

Summary: The summary/conclusions points to what is missing in the paper, namely a a rigorous testing against data (page 15, line 16). Overall, I consider this an interesting paper and valuable expansion on an existing model. It clearly is a framework to test scientific hypotheses. The potential is undoubtedly there, but the feasibility of establishing the mechanistic explanations for empirical relationships largely remains to be demonstrated and will be a significant undertaking.

additional notes:

page 5/ line 20: avoiding oxygen depleted conditions does not necessarily translate into moving against the O2 gradient. This seems to align with the statement on 14/34 that stresses the importance of food availability

9/24: it says that the infaunal respiration flux = total O2 consumption flux - O2 flux by aerobic decomposition. I may be thrown off by the terminology (flux, rates), but what about non-steady state effects, and advective or diffusive transport?

10/18: it states that organic matter concentration is assumed to decrease with depth.

However, on page 3, deterministic calculations of organic matter distributions are discussed. Please clarify

11/11: how are permeability and porosity connected in the model? If this is explained in LABS papers cite the relevant publication.

Consider discussing the role of predation on burrowing, in addition to the role of organic matter and oxygen

Is figure 3 necessary?

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