Particle-Lattice and Automaton Model of Bioturbation

Bernard P. Boudreau

Department of Oceanography
Dalhousie University
Halifax, Nova Scotia B3H 4J1, Canada
phone: (902) 494-8895 fax: (902) 494-3877 e-mail: bpboudr@is.dal.ca

Award Number: N00014-99-1-0100
http://129.173.3.163/res.html

LONG-TERM GOALS

My long term goal is to help the quantitative understanding of the relationship between infaunal behavior and consequent sediment modifications, and their effects on acoustic propagation in marine sediments. I hope to supply information on this relationship to the acousticians in our group (i.e. Darrel Jackson and co-workers) for incorporation in their forward and/or backward acoustical models.

OBJECTIVES

The objective is to create a mechanistic mathematical model of animal-sediment interactions. Current models that are based on biodiffusion, nonlocal mixing, etc. cannot easily simulate, for example, animal-produced density heterogeneities, which affect acoustics, as they are essentially all dissipative processes, i.e. smooth out , rather than generate heterogeneities. My new model is capable of generating sediment heterogeneities.

APPROACH

My approach is the direct modelling of organism-sediment interactions via a new type of model. Biologically active sediment is represented on a computer as a regular lattice of quasi-particles with individually assigned chemical, biological or physical properties. Model benthic organisms are introduced in the form of automatons, i.e. programmable entities, that are capable of moving through the particle lattice by displacing or ingesting-defecating particles. Each automaton obeys a set of rules, both deterministic and stochastic, designed to mimic real organism behavior, and different types of organisms have different sets of rules.

The computer coding of the model is being done by a PDF, i.e. Frederique Francois (March to August) and Jae Choi (since August). The code is in FORTRAN 90 with user interface and automated graphical (raster) output (see below for examples). A current version of the code can be viewed at ftp://mudchem.ocean.dal.ca/ONR.

WORK COMPLETED

An initial version of the code with simple deposit feeding organisms is now complete.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **30 SEP 1999**	2. REPORT TYPE	3. DATES COVERED **00-00-1999 to 00-00-1999**

4. TITLE AND SUBTITLE **Particle-Lattice and Automaton Model of Bioturbation**	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Dalhousie University,Department of Oceanography,Halifax, Nova Scotia B3H 4J1, Canada,**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR’S ACRONYM(S)
	11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**5**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

RESULTS

The model sediment is represented in Fig. 1 (nota model output), with no organisms present.

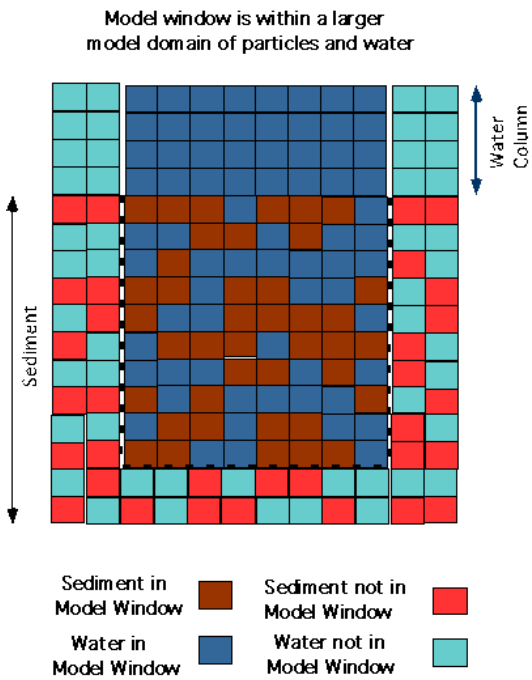

Figure 1. Mock-up of the Particle Lattice and Model Window, i.e. Output Portion (No Organisms).

In order to move, the code makes the organism either push aside sediment (brown/red) particles (Fig. 2A) or ingests (Fig. 2B) them with subsequent defecation in the burrow. These are the typical types of rules for organism behavior, and they are limitless. (Water particles are not conserved.)

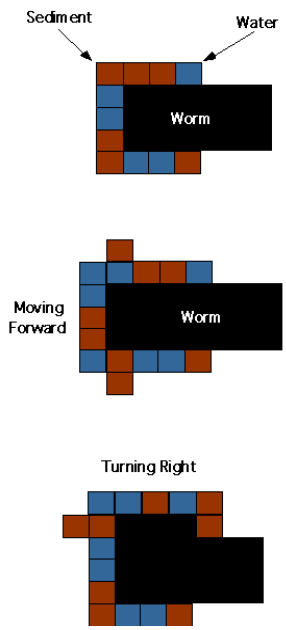

Figure 2A - Pushing Particles.

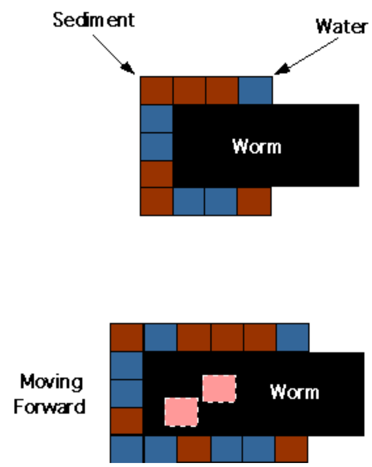

Figure 2B - Ingesting Particles.

We have managed to this points to allow the coexistence of any number of organisms, e.g. 4 in Fig. 3, and look at heterogeneities in porosity develop. For example, Fig. 3A illustrates an initial sediment with random porosity of mean value of 0.5. The blue is water, brown/grey is sediment and red/orange are the deposit feeders. The organisms have 50% chance of ingesting and 50% chance of pushing particles. After 200 time steps, the sediment still has a mean porosity of 0.5, but heterogeneities have developed where burrows (negative anomalies) and compressed areas (positive density anomalies) have developed.

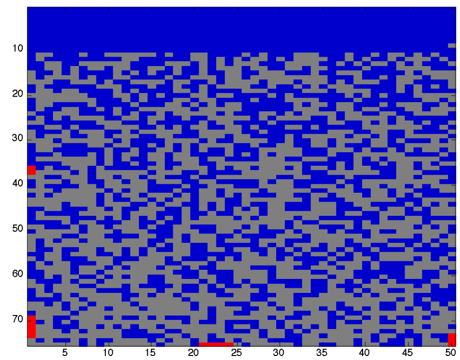

Figure 3A - Initial Model Window

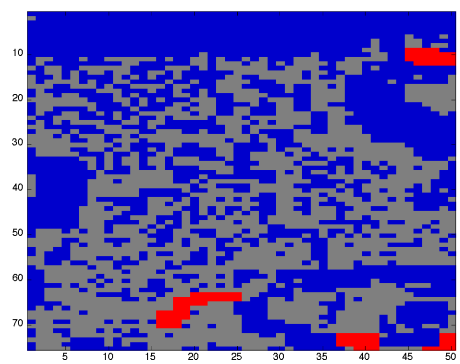

Figure 3B - After 200 Time Steps

We have not as yet done a statistical analysis of this output; the number of particles is too small to get good statistics, and we wish to scale up the size of the organisms relative to the particle size, in order to achieve a better simulation of nature. However, we are well on our way to our stated goal of predicting heterogeneity and its causes. We have also started to model the heterogeneities that result when an underlying sand is mixed into an overlying mud; Fig. 4A gives the initial step up, and Fig. 4B is the condition after 800 time steps. Note the "fingering" of sand into the overlying mud.

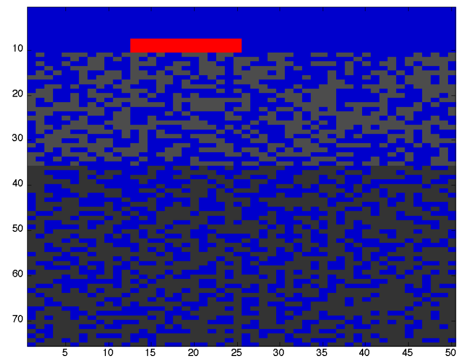

Figure 4A - Mud layer (light greyish brown) overlying a sand (dark brown) and one deposit feeder (orange/red).

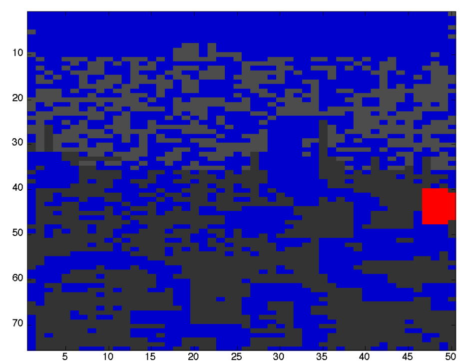

Figure 4B - Sand-mud distribution after 800 time steps

We will now be communicating more intensively with our project partners in order to obtains results from simulations that are relevant to their purposes. In addition to the study of porosity and sediment-type mixing, we will also be examining the redistribution of radioactive isotopes, attached to particles, in order to relate the current mixing model to past biodiffusion models, and the redistribution of food (organic matter), which is crucial to the biogeochemistry of sediments. We also need to better define the absolute meaning of a time step.

IMPACT/APPLICATIONS

For the first time ever, there is a direct mathematical representation of the mechanistic link between organisms activity (activities) and the resulting distribution of sediment properties. This is not only important to our acoustics project, but constitutes a fundamental advance in the modelling of bioturbation and its effects.

TRANSITIONS

We have not as yet fully communicated these results to the others in the project, or the outside scientific community. We will be doing so in the next year.

RELATED PROJECTS

Two colleagues are working on strongly related projects. Peter Jumars is attempting to relate biological sediment mixing rates to the rate of change of acoustic backscatter. The questions he and I are considering are intimately related, and he is acting as a consultant on animal behavior for our models. Darrell Jackson and Chris Jones are working on measuring acoustic backscatter in bioturbated sediment, and it is they to whom we hope to provide a finished product.