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Geoscientific Model Development

MS No. gmd-2014-159

EDDA: integrated simulation of debris flow erosion, deposition and property changes

By H. X. Chen, and L. M. Zhang

We would like to thank Referee #2 for making thoughtful comments and constructive suggestions. We have carefully considered all the review comments and revised the paper to the best of our ability. Listed below please find our responses to the review comments. Both the review comments and our corresponding responses have been tabulated for ease of reference. The major changes are also highlighted in the text.

<u>**Response to Comments from Referee #2:**</u>

Reviewer's Comments	**Response by the Authors**
1. Referring the equations (1)-(3), although they are very similar to the ones adopted by Takahashi et al., (1992) and Egashira et al., (2001), I think they are different on at least two sides. One side is the coordinate system (here is global coordinate with x-axial horizontal, while the x-axial is along the inclination of the original bed surface in the two references). The other side is originated from the way how they extend their one-dimensional mass and momentum equations to two-dimensional cases. Thus, the authors should clearly state the differences of the proposed model in this manuscript.	Thanks so much for the thoughtful suggestions. The governing equations and the expression have been revised (P5 L7): $\frac{\partial h}{\partial t}+\frac{\partial (hv_x)}{\partial x}+\frac{\partial (hv_y)}{\partial y}=i[C_{v*}+(1-C_{v*})s_b]+A[C_{vA}+(1-C_{vA})s_A]$ $\frac{\partial (C_v h)}{\partial t}+\frac{\partial (C_v hv_x)}{\partial x}+\frac{\partial (C_v hv_y)}{\partial y}=iC_{v*}+AC_{vA}$ $\frac{\partial v_x}{\partial t}+v_x\frac{\partial v_x}{\partial x}=g\left[-\text{sgn}(v_x)S_{fx}-\frac{\partial (z_b+h)}{\partial x}\right]-\frac{v_x\{i[C_{v*}+(1-C_{v*})s_b]+A[C_{vA}+(1-C_{vA})s_A]\}}{h}$ $\frac{\partial v_y}{\partial t}+v_y\frac{\partial v_y}{\partial y}=g\left[-\text{sgn}(v_y)S_{fy}-\frac{\partial (z_b+h)}{\partial y}\right]-\frac{v_y\{i[C_{v*}+(1-C_{v*})s_b]+A[C_{vA}+(1-C_{vA})s_A]\}}{h}$ "Similar with the two-dimensional model proposed by O'Brien et al. (1993), the governing equations above use a global coordinate system, which has been proven to simulate well flows in channels and alluvial fans (Akan and Yen 1981; O'Brien et al., 1993). The difference is that EDDA considers changes in debris flow properties due to material entrainment and the induced momentum exchange." (P5 L22) The governing equations have been revised to a two-dimensional form. A volume conservation algorithm is proposed to solve the governing equations (P11 L5): "As shown in Fig. 5, each cell has eight flow directions; namely, four compass directions (i.e. north, east, south and west) and four diagonal directions (i.e. northeast, southeast, southwest and northwest). In each

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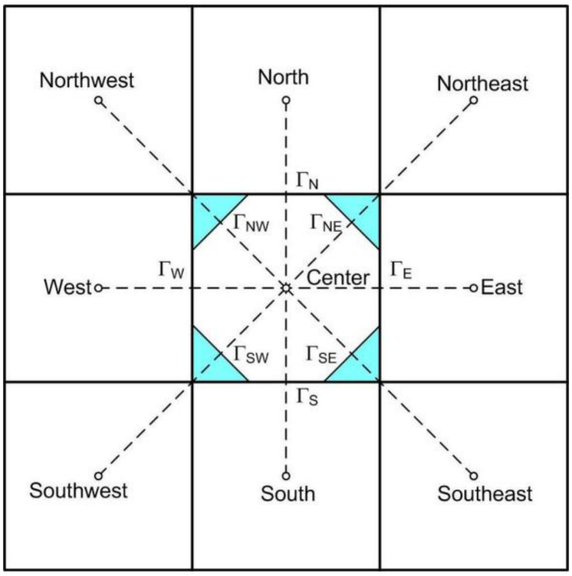
<td>time step, the changes in h and C_v at each cell due to erosion or deposition are first evaluated. After that, the flow velocity, the flow discharge, and the density of the exchange flow across each flow boundary (i.e. Γ_N, Γ_E, Γ_S, Γ_W, Γ_{NE}, Γ_{SE}, Γ_{SW}, Γ_{NW}) of all the cells are computed; and the changes in h and C_v at each cell due to the flow exchange among the cells are then evaluated. The computation of the flow velocity in each of the eight directions is independent. Therefore, Eqs. (3) and (4) are reduced to one equation. This type of method has been proven to be sufficient and efficient for simulating overland flows (FLO-2D Software Inc., 2009)."



FLO-2D Software Inc.: FLO-2D reference manual, Nutrioso, Arizona, USA, 2009.

O'Brien, J. S., Julien, P. Y., Fullerton, W. T.: Two-dimensional water flood and mudflow simulation, Journal of Hydraulic Engineering 119: 244-261, 1993.</td>
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<td>2. The pattern of manifestation of the equations (1)-(3) seems flawed. The left sides of equations are one of eight directions, while the right sides are physical quantities of comprehensive directions. Such as equation (1), the left side is referred to one of eight directions, while the right side is the whole erosion or deposition depth. Thus, the authors should check these equations and write them in a proper pattern.</td>
<td>The suggestion has been well taken. The governing equations have been revised to a two-dimensional form as shown in the last question.

"As shown in Eqs. (1) and (2), the changes in h and C_v are governed by two effects; namely, erosion or deposition, and the flow exchange among cells. The change in flow velocity is governed by four effects; namely, convective acceleration, flow resistance, total head, and momentum exchange due to entrainment of material or deposition." (P 10 L23)

Then the method to solve the two-dimensional</td>
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	equations is shown as follows (P11 L5): "As shown in Fig. 5, each cell has eight flow directions; namely, four compass directions (i.e. north, east, south and west) and four diagonal directions (i.e. northeast, southeast, southwest and northwest). In each time step, the changes in *h* and C_v at each cell due to erosion or deposition are first evaluated. After that, the flow velocity, the flow discharge, and the density of the exchange flow across each flow boundary (i.e. Γ_N, Γ_E, Γ_S, Γ_W, Γ_{NE}, Γ_{SE}, Γ_{SW}, Γ_{NW}) of all the cells are computed; and the changes in *h* and C_v at each cell due to the flow exchange among the cells are then evaluated. The computation of the flow velocity in each of the eight directions is independent. Therefore, Eqs. (3) and (4) are reduced to one equation. This type of method has been proven to be sufficient and efficient for simulating overland flows (FLO-2D Software Inc., 2009)."
3. The four computational cases are not very suitable to verify the model and numerical framework. Three cases are one-dimensional. And the fourth case is also hard to evaluate the advantage of the proposed model. As the way to extend to two-dimensional framework is unique in this manuscript, I think a two-dimensional dam-break/debris flow case without and one two-dimensional dam-break/debris flow case with erosion compared with experiments or previous results is needed.	Thanks so much for the constructive suggestions. Following your suggestion, in Section 3.2, a two-dimensional dam-break water flow has been adopted to test the performance of the model in simulating two-dimensional flows (P14 L13): "A two-dimensional partial dam-breach problem reported by Fennema and Hanif Chaudhry (1987) is adopted. The sketch of the problem is shown in Fig. 8a. The computation domain is a channel 200 m in length and 200 m in width. The depth of the reservoir water is 10 m, and the depth of the tail water is 5 m. The boundary is assumed to be frictionless. The dam is assumed to fail instantaneously and the breach width is 75 m. The computation domain is discretised into a grid with cell dimensions of 2.5×2.5 m. The time step is kept at 0.01 s. The flow resistance slope, S_f, is taken as 0 in this test as the channel is assumed frictionless. The water depth at 7.1 s after the dam breaches is shown in Fig. 8(a), which agrees the result of Fennema and Hanif Chaudhry (1987) well. Two points in Fig. 8(a) are selected for investigating the variation of water depth with time. The results from the numerical solution using EDDA and two numerical solutions by Fennema and Hanif Chaudhry (1987) are compared in Fig. 8(b), which again agree reasonably well. "

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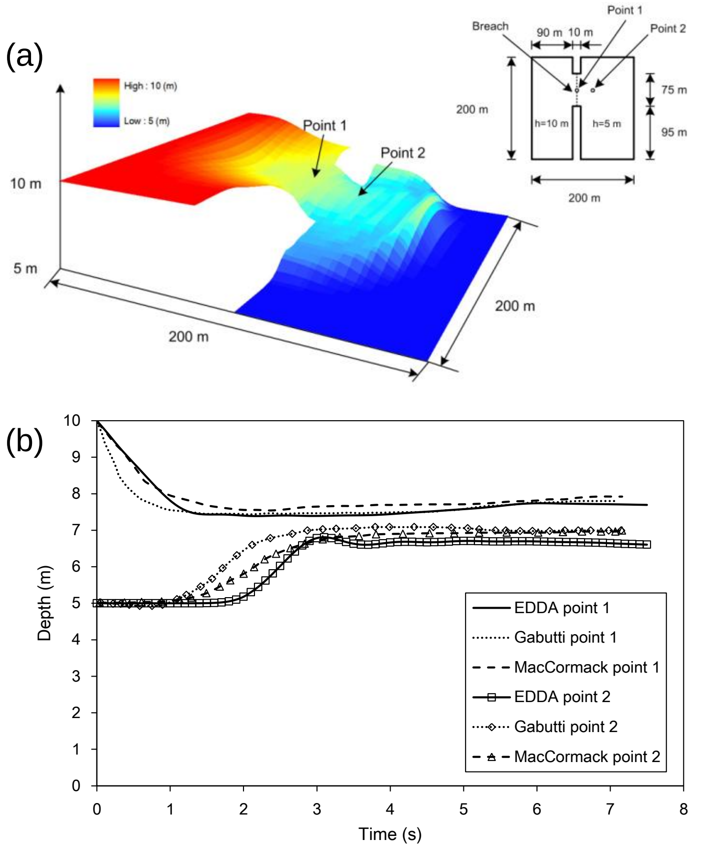

In Tests 3 and 4, a very small grid size of 0.02×0.02 m is adopted since the width of the flume is only 0.1 m. The two numerical tests are now two dimensional. The model also performs well in these two tests.
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<td>4. The Introduction should be strengthened and more attention should be paid to the advances of depth-integrated model involving erosion/deposition and associated rheology model. The following references (even more) associated erosion effects should be included in Instruction.</td>
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The suggestion has been well taken. The advances of depth-integrated models involving erosion/deposition and associated rheological models have been reviewed in depth in the introduction part (P3 L16):
“Depth-integrated models have been widely adopted to describe erosion and deposition (e.g. Takahashi et al., 1992; McDougall and Hungr, 2005; Armanini et al., 2009; Hungr and McDougall, 2009; Iverson et al., 2011; Quan Luna et al., 2012; Ouyang et al., 2014). The Mohr-Coulomb failure process is adopted to simulate bed erosion (e.g. Medina et al., 2008; Quan Luna et al., 2012). Ouyang et al. (2014) further combine the Mohr-Coulomb model and the Voellmy model to overcome the flaws of each of these two models. The changes in flow depth, flow velocity and debris mass have been accounted for in the literature. Limited attempt has also been made to consider the evolution of volumetric sediment concentration (Takahashi et al., 1992; Denlinger and Iverson, 2001; Ghilardi et al., 2001). Several key problems, however,
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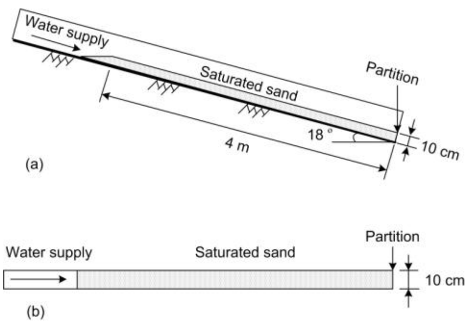
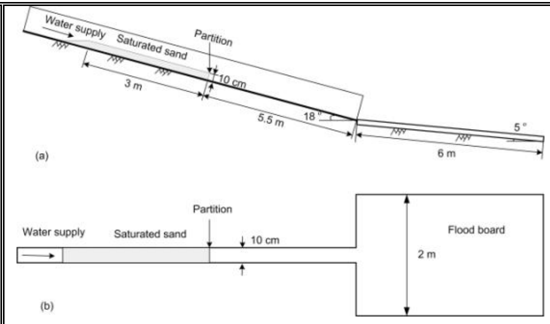
	still remain. How can one describe the various phases of a debris flow (e.g. clear water flow, hyper-concentrated flow, and fully developed debris flow) using a general rheological model? How do the properties of debris flows (e.g. volumetric sediment concentration, yield stress, viscosity) change in the erosion and deposition processes? How do these changes affect the runout characteristics of the debris flow? ”
5. 7273/1-5, simulution should be modified to be simulation.	The word has been corrected.
6. 7280/1-5, the equations (29) and (30) seems to have some clerical mistakes.	The two equations have been revised (P12 L6). $$h_{new} = h_{predi} + \frac{\sum_{b=1}^{nb}(q_b \Delta t)}{A_{cell}}$$ $$\rho_{new} = \frac{\rho_{predi} h_{predi} A_{cell} + \sum_{b=1}^{nb}(\rho_b q_b \Delta t)}{h_{new} A_{cell}}$$ where h_{new} and ρ_{new} are the updated flow depth and density, respectively; q_b and ρ_b are the discharge and density of the exchange flow across a boundary, respectively; *nb* is the number of flow boundaries of the cell (i.e. eight); A_{cell} is the area of the cell.
7. In Figure 10 and 11, the description of sediment part is bad and need redraw.	The two figures have been revised as follows. 

	
8. 7314/figure 16, Time(h) or Time(t)??	It has been revised to Time (hour).