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Reply on RC2

W. Marijn van der Meij et al.

Author comment on "ChronoLorica: introduction of a soil–landscape evolution model combined with geochronometers" by W. Marijn van der Meij et al., EGUsphere, https://doi.org/10.5194/egusphere-2022-934-AC2, 2023

Review of ChronoLorica – Introduction of a soil-landscape evolution model combined with geochronometers by van der Meij et al.

H. Gray, PhD

Research Geologist

U.S. Geological Survey

Van Der Meij et al. present an introduction to an adaption of an established soil landscape evolution model by including new processes controlling Optically Stimulated Luminescence (OSL) and cosmogenic geochronometers. The authors introduce this new model as a start into delving into broader scale questions of landscape dynamics.

Overall, I am very supportive of this paper. I think that coupling luminescence (and cosmogenics) into a large-scale landscape evolution model is a great idea. In particular, as the authors note, this approach has the potential to uncover new predictions and hypotheses that would be hard to develop outside of a modeling framework. Also it is really admirable the work done to build such a comprehensive model incorporating the wide array of processes involved in a soil-focused landscape evolution model. I have some comments below on specific things, but I want to acknowledge ahead of time that the model is pretty broad and these comments may not change the broader results.

Response:

Dear Harrison Gray,

Thank you for the nice remarks about the manuscript and the constructive comments. Below we will address the comments one-by-one. Your comment are marked in italic.

With best regards, on behalf of all authors,

Marijn van der Meij

Main Comments:

Soil transport in ChronoLorica

One thing that I wondered about is whether the treatment of soil horizonal and vertical transport is internally-consistent. An example may be the comparison between the soil creep function and the bioturbation function along with the particle transport formulae of Anderson (2015) and Furbish et al. (2018b). There isn't enough detail in this section for me to fully understand how the model is working, but I wonder are the ddCR and ddBT values consistent with that input into Anderson/Furbish? If so, how is this done?? The second point on this is that it isn't clear what the justification is for exponential decay functions for soil creep and bioturbation. It would be helpful to back this up with references. Perhaps with some of the Young's pit studies?

Response: In our model, vertical transport is driven by bioturbation, while horizontal transport is driven by soil creep. These processes influence the bulk of the soil, by mixing and transporting material between different layers. Our depth parameters $dd_{CR}$and dd_{BT}, with the unit m^{-1}, determine how the intensity of these processes changes with soil depth. This is similar to the exponential speed profile reported in Anderson (2015). Anderson (2015) divides the soil depth by his depth scale of creep (z_a = 0.15 m), while we multiply our soil depth with dd_{CR}ordd_{BT}. The inverse of $z_a$is 1 / 0.15 m = 6.67 m^{-1}, which is consistent with our depth parameters of 5 m^{-1}. We will better support our parameter selection in the manuscript, including this example.

We chose to work with an exponential decay function for creep and bioturbation, because this is the standard in the Lorica model and its predecessors (Vanwalleghem et al., 2013; Temme and Vanwalleghem, 2016). This shape is found in many soil processes and properties (Minasny et al., 2016) and represents diminishing temperature and soil moisture variations with depth (Amenu et al., 2005), biological activity for some organisms (Canti, 2003), as well as root distributions of some plants (Gregory, 2006). However, we're aware that the exponential profile is not valid for all settings, as the references above also state. We will mention the selection of the exponential profile, and its alternatives, in the manuscript. We will also emphasize that for in each field setting there are different organisms and processes responsible for soil mixing and transport. For each study, the processes, depth functions and parameters should thus be derived from field data or similar studies.

As another comment on this: On line 119, the authors say they use the formulae of Anderson (2015) and Furbish et al. (2018b) to model downhill transport of soil particles. However, these papers disagree with each other on the base principles of how soil moves downhill with the Anderson study assuming a continuum-style flux of soil (basically soil treated as a fluid) and the Furbish et al. study explicitly treating the soil particles as non-fluid with the advection-diffusion style equations describing the ensemble averaged conditions of soil particle transport using statistical mechanics. The advection/diffusion equations describe the flux of probability of the expected value of the ensemble average. The particle transport was handled with different random-walk equations. This in effect means that if you use Furbish theory, you cannot calibrate your OSL/cosmo field data against the advection/diffusion model because the model and data are two fundamentally different things. The model being a theoretical average of a uncountable number of theoretical soils. In contrast if you use the Anderson approach, you will be wrong because soil doesn't follow continuum mechanics as in the base assumptions of that paper.

Response: Thank you for the clarification. We actually borrow from both descriptions, but we approach the issue from the bulk soil instead of from the individual particles. The bulk soil moves downslope, following diffusive transport. The changes in downslope velocity with soil depth is similar to the exponential profile of Anderson (2015) and Figure 6 of Gray et al. (2019), that refers to the Furbish theory. Vertical transport of soil particles is governed by the bioturbation process, that follows the same exponential depth dependence, meaning that there is more material exchange in soil layers nearer to the surface.

In ChronoLorica, the horizontal and vertical transport of bulk soil is coupled to the stochastic transport of individual particles. The fraction of bulk soil that is transported from a layer is used to randomly assess whether a particle is transported as well. Each particle follows its own unique trajectory.

The distribution of particle ages in certain soil layer at the end of the simulations can be expressed as a probability density function (PDF) of particle ages. These PDFs can be compared with PDFs of measured OSL particle ages. Calibration or validation can be done by comparing the PDFs, or specific statistics calculated from the PDFs, such as mean, median or spread.

We will rephrase the sentence on line 119, to clarify how we model soil and consequently particle transport.

OSL physics

One thing that this paper made me think was that it would potentially be useful for the authors to directly simulate the luminescence. It seems like the authors get into a high level of detail with the cosmogenic physics but not the OSL physics. I think this is worth exploring in the model because the model is intended to be an explicit coupled soil-landscape-geochronometers model, yet the physics of cosmogenic is treated very in depth but the OSL isn't. Right now the model feels very focused on the cosmo

Response: We simplified physics behind OSL and cosmogenic nuclides to match the reduced complexity of our model. In case of particle ages, this simplification leads to the tracing of individual particle ages, rather than the dose rate and palaeodose of each particle. This approach is sufficient to simulate the required age distributions at this stage, see also the our response to the next comment. In the case of cosmogenic nuclides, the simulated processes are indeed a bit more detailed, because the nuclides have multiple production pathways, the production is linked to soil depth and certain particle sizes and cosmogenic nuclides behave differently in soils compared to particle OSL ages. Nonetheless, also these physics were simplified compared to conventional cosmogenic nuclide models (Balco, 2017).

One thing that brought this up is the assumption that the burial age equals the OSL age, which I think isn't always an easy assumption in soils! As a particle travels through various soil layers, the background dose rate, DR(z), can change due to a variety of processes, but particularly with soil density and water content which affects the density of the natural background radiation intensity and the cosmogenic radiation flux. I didn't see any content or discussion on how this could affect the OSL geochronometer results, but I could imagine that the burial age and the OSL age could vary a lot (it does from my field experience with OSL in soil). I think it is important for the authors to explore this assumption and show, perhaps with a sensitivity analysis that it does or does not matter.

As an admission, I assumed constant DR with soil depth in past work and I think Furbish et al. (2018b) made a case for why this does not matter but I don't remember fully. I'm bringing this up because treatment of specific soil layers seems to be an important benefit of Chronolorica.

*One could model the change in luminescence (and assumed an idealized luminescence geochronometer, the luminescence grows in at dL(z)/dt = DR(z)/D0 * (Ls – L(z)) where L is luminescence, z is vertical height in the soil, t is time, DR(z) is dose rate, D0 is a dose e-folding scale, and Ls is the luminescence at saturation. A really good source for this type* *of modeling is Brown, N. D. (2020). Which geomorphic processes can be informed by luminescence measurements?. Geomorphology, 367, 107296 Where the author gives the equations that could be directly incorporated into the model.*

Response: The reviewer points out an important shortcoming in the way OSL ages are currently calculated for bioturbated soils. In most experimental studies it is assumed that the dose rate at sampling position is the best estimate for all particles at this position. In the case of bioturbation with mobile particles, this is only a fair assumption if a constant dose rate with soil depth is assumed or measured. Therefore, we think that our approach of tracing particle ages is sufficient for comparison with most measured ages.

However, we agree that spatial (and temporal) changes in the effective dose rate that a particle receives during its soil passage can have a large effect on the age determinations, and that ChronoLorica is a suitable tool to explore the impact of spatiotemporal variations of this dose rate on particle OSL ages. This can be interesting for future work for sure. We therefore will add this as a possible application of the model in Section 5.3.

Minor Comments:

Line 41: if helpful, Gray et al 2019 has a section on soil mixing and methods that might be helpful for this review paragraph: Gray, H. J., Jain, M., Sawakuchi, A. O., Mahan, S. A., & Tucker, G. E. (2019). Luminescence as a sediment tracer and provenance tool. Reviews of Geophysics, 57(3), 987-1017.

Response: This paper is indeed a useful addition to the review paragraph. We will add the reference to the list at the end of this paragraph.

Line 64: Hmm. The comparison with field studies is a bit weird as SLEMs are hypothetical scenarios but are not actually reality in the way that field studies are.

Response: We understand your concerns with this statement, but we prefer to keep this comparison in the manuscript to show the differences in scale and continuity between field and model data. We will nuance this statement by adding a sentence the end of this paragraph to indicate that the model data are hypothetical and simplified compared to the field data.

Line 198, 459: 10 mm seems high for light penetration in soil. See: Ciani, A., Goss, K. U., & Schwarzenbach, R. P. (2005). Light penetration in soil and particulate minerals. European journal of soil science, 56(5), 561-574.

Response: In the paper you cite, the authors create samples of particles smaller than 0.355 mm, which they press into a container with a sheet of paper on top to provide some surface roughness. These are then measured for light penetration. We don't think that this method is representative for light penetration in soil in the context of OSL dating of quartz particles, because the sand fraction is removed, and effects of soil structure and soil surface roughness are left out. We think these factors all lead to higher porosity and deeper light penetration. Moreover, the measurement time is probably much shorter than the annual time step in our model. Sub-annual mixing can transport bleached particles deeper in the soil as well.

In our simulations, we used a light penetration depth of 5 mm (Table 1), which in between the 1 and 10 mm used in Furbish et al. (2018), and which is consistent with long-term bleaching depths in soils (Sellwood et al., 2019). We expect that the light penetration depth in soils is in this order of magnitude, but experimental data is required to make better supported estimates, as we also address in lines 457-462.

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