Solid Earth Discuss.,
https://doi.org/10.5194/se-2018-46-AC1, 2018

Interactive comment on "The effect of rock composition on muon tomography measurements" *by* A. Lechmann et al.

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Received and published: 3 October 2018

We thank the anonymous reviewer for the comments and the positive reception of our idea.

In our view, reviewer 1 raises 4 major points. The first one concerns the propagation of any uncertainty in the energy loss calculations and the flux model to the simulated data and a subsequent error propagation of these calculated fluxes to the flux ratio. We completely agree with the reviewer that the related uncertainties exist and should be propagated to the simulated flux. This can be seen in Eq. (1), where the lower integration boundary, i.e. E_cut, carries the error of the interaction cross-sections. Furthermore, the integrand, i.e. dI/dE , has also an error attributed to it. As a consequence,

the simulated flux, i.e. the left side of Eq. (1), has to be represented by a probability distribution. If the errors in the nominator and the denominator were independent from each other, we would have to fully propagate the error to flux ratio according to the gaussian law of uncertainty propagation. However, as both simulations were obtained with the exact same energy-loss and flux models, the errors are even correlated one to one. Thus, the error propagation can be treated much more efficiently. We will visualise these points by adding an additional figure. We will then show how these errors are propagated to our final parameter, which is the flux ratio. We will address this issue in a new section, which is dedicated to the discussion of the involved errors in our study. Following the reviewer's advice, we will also add errors to our existing flux ratio figures.

A further point mentions the limitation of our approach to a volume averaging of element properties. We apologise if we might not have completely and clearly conveyed the idea of our method. We would like to clarify that our rock model incorporates two different kinds of averaging. Element properties are averaged by their mass to crystal properties. Only then did we employ a volume averaging of these crystal properties to rock properties. That being said, we have to add that the volume averaging is a procedure, which is equivalent to the mass averaging. In fact, we derived the volume averaging approach through a mass averaging of crystal properties as can be seen from Eq. (B16) onwards. We justify this approach through our observations, where a rock is made up of several minerals that have their own spatial extent. In turn, each mineral has its own elemental composition and crystallographic structure. This approach allows for much more detailed models to be used for the description of rocks, than those that are based on bulk compositions which are only represented by oxide fractions. We suggest that this different view better serves the need in muon tomographic studies. We will thus adapt our manuscript accordingly to express the idea of our approach more clearly. We will gladly provide also the energy loss equations for a rock that has been obtained by a mass averaging procedure of crystal properties in the supplementary material.

The third issue states that experimental data could greatly improve the impact of our study. We agree with the fact that our work would benefit if experimental data would confirm our theoretical findings. However, we acknowledge that we cannot offer quantitative measurements to test and constrain our model, mainly because the required data is not available. We do see major advances in this field if quantitative data on the dependency of muon flux attenuation on lithology would be available. Nevertheless, we based our inferences on the same conceptual framework as those that have been applied for any other material, including standard rock. As a result of this, we find differences if the rock parameters are changed. Therefore, we see the need that interpretations of muon fluxes need to be adjusted according to the geological architecture. We implement this in our work by discussing the role of experimental data for this sensitivity study.

The last matter raised by the reviewer is the significance of our findings in light of the prevalence of the flux model error. We agree with the reviewer that in a standard, present-day muon tomographic experimental setup (i.e. measuring the muon flux on the "back"-side of the target and assuming a flux model for the muon flux in "front" of the target), the dominating systematic error originates generally from the flux model, such that the compositional error would be regarded as negligible. However, one could imagine an experimental setup, where the flux in front of the target is also measured. Thus, the necessity of imposing a flux model disappears and one is limited only by the measurement accuracy. It is also possible that the community measuring the muon flux will improve their models in a way that the errors associated with it become smaller. An extreme view would even be to draw inferences on rock composition from muon flux measurements. Either way, the problem of the sensitivity to compositional changes will resurface in the future as this technology will be constantly refined. We address this issue more carefully in our work, such that we can emphasise that our technical developments were not tied to a rigid experimental setup and might be useful for future studies.

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