In the 4th paper of the companion papers, the authors explain their scientific strategy and philosophical viewpoint for attacking the highly important and yet unsolved problem of soil transport on rough landscapes over a wide range of space and time scales. The paper covers a very broad range of significant issues, that all of them are pertinent to soil and sediment transport in various settings (and not necessarily on hillslopes). The work also sets a high bar and a valuable example for future research in this and adjacent fields. It further provides variety of ideas and problems that can become future research topics by other researchers and inspire much needed work to explore and illuminate the physics and mechanics of soil and sediment transport. At this point, I would like to add that the paper is also heavy in arguments based on statistical mechanics and kinetic theory of gases. This reviewer is not an expert in either of these fields, and they only have an introductory knowledge to follow the argument. Therefore, I encourage the editors or interested readers to further evaluate the statistical mechanics-based arguments presented in the paper by themselves, or by seeking additional input from experts in those fields (I noticed that editors might have already sought feedback from experts in those areas). I support the publication of this part of the companion papers, after the authors have revised the paper to address my mostly minor comments and questions below:

- This might have been discussed in the earlier parts of the companion papers — which I didn't have the resources to study in detail, before completing my review task —, however, I would appreciate it if the authors can elaborate in this part, the conditions under which particle transport can be considered rarefied. I think providing a quantitative statement, potentially a dimensionless number or a metric that can be measured in experiment/simulation/field, would be very valuable.

- Related to my previous comment, do the authors think or advocate that all soil transport (or all that matters for soil transport phenomenon) is in rarefied condition? I have an opposing view, but at this point, it maybe just a matter of my misunderstanding. I try to explain my view in the next few sentences. I think of soil transport as a continuum — i.e., coexisting and gradually transitioning between them — of modes of transport and transport conditions. I agree that rarefied condition is a big part of that. However, as the ratio of particle per volume (packing fraction or solid fraction) increases as we get closer (from air) to (hillslope) surface, the transport condition becomes closer to the dense flow or dense particle transport. My view is in part informed by the experiments by Houssais et al (2015), where the authors show that in the case of fluvial sediment transport, there are three regimes (suspended particles, bedload, and creep; see their Fig. 1D). Some may argue that these are just two regimes by considering suspended transport as a part of the bedload, from the viewpoint of sediment transport, or by considering creep as part of the bedload, from the viewpoint of granular flow and physics; but in any case, there are at least two regimes there. How can the framework described here be applied to, or otherwise remain relevant to, such conditions in the lab and field, where the entire system may not be in the rarefied condition? Would you advocate for ignoring the contributions of the dense regimes, or otherwise suggest to readers to focus for future research on the rarefied condition of soil transport? Do you consider the contributions of the dense flow part of the transport as *solved* with the existing heuristic equations and relations, especially if they cannot be explained or adequately modeled in the rarefied framework described in the companion papers?

- The behavior of materials (and not general phenomenology of transport) in the dense regime is highly sensitive to size and size distribution, shape, etc of granular materials. I think there is an over emphasis in the manuscript on the probabilistic approach to the problem (which I feel like to be very useful for rarefied transport condition). However, to the degree that the contributions of dense flow regime remain relevant to soil transport, I would favor a slightly more balanced research and scientific strategy, where there is enough space to explore and investigate the physics and mechanics of dense regime. I would also argue for integrating more of reductionist studies, e.g., on the physics of mixing using the laboratory or simulation data on the feasible spatiotemporal scales, and less worry in the first instance about the uncertainty of those measurements for application to the geological space and time. The authors have mentioned this at some points in the paper (the part about discrete element modeling simulations or other first principle or ab initio studies that can be accompanied by carefully crafted experiments and theory development), but I think those avenues might be worthy of some more attention, especially in this philosophical part of the companion papers.

- This a very minor comment. On page 19, ~line #30, the authors put close to each other, what is called "nonlocal behavior/rheology" in the dense granular flow research community, and the nonlocal transport in the sediment transport research community. First, this gives me the impression that the authors consider dense granular/particle flow to be in the rarefied condition. I don't think this is a correct view, but I am happy to learn more about the authors viewpoint on that, so it would be helpful if they can clarify on this matter. Second, I think there is still ongoing debate related to the dense granular flow behavior, and whether it should be called "nonlocal behavior" or "nonlocal rheology". This issue is not yet settled in the granular and complex fluids research communities, and the resembles between the two terms (nonlocal rheology and nonlocal transport) may cause confusion or concern for some readers.

References

Houssais, M., Ortiz, C. P., Durian, D. J., & Jerolmack, D. J. (2015). Onset of sediment transport is a continuous transition driven by fluid shear and granular creep. Nature communications, 6(1), 1-8.