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Earth Surface Dynamics Discussions



# *Interactive comment on* "Catchment power and the joint distribution of elevation and travel distance to the outlet" *by* L. S. Sklar et al.

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We would first like the thank Reviewer 2 for their constructive comments. In this response we provide answers to each comment and detail the changes that will be applied in the revised manuscript. Please note that line numbers refer to the numbering of the original discussion manuscript.

Overview

"This paper proposes two new metrics to quantify landscape morphology based on the distribution of elevation and travel-distance, brought together in the concept of catchment power. Three examples of catchments with different morphologies are explored and a method is proposed by which artificial catchments with specified source-area power distributions can be synthesised. The paper's methods are certainly novel and



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raise some important questions about the formation of landscapes and the topic will be of broad interest to readers of ESurf. The manuscript is well written and carefully presented. I suggest that the manuscript is suitable for publication in ESurf, subject to satisfactory additional clarification and discussion of the following points."

Response: Thank you for this positive summary and overall assessment of the paper. As detailed below we have done our best to provide the requested clarifications.

Comment 1: The paper concludes by stating that its major contribution is to offer a "fresh perspective". That's fine, but it would be better in my view to explain what new knowledge is available through the use of the new landscape metrics. The reader is left unclear on how this particular set of metrics might shed light on important problems in geomorphology.

Answer: Thank you for highlighting the need for greater clarity on how these new metrics, source-area power and catchment power, might shed light on important problems in geomorphology. We have made changes (detailed below) the expand the discussion of future research opportunities and in the conclusion. In particular, we provide specific examples of questions for which these new metrics might help provide answers. These include what controls the size of sediments delivered to catchment outlets, and how does topography mediate the linkages between tectonics and climate?

Changes in the manuscript: In the first paragraph of section 5.2 (future research opportunities), we have added text to help illustrate the claim that "this framework can be used to understand how the size distribution of sediments passing through a catchment outlet is influenced by weathering conditions at source elevations (Sklar et al., 2016), and by particle breakdown in transport (Attal and Lave, 2009)." The new text reads: "Specifically, the initial particle size produced on hillslopes may vary systematically with local climate, vegetation, and erosion rate, factors that commonly vary with elevation within catchments (Riebe et al., 2015). In the absence of particle size reduction in transport, the size distribution of sediments delivered to the outlet would then reflect the distribution of source elevations, weighted by the local erosion rate. Yet particle wear is likely to be significant except in small catchments underlain by exceptionally durable rock. The overall extent of particle size reduction in transport will depend on the distribution of travel distances and the rates of energy dissipation along those transport paths. Thus the evolution of sediment sizes in catchments, from source areas to the catchment outlet, and the resulting size distribution passing through the outlet, depend on the factors that together determine source-area power."

We have added a new paragraph to expand on the claim that "catchment power, the integral of source-area power for a given material over the entire catchment (equation 5), provides a metric for comparisons between catchments, and could be used to quantify, and help explain, the variation in topography across gradients in climate, tectonics and lithology." The new text reads "For example, Reiners et al., 2003, found a strong correlation between spatial variation in erosion rate and precipitation in the Cascade Mountains of Washington, but no corresponding trend in conventional topographic indices such as local relief. Catchment power, calculated for water delivered by precipitation, for sediment produced by erosion, or as the ratio of water to sediment power, could provide a metric that captures how topography varies across gradients in precipitation and erosion. In this way, catchment power could help explain how topography mediates the linkage between climate and tectonics. Catchment power could also be used to compare numerical simulations of landscape evolution with real landscapes (Willgoose 1994; Willgoose et al., 2003), and contrast terrestrial catchments with catchments on Mars or Titan, where the topography reflects differing gravitational accelerations, fluids and rock properties (Mest et al., 2010; Burr et al., 2012)."

Comment 2: The calculation of stream power (line 224) takes as the relevant slope the mean slope along the path to the catchment outlet. If the actual slope is close to the mean slope then this may be a good approximation. If not (for example, if the pathway might involve a very steep upper section with a long flat floodplain, or alternatively a high elevation plateau with a steep ravine descending from it) then the virtual velocity





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of sediment through the system will differ substantially, with important implications for residence time of sediment in floodplains etc (which is itself relevant geochemical residence times in the catchment, cosmogenic methods, and carbon sequestration). This warrants some further discussion.

Answer: This is a very helpful comment in that it highlights the need to explain how source-area power is different from stream power. There are two key differences. First stream power uses the entire upstream contributing area to calculate the material flux, whereas the contributing area for source-area power is limited to the smallest unit of analysis, such as a single pixel in a DEM. Second, stream power quantifies the local rate of energy dissipation across a short distance, such as a reach of river represented by the distance between two pixels, whereas source-area power averages energy dissipation over the entire travel distance from source to catchment outlet. Unlike stream power, source-area power quantifies the production rate of material potential energy in terms of the position of the source location relative to the catchment outlet. This provides a distinct metric for analyzing spatial patterns in how energy is produced within catchments, relative to the distance over which the effects of energy dissipation are realized.

Changes in the manuscript: A new paragraph has been inserted following the paragraph containing equation 3 at line 224. “Source-area power is distinct from stream power, which is how energy dissipation in landscapes is commonly quantified (Rodriguez-Itrube et al., 1992; Lague, 2014). Stream power uses the entire upstream contributing area to calculate the material flux, whereas the contributing area for source-area power is limited to the smallest unit of analysis, such as a pixel in a DEM. Moreover, stream power quantifies the local rate of energy dissipation across a short distance, such as a reach of river represented by the distance between two pixels, whereas source-area power averages energy dissipation over the entire travel distance from source to catchment outlet. Hence, unlike stream power, source-area power quantifies the production rate of material potential energy in terms of the position of the source location relative to the catchment outlet. This provides a distinct metric for analyzing spatial patterns in how energy is produced and dissipated within catchments."

Comment 3: In section 3 (line 243 onwards) the notation switches from the generic subscripts i,j to w and s for water and sediment, and the dimensionless ratio \omega^* is defined as the ratio of source-area power of water per mass of sediment. The intuitive/conceptual significant of this ratio is not clear, which makes it hard to interpret the values 36–653 in the subsequent paragraph.

Answer: We agree that the motivation for this analysis was poorly articulated in the original draft. The goal of comparing source-area power for water with sediment production rate is to explore how the topography, as expressed in the joint distribution of elevation and travel distance, reflects the spatial variation and relative importance of water-mediated sediment transport processes, such as overland, debris, and fluvial flows, as opposed to primarily gravity-driven processes such as creep and landslides. We have added several sentences to the paragraph beginning at line 243 to more clearly motivate this analysis.

Thank you for pointing out the inconsistency in the sub-script notation. The first subscript should always refer to a location and the second subscript should refer to a material, or in this case a ratio of one material to another. We have adjusted the notation for the quantity defined in equation 4 to be consistent with this subscript convention.

Changes in the manuscript: The new text reads "Comparisons of source-area power and production rates for different materials may provide insight into the spatial variation of catchment processes. For example, sediment produced by erosion at source areas is transported to the outlet by a combination of primarily gravity-driven processes, including creep and landslides, and by water-mediated processes such as overland, debris, and fluvial flows. Catchment topography, as expressed in the joint distribution of elevation and travel distance, may reflect the spatial variation and relative importance of these different processes."

The symbol for the dimensionless ratio of water source-area power to sediment mass production rate is now written as in equation 4 and in the accompanying text.

Specific comments / Minor points Line 86 Tarbotton -> Tarboton

Response: Thank you for catching this, the misspelling has been corrected.

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