

EGU2020-10639

<https://doi.org/10.5194/egusphere-egu2020-10639>

EGU General Assembly 2020

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Geometrical Scaling Relations of Drainage Basins During Basin Evolution

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Fluvial drainage systems are organized in drainage basins, whose boundaries are defined by water divides. The network of divides determines the geometry of the basins and the distribution of drainage area along flow. Drainage basins obey global geometric-geomorphic scaling relationships. These include Hack's law that predicts the relation between channel length (L) and drainage area (A): $L = cA^h$ where c and h are referred to as Hack's coefficient and exponent, respectively. These parameters have a relatively narrow range of $1.1 \leq c \leq 2.7$ and $0.45 \leq h \leq 0.6$. Additionally, the distance between basin outlets (S) has been shown to scale linearly with the distance between the main divide and the mountain front (W) and is expressed by the ratio: $R = W/S$, where R is within the range of $1.91 \leq R \leq 2.23$. When the tectonic and climatic conditions change through time, drainage basins can change their geometry. It is not clear, however, if and how the global scaling relations evolve when basins change their shape and size. This gap in our understanding specifically relates to the links between geomorphic processes and surface forms. A promising approach to study fluvial landscape evolution is by using physical laboratory-scale models. These models provide a unique opportunity to study the details of drainage network evolution and geometrical changes by constraining climate and uplift and by maintaining the lithological parameters constant and uniform. In the current study, we utilize DULAB (Differential Uplift Landscape-evolution Box), an experimental apparatus that simulates mountainous landscape evolution, to study the evolution of basin geometrical scaling relations. Our experimental scheme consists of two distinct settings: (1) uniform uplift, with basins that grow by incising backward towards an uplifting and shrinking plateau, and (2) differential uplift, where the main drainage divide migrates towards the higher uplift rate side, and the drainage basins adjust accordingly. During the experiments, precipitation is held constant, and we document the landscape geometry in predefined time intervals by applying a "Structure from Motion" algorithm on a series of photos. Experimental results show that while basins drastically change their size and shape, they tend to maintain the globally observed geometrical scaling relations. Hack's parameters are computed to be $c = 2.29 \pm 0.08$ and $h = 0.51 \pm 0.02$ and the spacing ratio, R is $R = 2.95 \pm 0.4$. This is achieved as only a subset of basins grow towards the migrating divide, while other basins maintain their former geometry or shrink. Additionally, processes of reorganization, such as basins merging close to their outlets and inter-basin divide migration, assist in maintaining the geometrical scaling relations.

How to cite: Havusha, K., Goren, L., and Nativ, R.: Geometrical Scaling Relations of Drainage Basins During Basin Evolution, EGU General Assembly 2020, Online, 4–8 May 2020, EGU2020-10639, <https://doi.org/10.5194/egusphere-egu2020-10639>, 2020