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Exploring 3D optimal channel networks by multiple organizing principles

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Catchment topography and flow networks are shaped by the interactions of water and sediment across various spatial and temporal scales. The complexity of these processes hinders the development of models able to assess the validity of general principles governing such phenomena. The theory of Optimal Channel Networks (OCNs) proved that it is possible to generate drainage networks statistically comparable to those observed in nature by minimizing the energy spent by the water flowing through them. So far, the OCN theory has been developed for planar 2D domains, assuming equal energy expenditure per unit area of channel and, correspondingly, a constant slope-discharge relationship. In this work, we apply the OCN theory to 3D problems by introducing a multi-principle minimization starting from an artificial digital elevation model of pyramidal shape. The OCN theory assumption of constant slope-area relationship is relaxed and embedded into a second-order principle. The modelled 3D channel networks achieve lower total energy expenditure corresponding to 2D sub-optimal OCNs bound to specific slope-area relationships. This is the first time we are able to explore accessible 3D OCNs starting from a general DEM. By contrasting the modelled 3D OCNs and natural river networks, we found statistical similarities of two indexes, namely the area exponent index and the profile concavity index. Among the wide range of alternative and sub-optimal river networks, a minimum degree of 3D network organization is found to guarantee the indexes values within the natural range. These networks simultaneously possess topological and topographic properties of real river networks. We found a pivotal functional link between slope-area relationship and accessible sub-optimal 2D river network paths, which suggests that geological and climate conditions producing slope-area relationships in natural basins co-determine the degree of optimality of accessible network paths.