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Long lasting dynamic disequilibrium in river basins

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The river basins of ancient landscapes such as the southeastern United States exhibit disequilibrium in the form of migrating divides and stream capture. This observation is surprising in light of the relatively short theoretical fluvial response time, which is controlled by the celerity of the erosional wave that propagates upstream the fluvial channels. The response time is believed to determine the time required for fluvial landscapes to adjust to tectonic, climatic, and base-level perturbations, and its global estimations range between 0.1 Myr and 10s Myr.

To address this discrepancy, we develop a framework for mapping continuous dynamic reorganization of natural river basins, and demonstrate the longevity of disequilibrium along the river basins in the southeastern United States that are reorganizing in response to escarpment retreat and coastal advance. The mapping of disequilibrium is based on a proxy for steady-state elevation, χ, that can be easily calculated from digital elevation models. Disequilibrium is inferred from differences in the value of χ across water divides. These differences indicate that with the present day drainage area distribution and river topology the steady-state channels elevation across the divides differs, and therefore divides are expected to migrate in the direction of the higher χ value.

We further use the landscape evolution model DAC to explore the source of the longevity of disequilibrium in fluvial landscapes. DAC solves accurately for the location of water divides, using a combination of an analytical solution for hillslopes and low-order channels together with a numerical solution for higher order channels. DAC simulations demonstrate topological, geometrical, and topographical adjustments that persist much longer than the theoretical response time, and consequently, extend the time needed to diminish disequilibrium in the landscape and to reach topological and topographical steady-state. This behavior is interpreted as resulting from a positive feedback between divide migration, which causes topological modifications and area change, on the one hand, and channel slope adjustments, which change the erosion rates on opposing sides of water divides and promote their migration, on the other hand. Furthermore, the constantly shifting drainage area and the changing topology of the drainage network are shown to be a possible source for autogenic sediment flux variations.