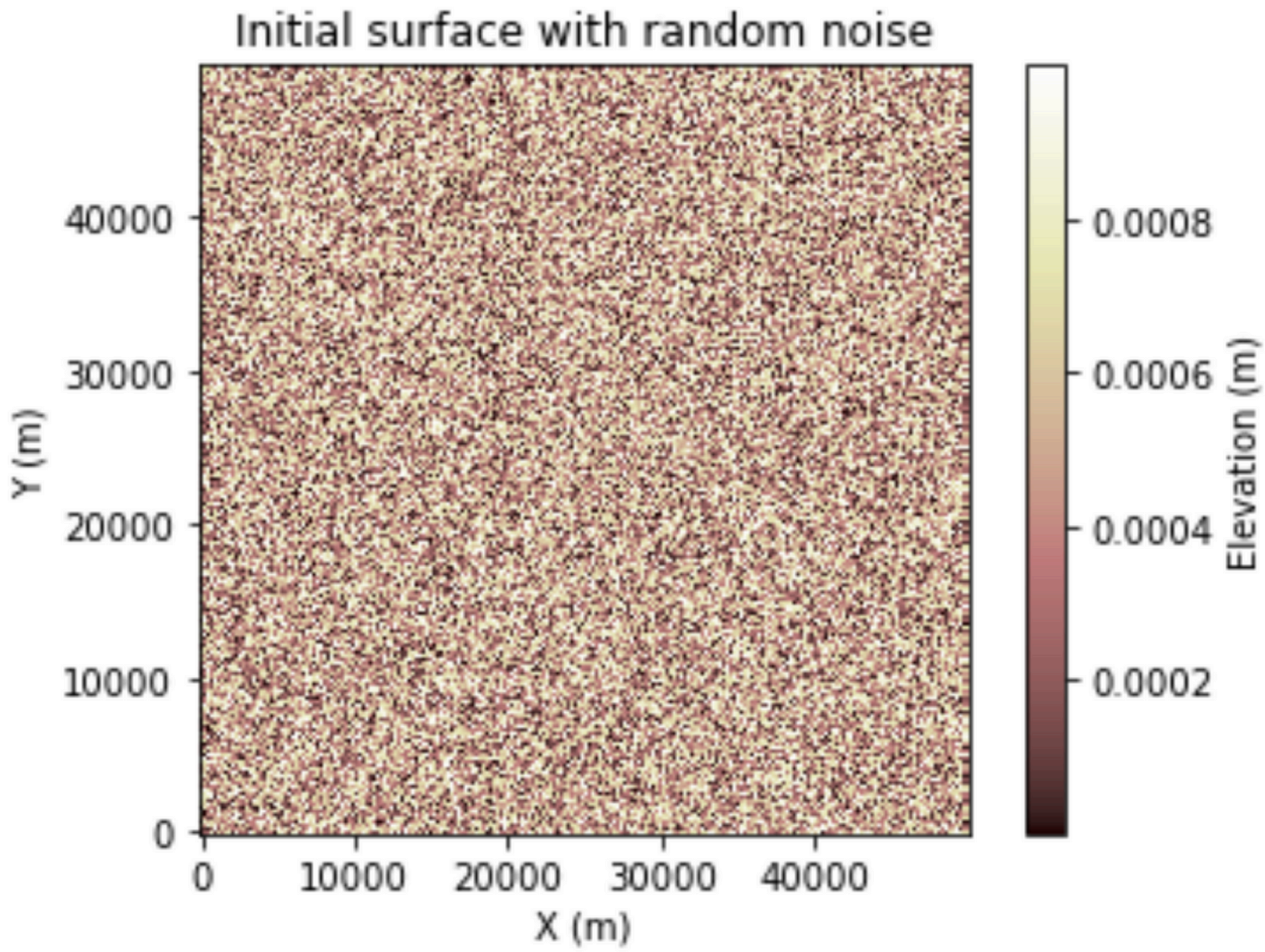
Simulation of fluvial and hillslope processes

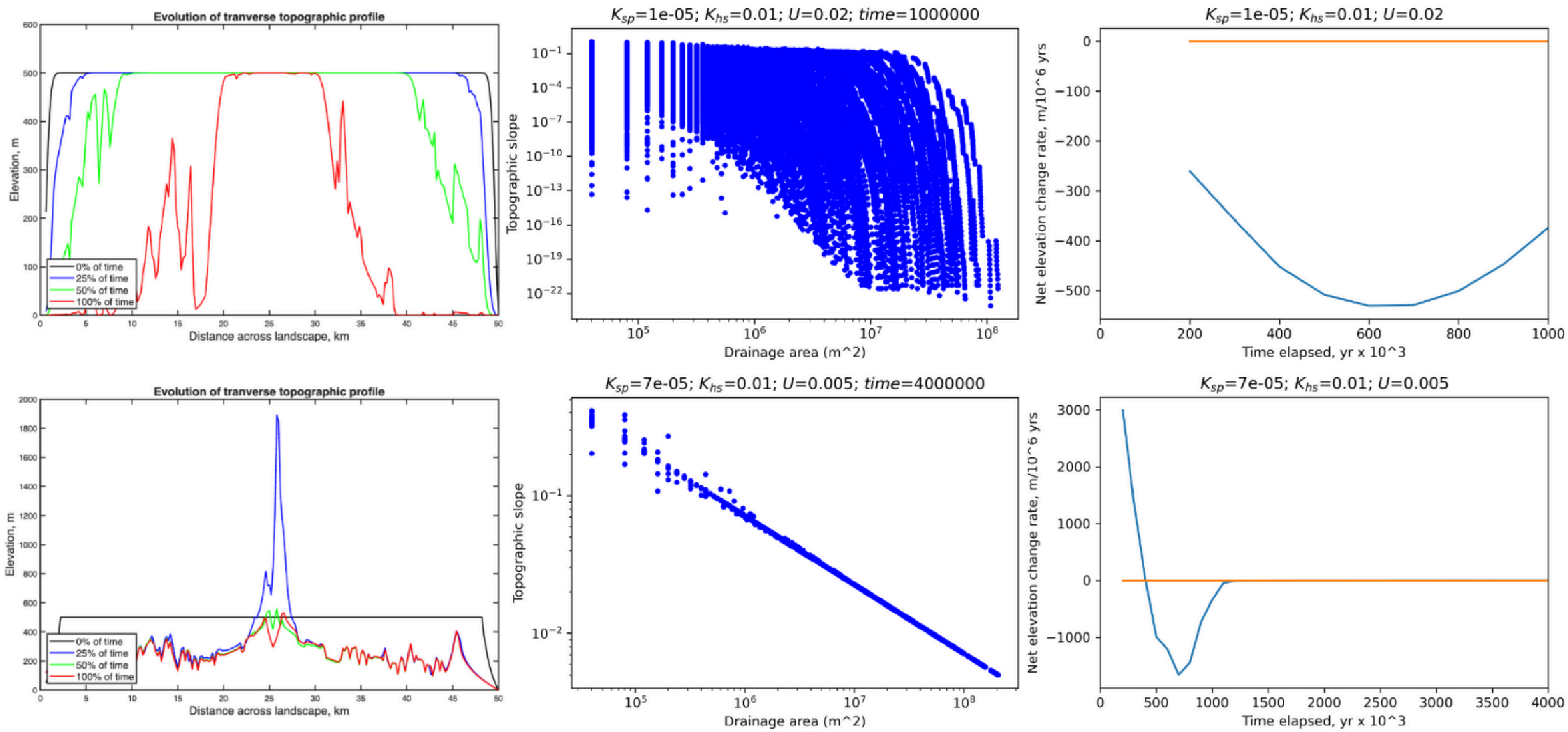
The project uses landscape evolution modelling (Landlab) to simulate how uplift, fluvial erosion, and hillslope diffusion interact to shape idealised landscapes over time. By systematically varying uplift models and rates, fluvial erodibility, and hillslope diffusivity, the study explores landscape response, transient behaviour, and steady-state morphology. The results highlight how tectonic forcing and surface processes control drainage patterns, slope-area relationships, and long-term topographic form.

Software:
Landlab, Python, MatLab

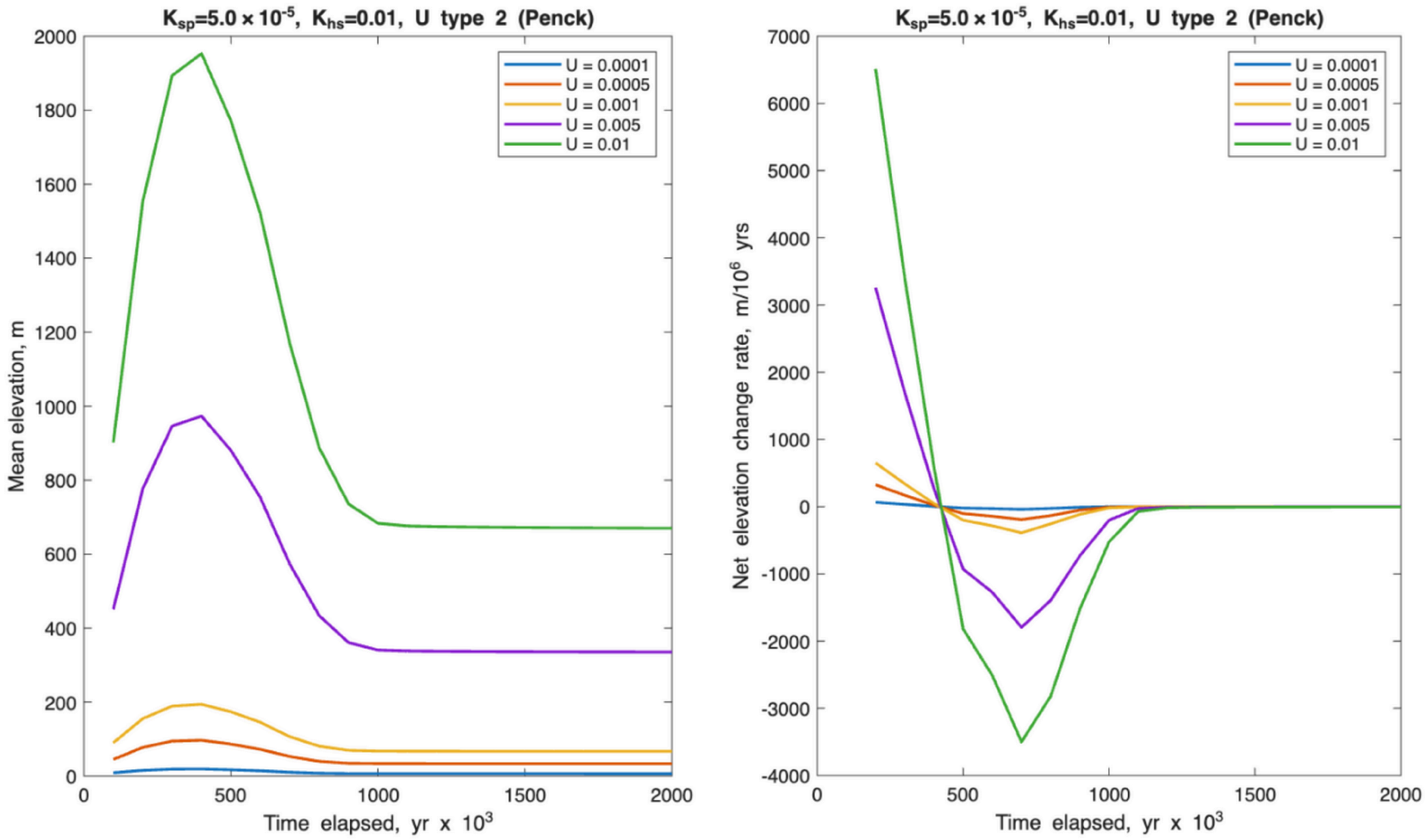
Mapping and data visualisation:



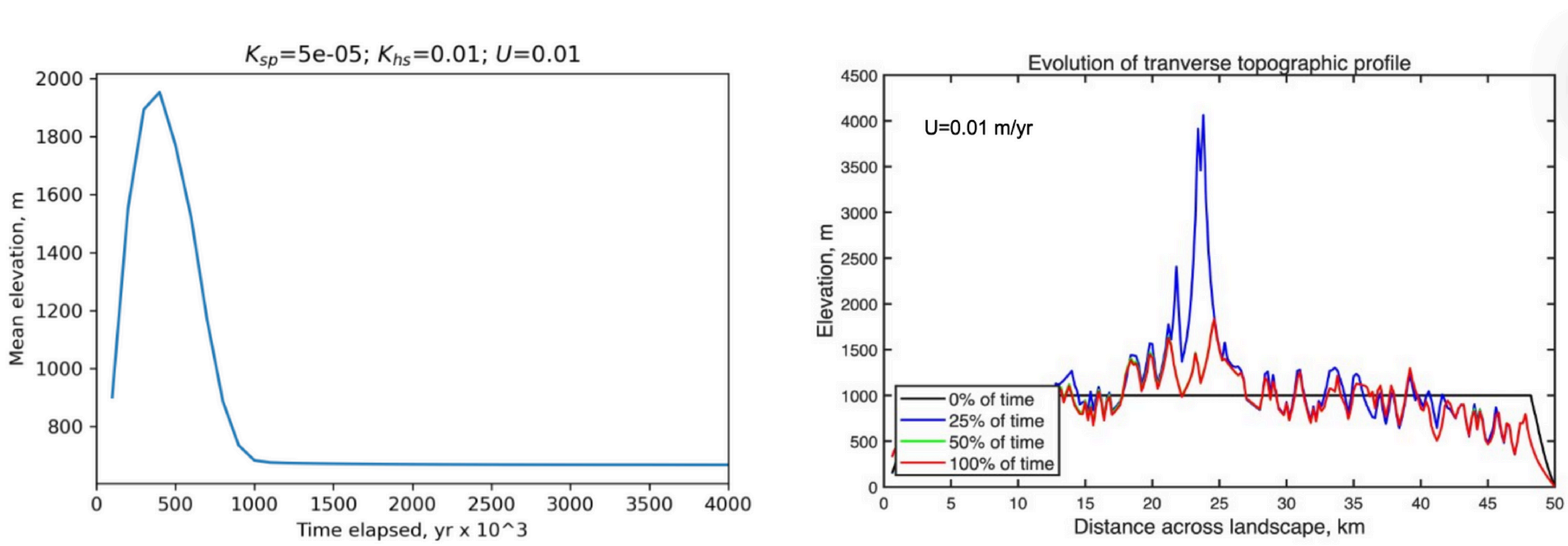
Initial model surface with random elevation noise. Initial condition for the landscape evolution simulations, consisting of a uniform surface perturbed by low-amplitude random noise to seed drainage development.



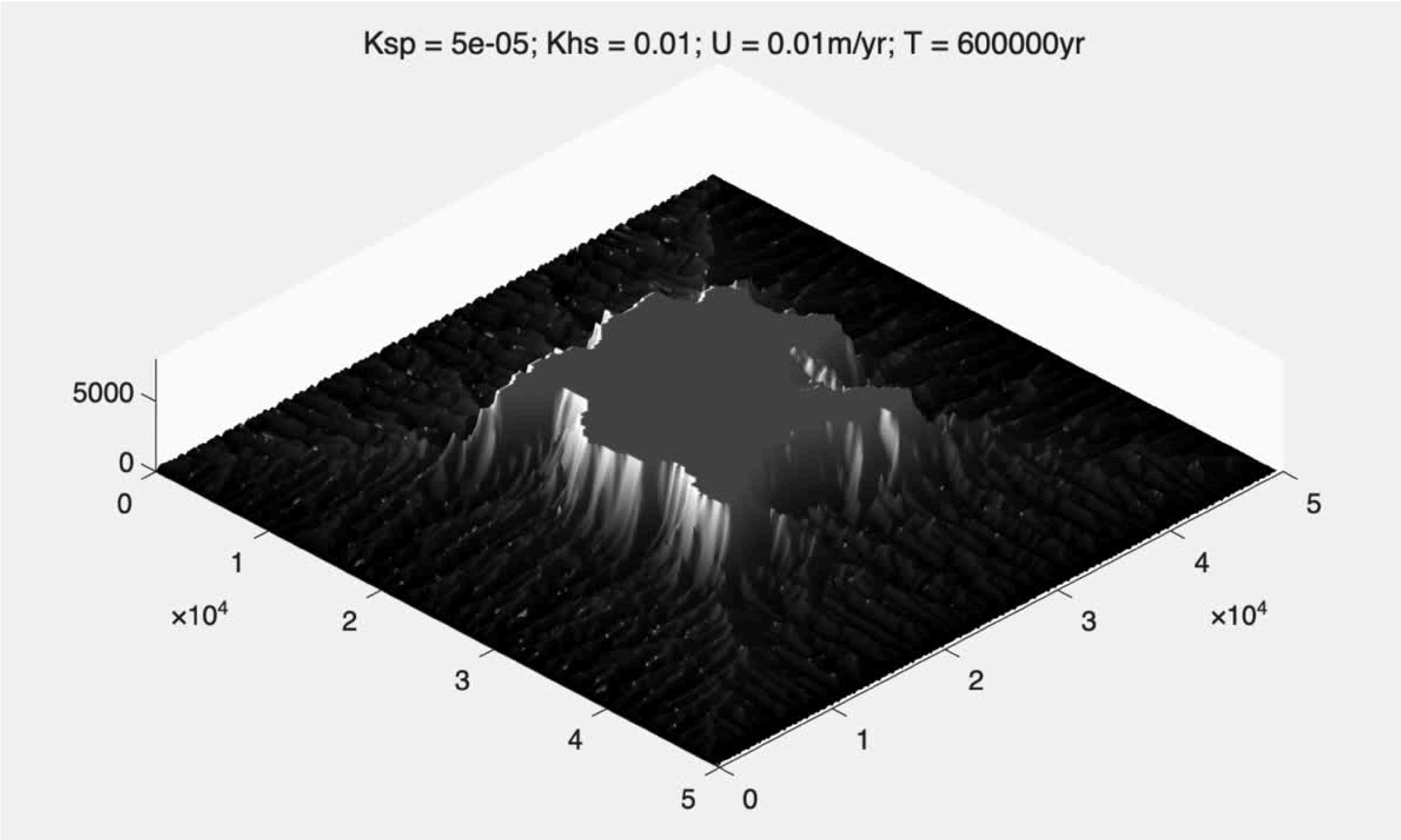
Comparing two uplift models, Davis (top row) and Penck (bottom row), using a landscape evolution model. Resulting outputs include the evolution of transverse topographic profiles through time, slope-drainage-area relationships, and net elevation change, illustrating contrasting transient landscape responses under different uplift histories.



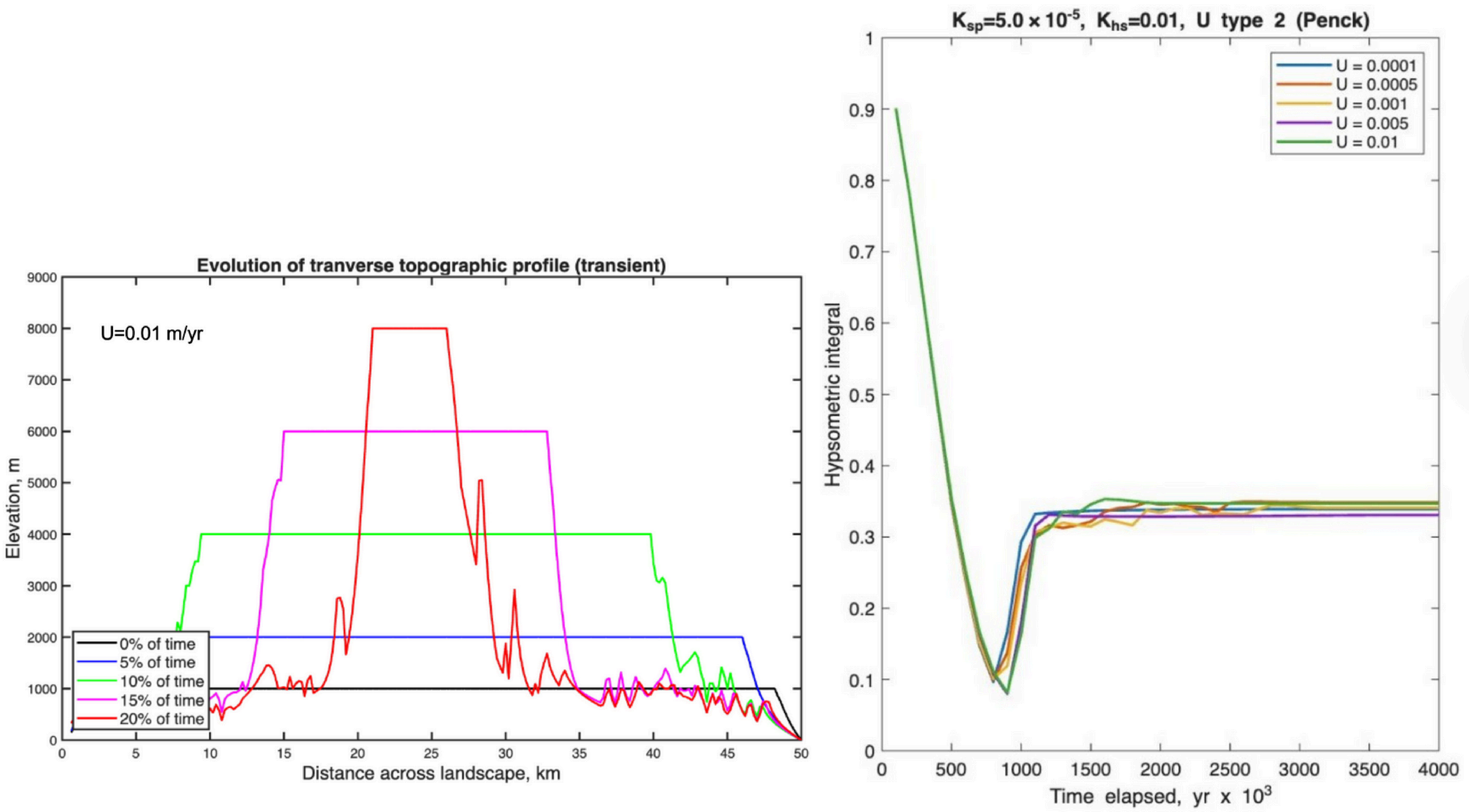
Effect of uplift rate on landscape evolution. Mean elevation over time (left) and net elevation change rate (right), higher uplift producing greater transient relief but converging towards steady state.



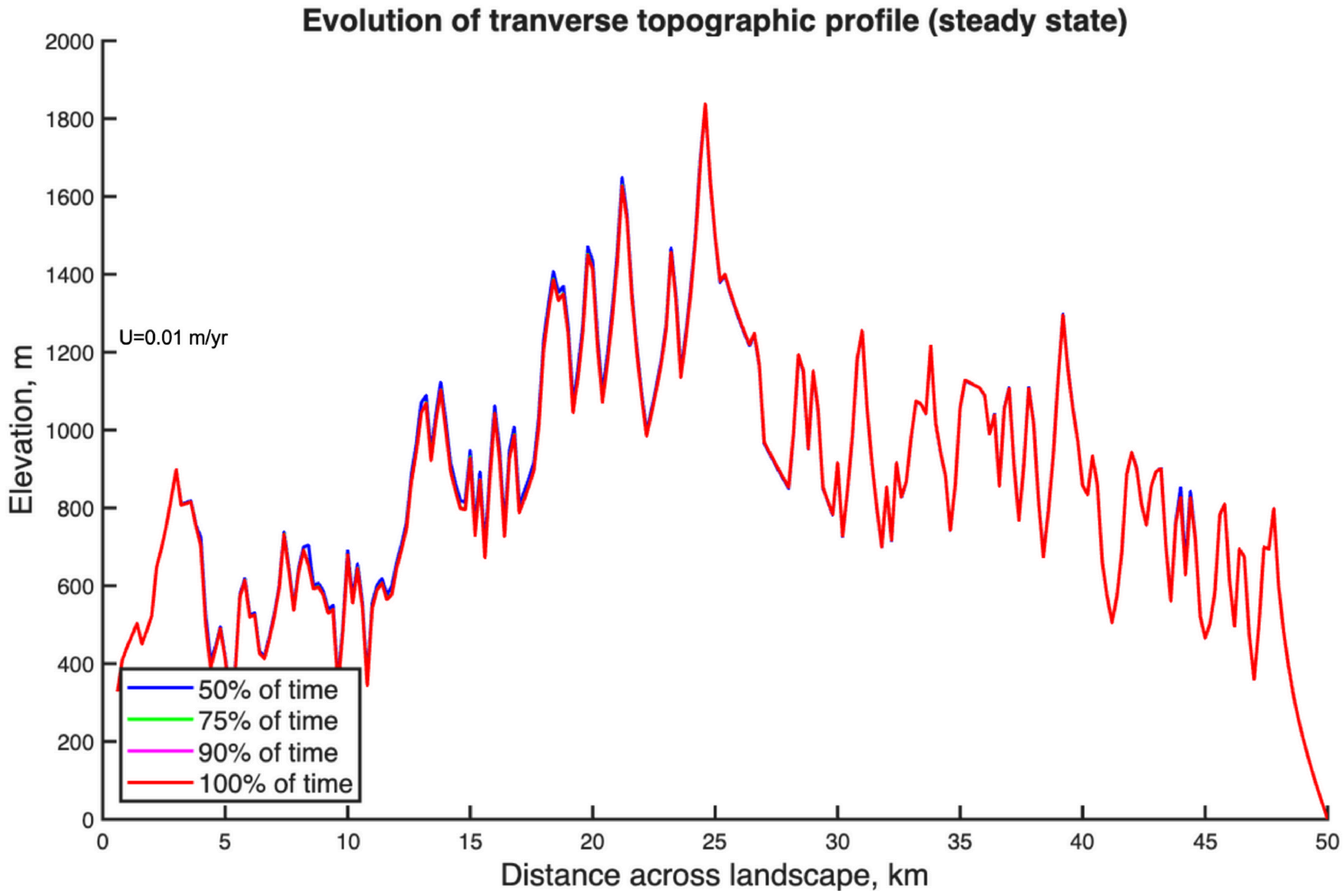
Mean elevation through time (left) and the evolution of transverse topographic profiles (right) show a strong transient response followed by adjustment towards steady state.



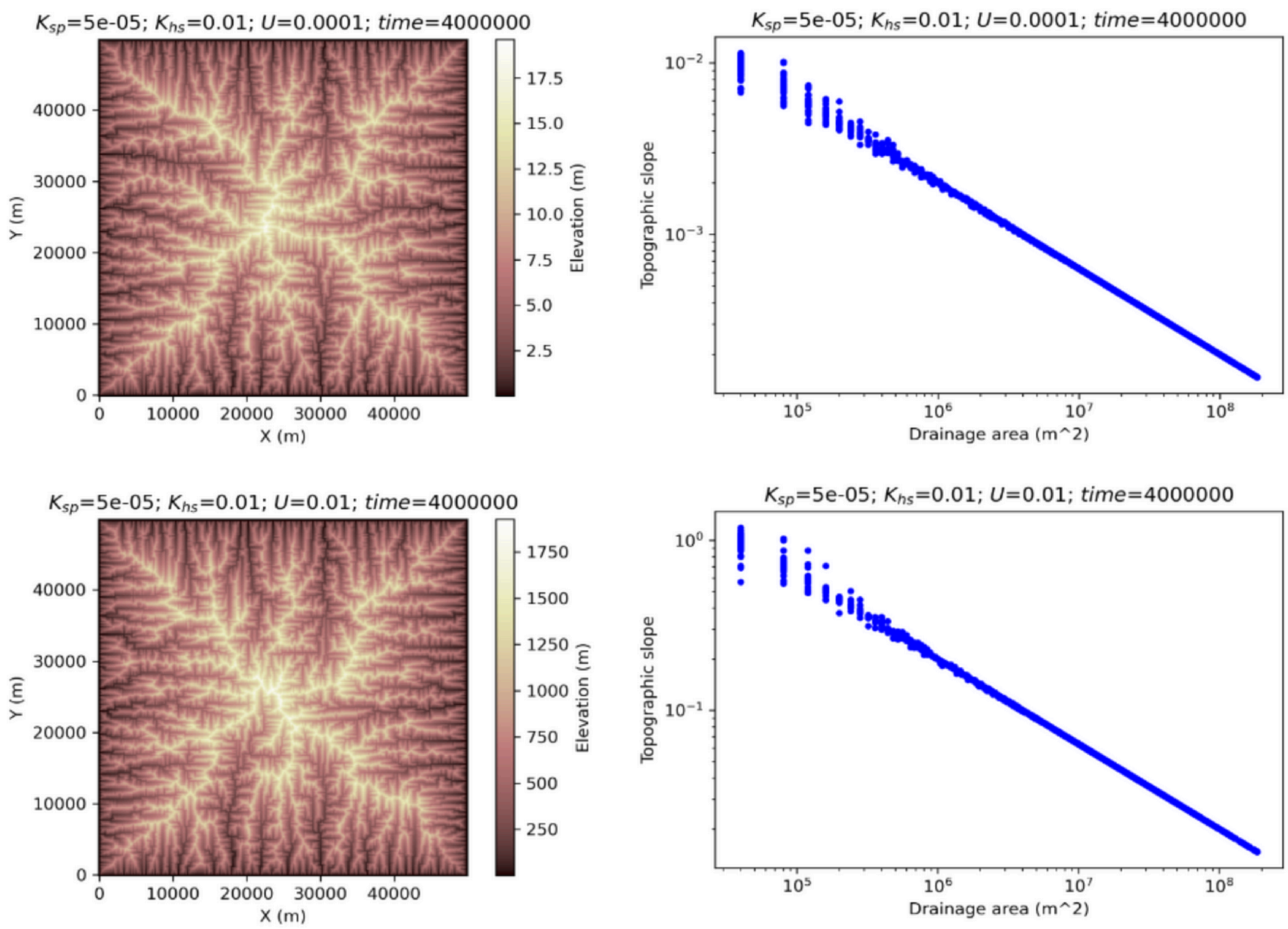
Time-evolving landscape simulation illustrating the interaction between fluvial incision and hillslope diffusion under uniform uplift, demonstrating drainage network development and hillslope smoothing within the landscape evolution model. Video available here.



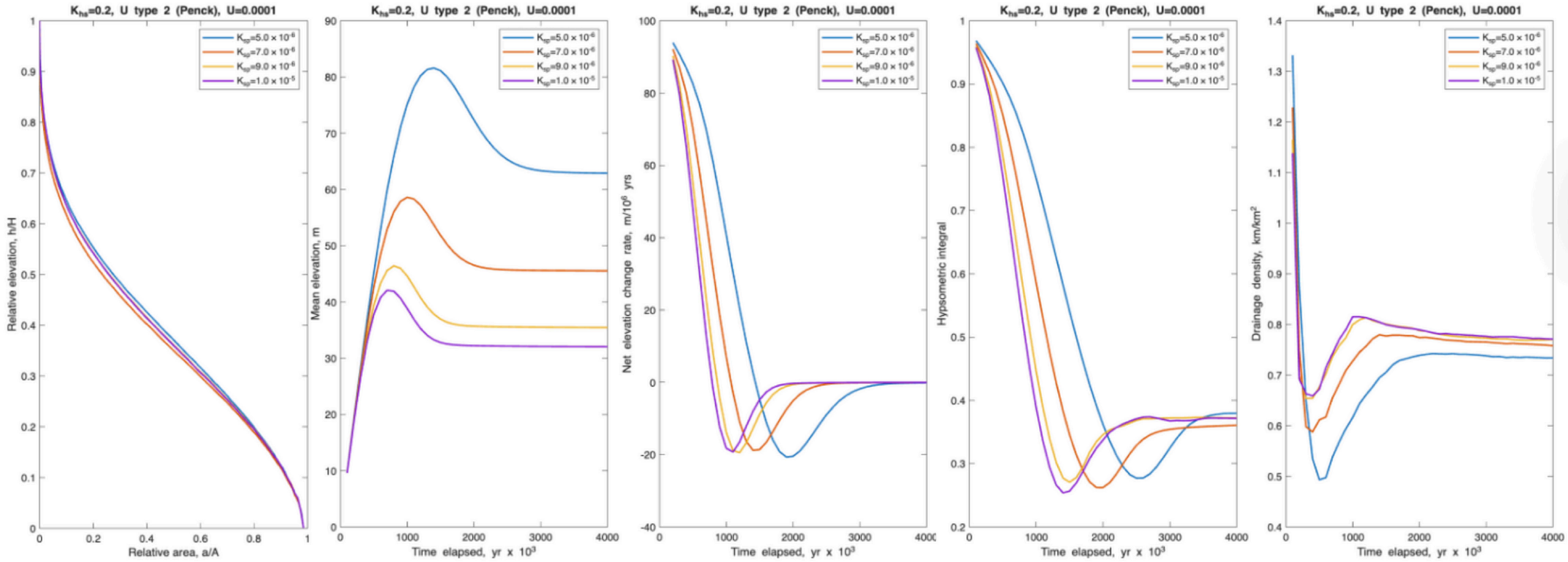
Transient landscape response under the Penck uplift model. The evolution of transverse topographic profiles through time (left) illustrates rapid relief growth and subsequent adjustment, while changes in the hypsometric integral (right) show a transition from strongly convex to more equilibrated landscape forms as steady state is approached.



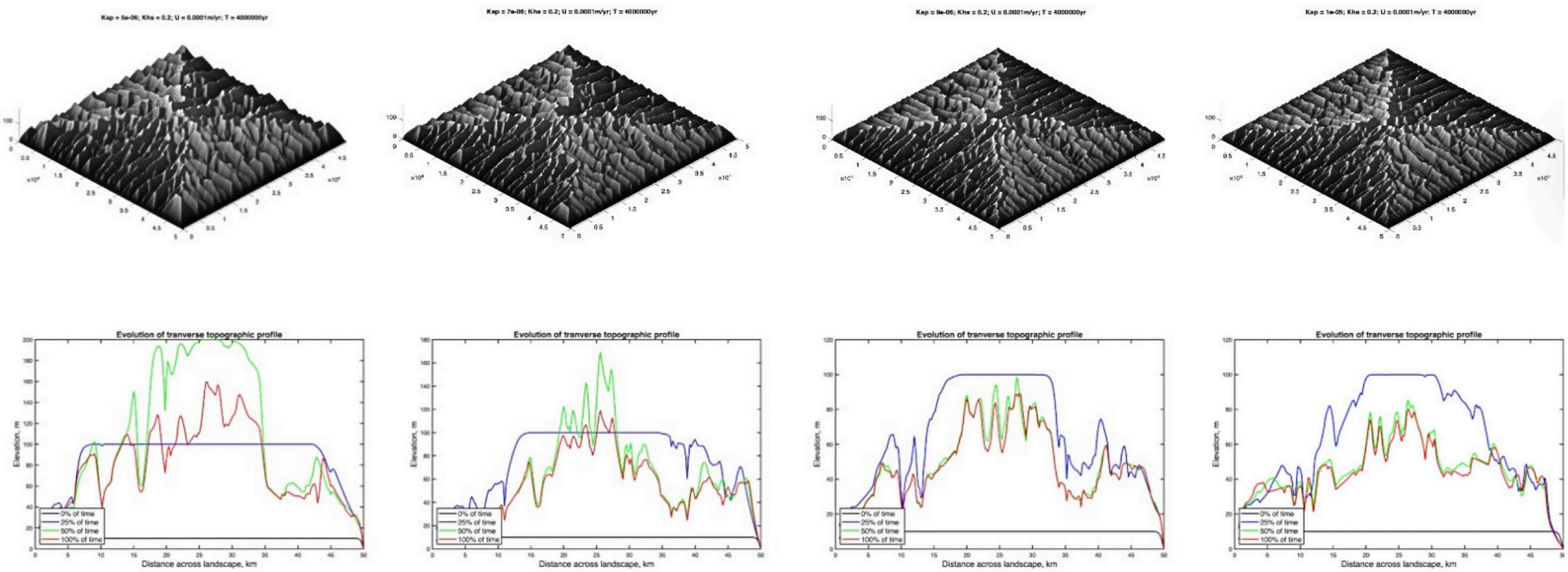
Steady-state transverse topographic profiles. Profiles extracted at late model times (50–100% of total run time) largely overlap, indicating that the landscape has reached a stable equilibrium form.



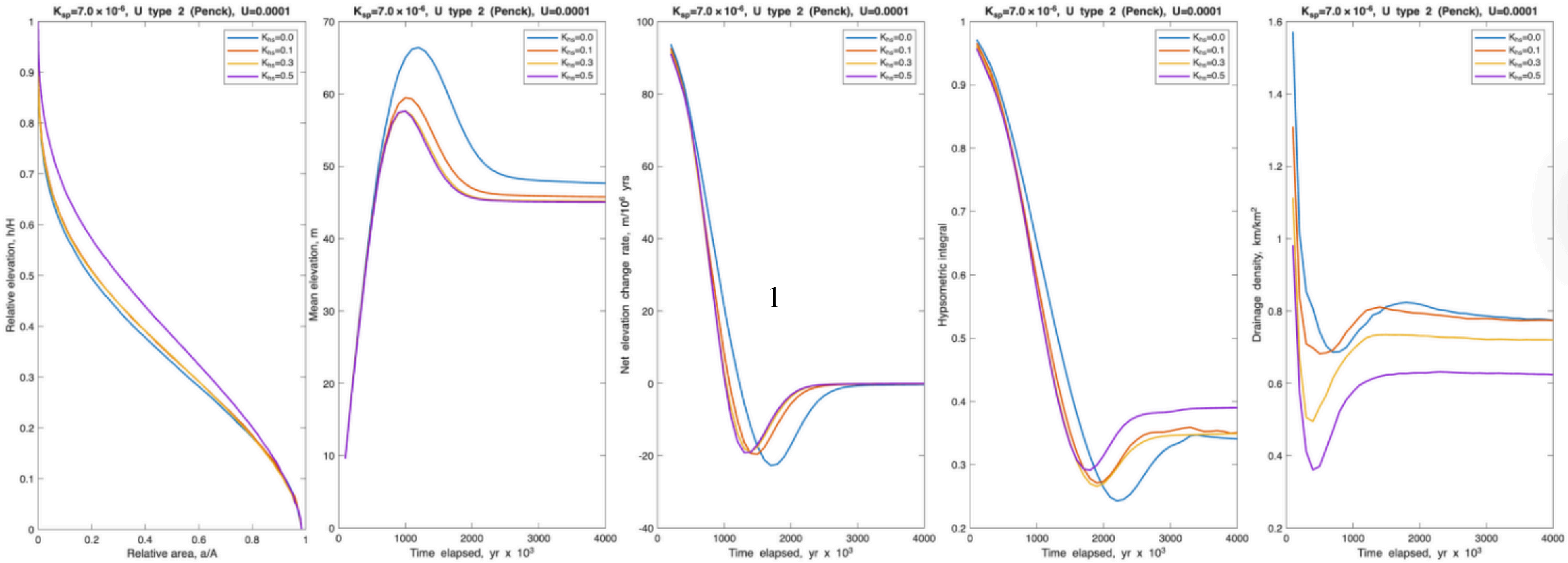
Comparison of steady-state landscapes formed under low (U = 0.0001 m yr^{-1}) and high (U = 0.01 m yr^{-1}) uplift rates with identical fluvial and hillslope parameters. Despite large differences in absolute elevation, both landscapes exhibit similar drainage network structure and slope-area scaling, indicating scale-invariant landscape organisation.



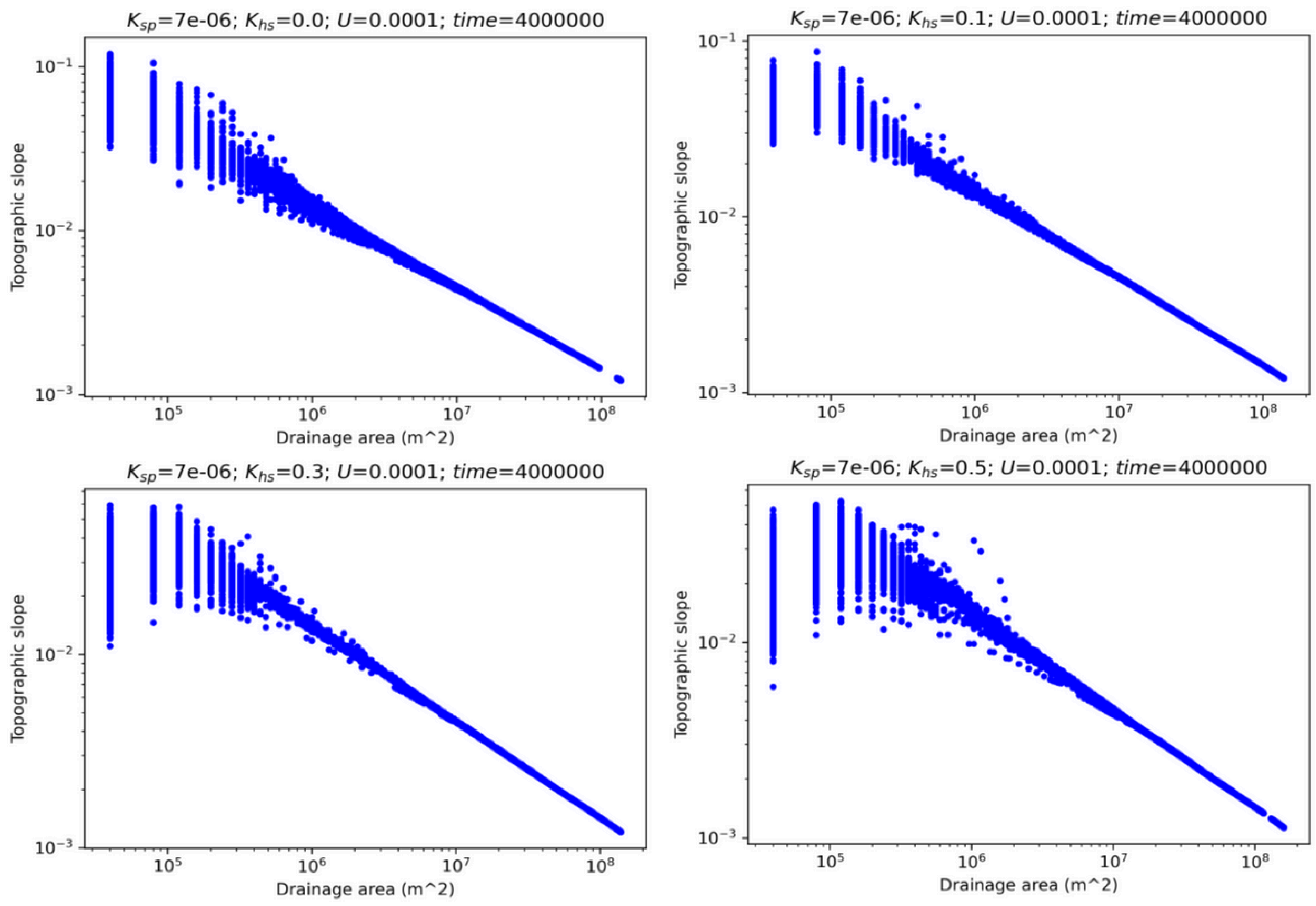
Sensitivity of landscape evolution metrics to stream-power incision efficiency (KspK_{sp}Ksp) under Penck uplift ($U = 0.0001$ m yr^{-1}, Khs=0.2K_{hs}=0.2Khs=0.2). Variations in KspK_{sp}Ksp strongly influence mean elevation, net elevation change rate, hypsometric integral, and drainage density through time, while relative elevation-area relationships remain broadly similar across runs.



Three-dimensional steady-state topography (top row) and corresponding transverse topographic profile evolution (bottom row) for contrasting process parameterisations under Penck uplift. Variations in incision and hillslope diffusion produce distinct landscape morphologies and profile shapes, despite similar boundary conditions and uplift histories.

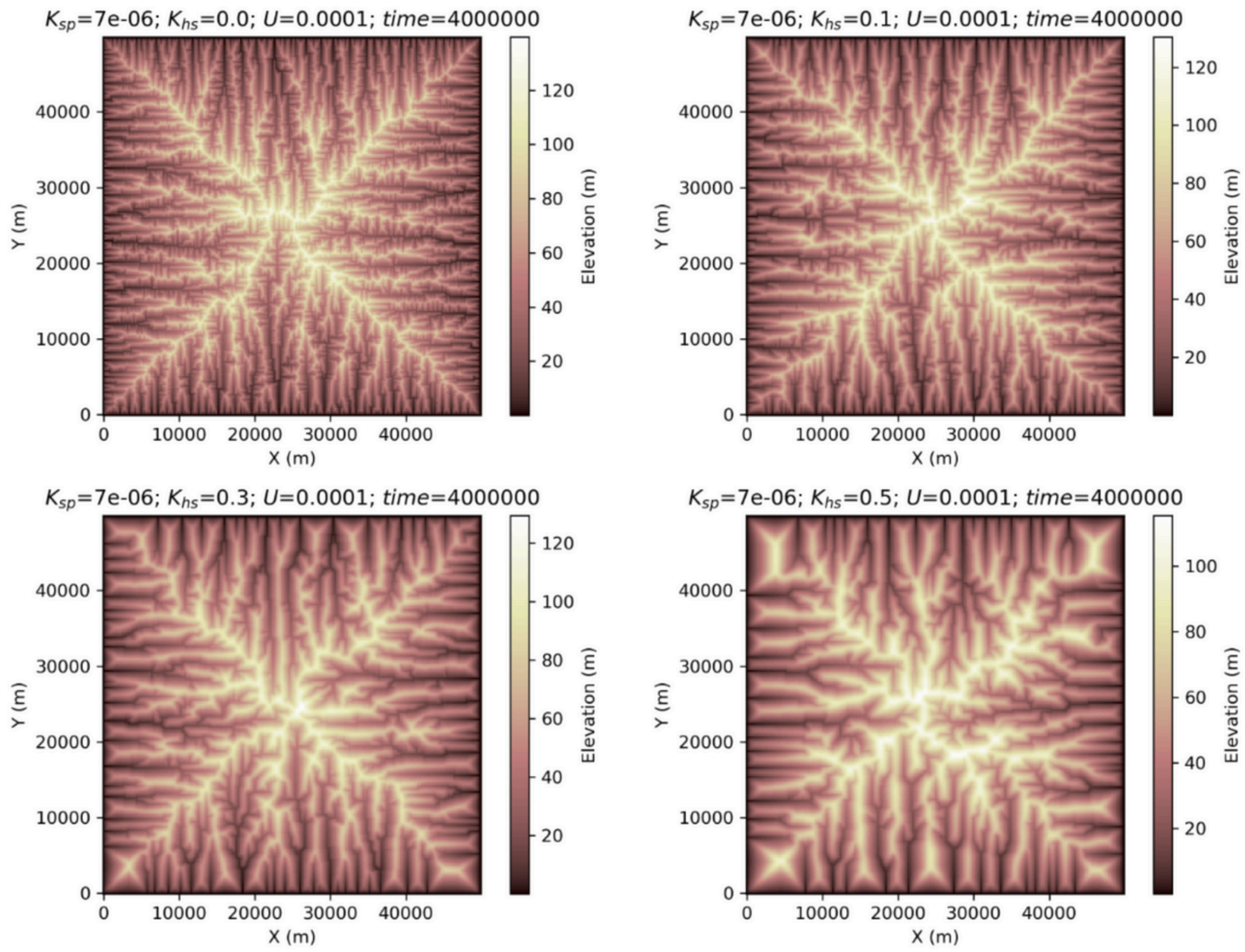


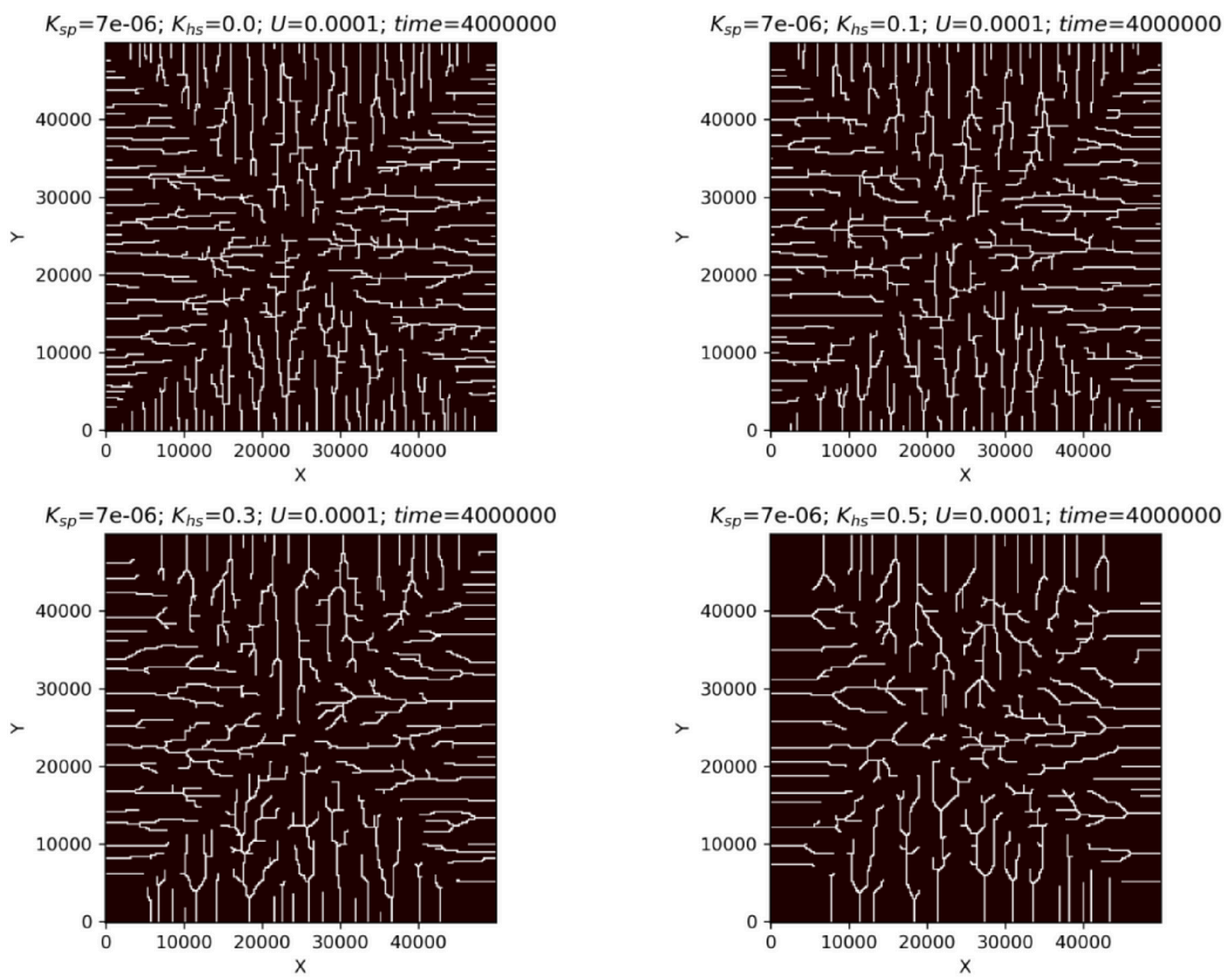
Sensitivity of landscape evolution to hillslope diffusivity (KhsK_{hs}Khs) under Penck uplift (U = 0.0001 m yr^{-1}). Increasing KhsK_{hs}Khs enhances hillslope smoothing, reducing relief, lowering drainage density, and moderating transient responses while preserving overall hypsometric form.



Slope-area relationships at steady state for increasing hillslope diffusivity (KhsK_{hs}Khs) under constant Penck uplift. Increasing KhsK_{hs}Khs introduces greater scatter at low drainage areas and suppresses hillslope slopes, while the large-area fluvial scaling remains largely unchanged.

Steady-state topography for increasing hillslope diffusivity (KhsK_{hs}Khs) under constant Penck uplift. As KhsK_{hs}Khs increases, landscapes become progressively smoother, with reduced relief and less well-defined channel networks, reflecting enhanced diffusive hillslope transport.





Extracted drainage networks at steady state for increasing hillslope diffusivity (KhsK_{hs}Khs) under constant Penck uplift. Higher KhsK_{hs}Khs values reduce drainage density and suppress fine-scale channel development, producing simpler and less connected channel networks.