Topographic evolution and climate aridification during continental collision: insights from numerical modeling

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What is the relative importance of tectonics, sediment transport and climate in shaping the topographic evolution of the Earth? And how much does the erosion and sedimentation at the crust's surface influence the distribution of tectonic deformation? During the last three decades, these questions have been often addressed via numerical models constrained with thermochronological and geomorphological data at scales ranging from local to orogenic.

Here we present a new numerical model that aims at reproducing these phenomena at the continental scale (Fig. 1). For this purpose, we couple in a single computer model: 1) a thin-sheet viscous model of continental deformation; 2) a stream-power surface transport approach; 3) flexural isostasy allowing for the formation of large sedimentary foreland basins; and 4) a orographic precipitation model that reproduces basic climatic effects such as continentality and rain shadow.

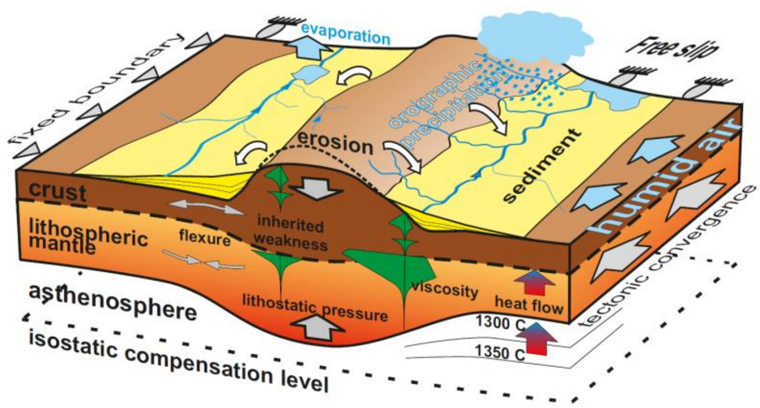

Figure 1. Conceptual cartoon with the processes integrated in the model. River erosion and sediment transport is calculated using a stream power approach and allowing the water follow the maximum slope. Evaporation is explicitly accounted for in lakes. The horizontal tectonic velocity is predefined at the boundaries. The viscosity of the lithospheric layer is dependent on the thermal regime and lithological parameters. The thickness of crustal and mantle varies according to the accommodation of the boundary velocities, depending on the viscosity distribution.

We quantify the feedbacks between these 4 processes in a synthetic scenario inspired by the India-Asia collision. The model reproduces first-order characteristics of the growth of the Tibetan Plateau as a result of the Indian indentation. A large endorheic, intramountain basin representing the Tarim Basin develops when predefining a hard inherited area in the undeformed foreland (Asia). The amount of sediment trapped in this basin is very sensitive to climatic parameters, particularly to evaporation, because it crucially determines its endorheic/exorheic drainage. We identify some degree of feedback between the deep and the surface processes, leading locally to a <50% increase in deformation rates in places where orographic precipitation is concentrated. This climatically-enhanced thickening of the crust takes place in areas of concentrated precipitation and steep slope as at the upwind flank of the growing plateau and the corners of the indenter (syntaxes). We hypothesize that this may provide clues for better understanding the mechanisms underlying the intriguing tectonic aneurisms documented in the Himalayas. In the continental scale, however, the overall distribution of topographic ranges and basins seems insensitive to climatic factors, despite these do have important, sometimes counterintuitive effects on the amount of sediments trapped within the continent. The dry climatic conditions that naturally develop in the interior of the continent, for example, are key in triggering large intra-continental basins and sediment trapping. Finally, the complex surface-tectonic interactions identified make the development of steady-state topography at the continental scale unlikely.

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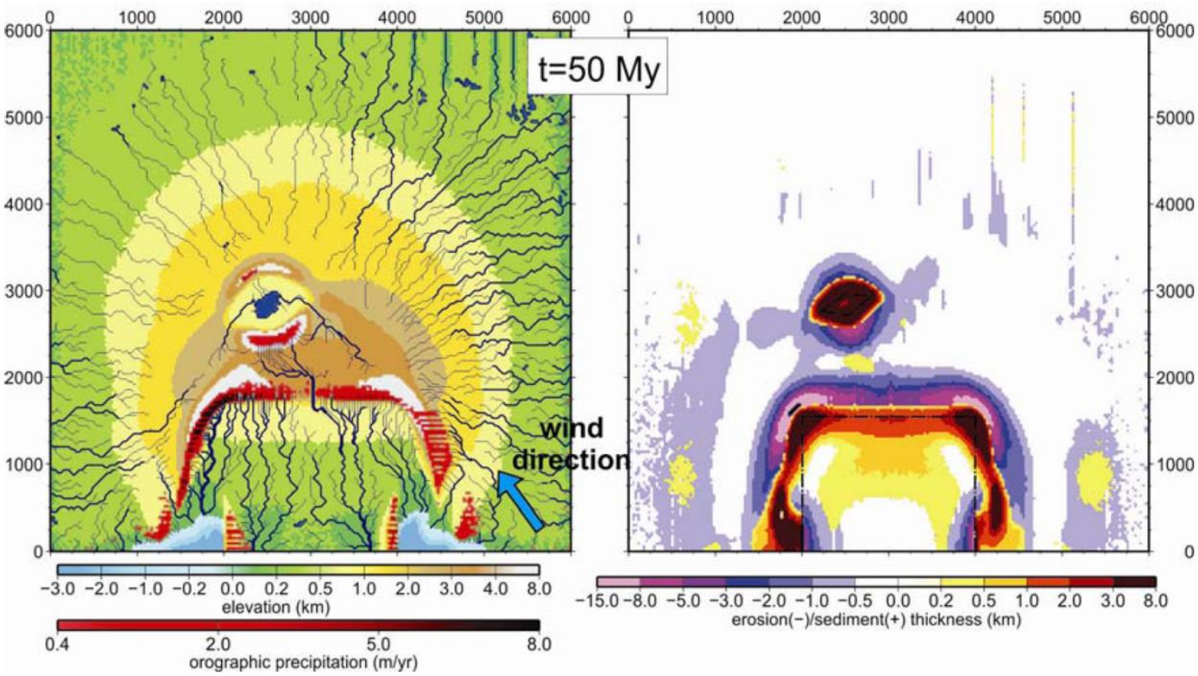

Figure 2. Final topography, precipitation, drainage (left panel), and erosion and sediment distribution (right panel) resulting from orographic precipitation and NW wind direction.