Response to comments from Anonymous Referee #1

The manuscript is well-organized, clearly written, and presents a rigorous investigation into how landscapes respond to tectonic and climatic forcing, with a focus on slope evolution at river headwaters. Using the Badlands landscape evolution model, the authors demonstrate that changes in rainfall rate, unlike uplift rate changes, can induce transient slope change reversals near drainage divides, a process strongly modulated by hillslope diffusion. This insight offers a novel perspective on differentiating between climatic and tectonic controls in geomorphic systems. The experimental design is systematic, the interpretation is robust, and the study is presented in fluent and technically precise language. The work makes a valuable contribution to Earth surface process research and is suitable for publication with minor revisions. To further improve the clarity and scientific strength of the paper, the following suggestions are offered:

1. The authors argue that the transient slope change reversals are driven by differential erosion rates between the divide and adjacent areas. It is recommended to elaborate on why changes in rainfall rate lead to this contrast, while changes in uplift do not. What are the respective roles of hillslope diffusion and river incision in generating or amplifying these differences? A more detailed mechanistic discussion would strengthen the internal logic of the manuscript.

Thank you for this excellent suggestion. We agree that a more detailed mechanistic discussion was needed to strengthen the manuscript's logic. To address this, we have significantly expanded the discussion in the new **Section 4.1 Mechanism of transient slope change reversal**. The revised text now elaborates on why rainfall and uplift changes produce different responses by detailing the temporal mismatch between river incision and hillslope diffusion at the headwaters.

We have added the following text to Section 4.1:

The transient slope change reversal arises from a lag between two characteristic timescales: the hillslope response time and the channel incision response time. Following a change in rainfall, the river incision rate adjusts almost instantaneously. However, hillslope response lags behind channel response (Clubb et al., 2019). Hillslope diffusion, which controls sediment transport from divides to channels, is driven primarily by slope and remains initially unchanged. Near drainage divides, the river incision is weak and hillslope diffusion dominates (Dietrich et al., 2003). The temporal mismatch creates the observed imbalance at the headwaters. For instance, following a decrease in rainfall rate, sediment continues to diffuse toward the channel at pre-disturbance rates, but the ability of the channel to transport sediment is reduced due to lower discharge (Mitchell, 2020; Montgomery et al., 2000). This imbalance causes the rate of sediment supply from hillslopes at the headwaters to exceed the rate of sediment removal by rivers, reducing channel slope temporarily and causing a transient slope change reversal. As the channel adjusts and the erosion wave migrates upstream, this reversal gradually disappears.

In contrast, a change in uplift rate uniformly raises the entire landscape without immediately affecting the efficiency of diffusion and incision. Because both the divide and its adjacent areas experience similar erosion conditions under constant discharge, no transient slope reversal occurs.

Notably, a lower Pe amplifies the imbalance between sediment supply from hillslopes and removal by rivers. This enlarges the zone where divide erosion rates differ from downstream areas. Therefore, the transient slope change reversal persists over a longer channel segment and for a longer duration, as observed in model M3 (Fig. 6 c2 and c3). In contrast, increasing Pe enhances river incision, which reduces the relative influence of diffusion. This leads to a shorter channel segment experiencing transient slope change reversal and a shorter duration of the transient response in model M4 (Fig. 6 d2 and d3).

2. Since the authors mention that slope-area and chi analysis can help identify transient slope change reversals, it is recommended to include representative plots from the numerical models. These visualizations would help illustrate how such plots reveal the geomorphic response to climatic or tectonic perturbations.

Thank you for this valuable suggestion. We have added a figure and the following text to Section 4.2:

In our models, a decrease in rainfall rate produces a localized flattening at high χ (headwaters), directly reflecting the transient slope-change reversal (Fig. 9). By contrast, in uplift-driven transients the χ–elevation profile bows downward at low χ, while the high-χ (headwater) segment remains straight and is simply translated upward. However, χ–elevation analysis has limitations: it requires a steady-state baseline profile to distinguish different types of disturbances. χ–elevation is therefore best used in concert with additional information, such as independent erosion-rate measurements, to robustly identify and attribute transient slope-change reversals.

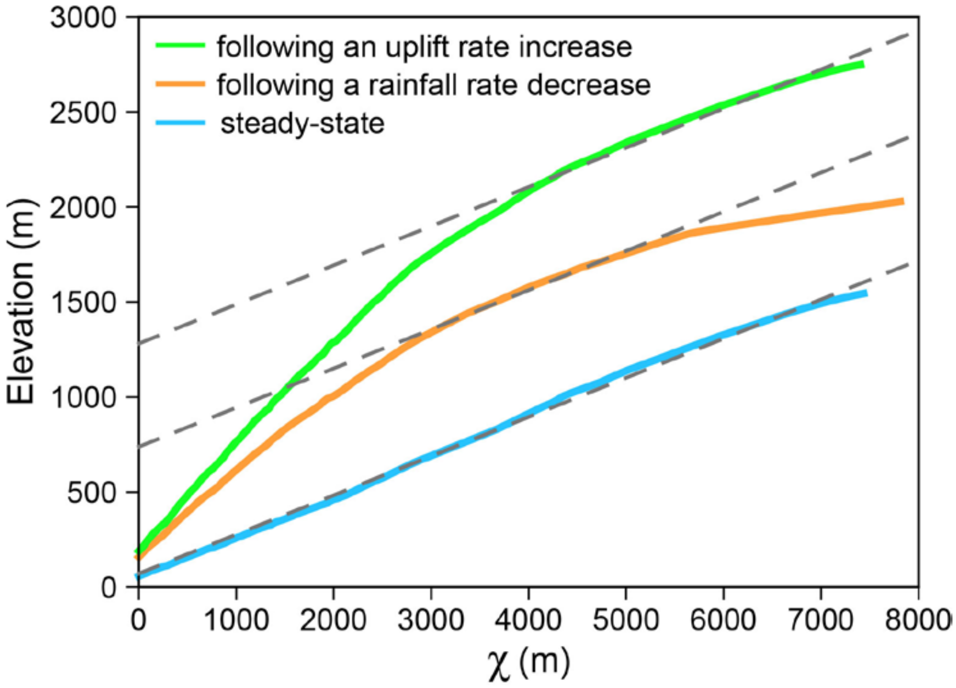

Figure 9. χ–elevation profiles of trunk streams in model M3 under three conditions: following an uplift rate increase (green), following a rainfall rate decrease (orange), and steady-state (light blue). The three gray dashed lines are parallel reference trends. χ–elevation profiles are calculated using a reference concavity index (θ_{ref}) of 0.4.

3. The manuscript suggests that erosion rate patterns near drainage divides, measurable through cosmogenic nuclides, may help distinguish between climatic and tectonic forcing. Including a brief geological example would help bridge the model findings with field-based applications and strengthen the practical relevance of the study.

Thank you for this great suggestion. We agree that a geological example would strengthen the practical relevance of our findings. Obtaining erosion patterns near drainage divides requires cosmogenic nuclide measurements at high spatial resolution across the divide zone. However, current studies focus on basin-averaged erosion rates with sparse sampling that cannot capture the spatial variation in erosion rates near divides that our model predicts. Our literature review confirmed that existing datasets lack the necessary spatial resolution to test our model predictions. This represents an important research gap that our study helps to identify. Perhaps, our paper will prompt experts to test our model.

4. In the methodology section, it is recommended that the authors clearly list all model parameters used, including the values of m and n in the stream power incision equation. Additionally, the initial condition is described as a uniform elevation of 10 meters; however, the landscape at the end of the first stage appears asymmetric. If any initial perturbation or

topographic noise was introduced to generate this asymmetry, it should be explicitly stated and justified in the methods section.

Thank you for this valuable suggestion. We have added a sentence stating that m = 0.5 and n = 1.0. We started with a perfectly flat 40 km × 80 km grid at 10 m elevation (400 m × 400 m cells). Badlands converts that grid into a triangular irregular network (TIN), which is asymmetric. Because erosion and diffusive transport in Badlands operate along those triangle edges (and depend on their length and slope), the tiny asymmetry of the TIN grows over time, yielding the slightly asymmetric topography at the end of Stage 1. We have verified that the asymmetry does not influence the conclusion.

5. Technical Corrections

Figure 4(a): The labels for 25 Ma and 26 Ma are reversed in the figure legend.

Thank you for catching this. We have corrected the time labels in the figure legend of Figure 4(a).

References

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