River channel lateral migration and strath terrace evolution: Quantitative predictions using a new bank coupling approach

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Motivation

Terrace formation and abandonment is commonly interpreted to record a pulse of vertical river incision due to changes in climate, tectonic uplift, or base level [1,2]. However, the ability of channel migration to alter the terrace record through eroding terraces or forming new terraces under steady vertical incision has not been explored quantitatively. Moreover, few tools currently exist to distinguish terraces that record such intrinsic stream dynamics [3] from those that record events with significance for the geologic record.

Methods

We adapted a numerical model [4] to map the trajectory of a laterally migrating and vertically incising channel. Width and depth are held constant, and the channel erodes bedrock to the bed elevation as it migrates laterally. All plots show the resultant topography, under the assumption that the channel maintains its width by depositing sediment on the trailing bank. In keeping with previous studies, topography is stored with a grid.

Modeling terrace geometry without bank feedbacks

Natural river valleys show a continuum of terrace geometries. In general, it appears that rivers with higher ratios of lateral to vertical erosion rate generate more wider and more numerous terraces (in green). We have run numerical experiments using the estimated average lateral and vertical erosion rates at the field sites in Figures 1-3 to qualitatively assess the the ability of the preliminary model, with no bank feedbacks, to reproduce terrace geometry.

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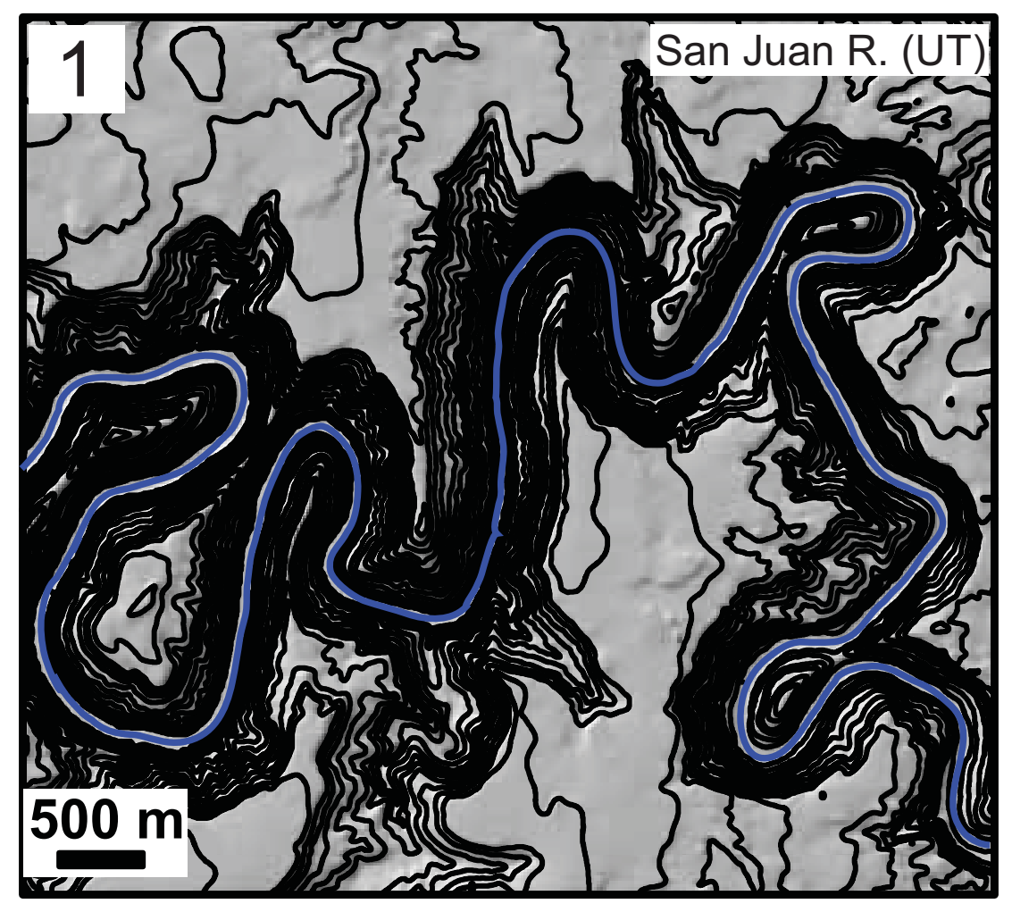

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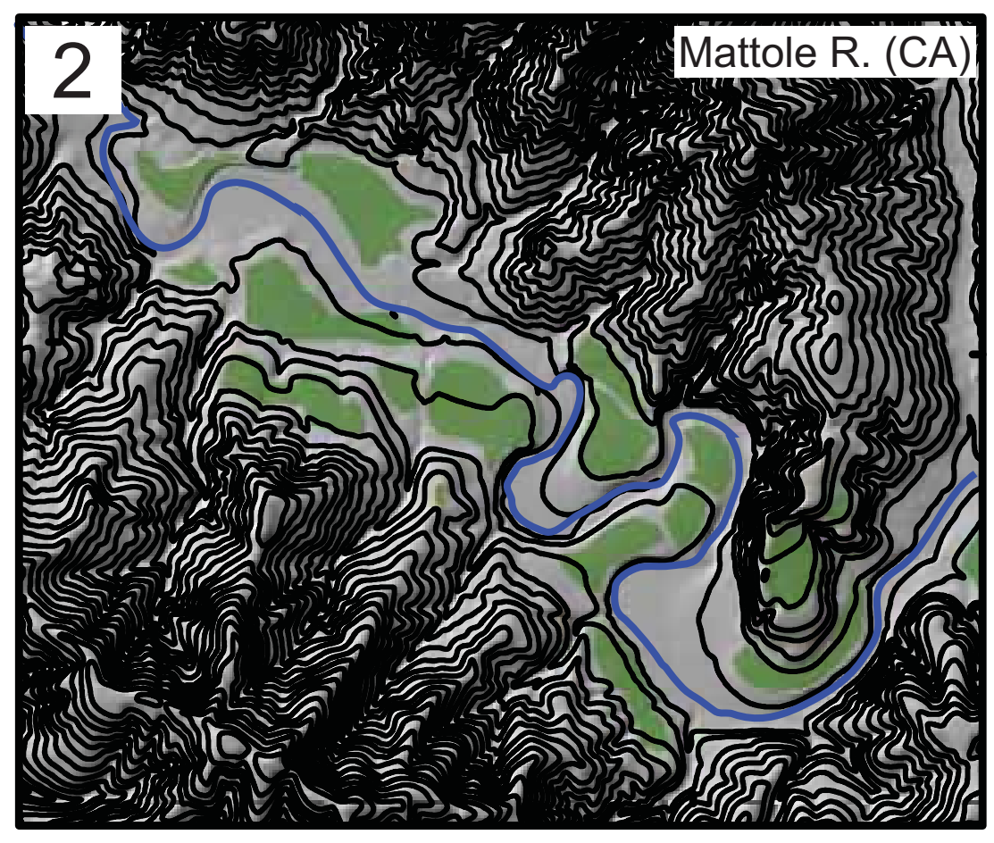

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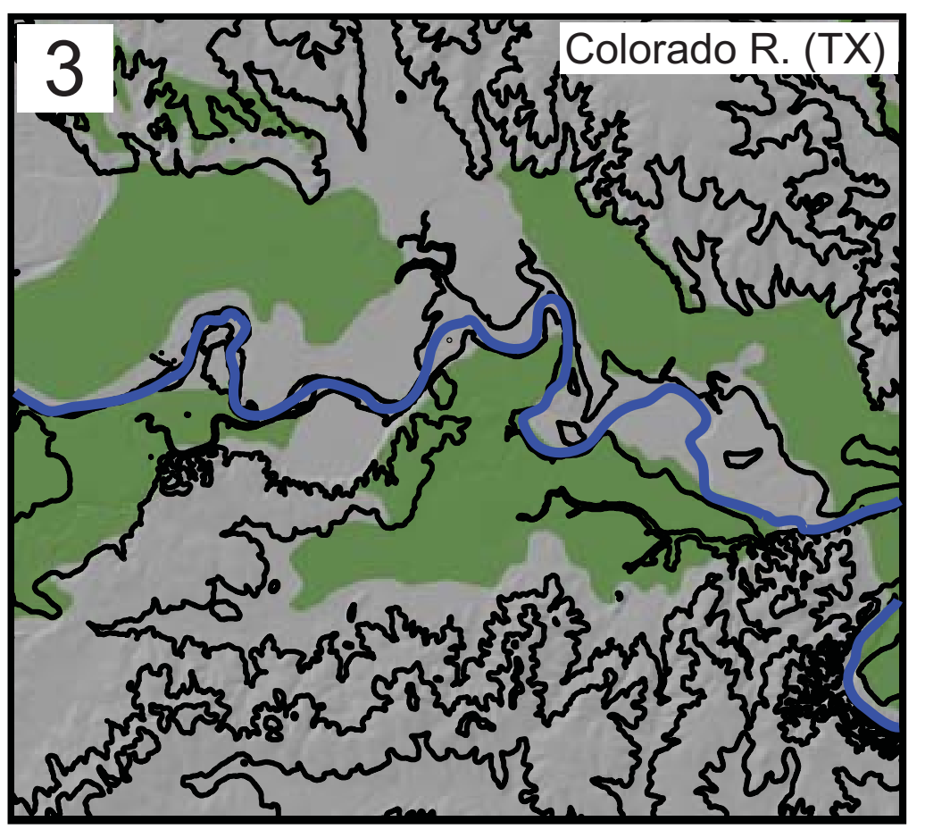

Low ← $\frac{\text{Lateral erosion rate}}{\text{Vertical erosion rate}}$ → High

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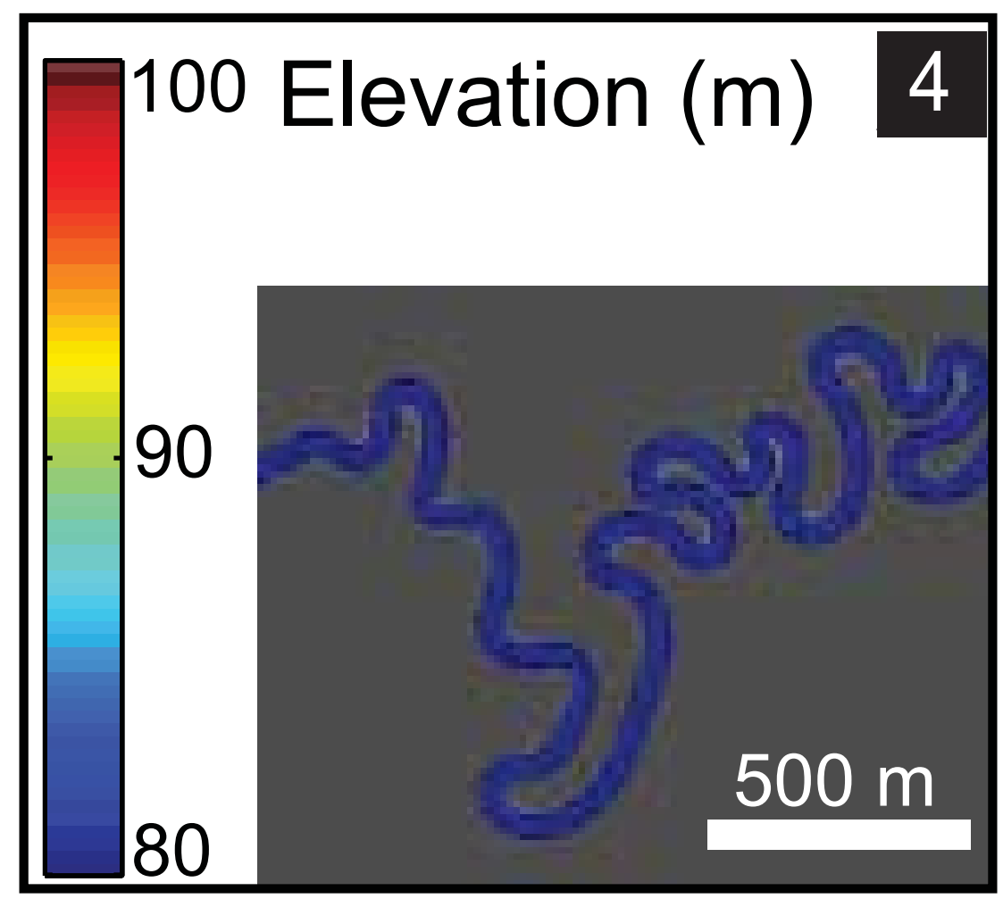

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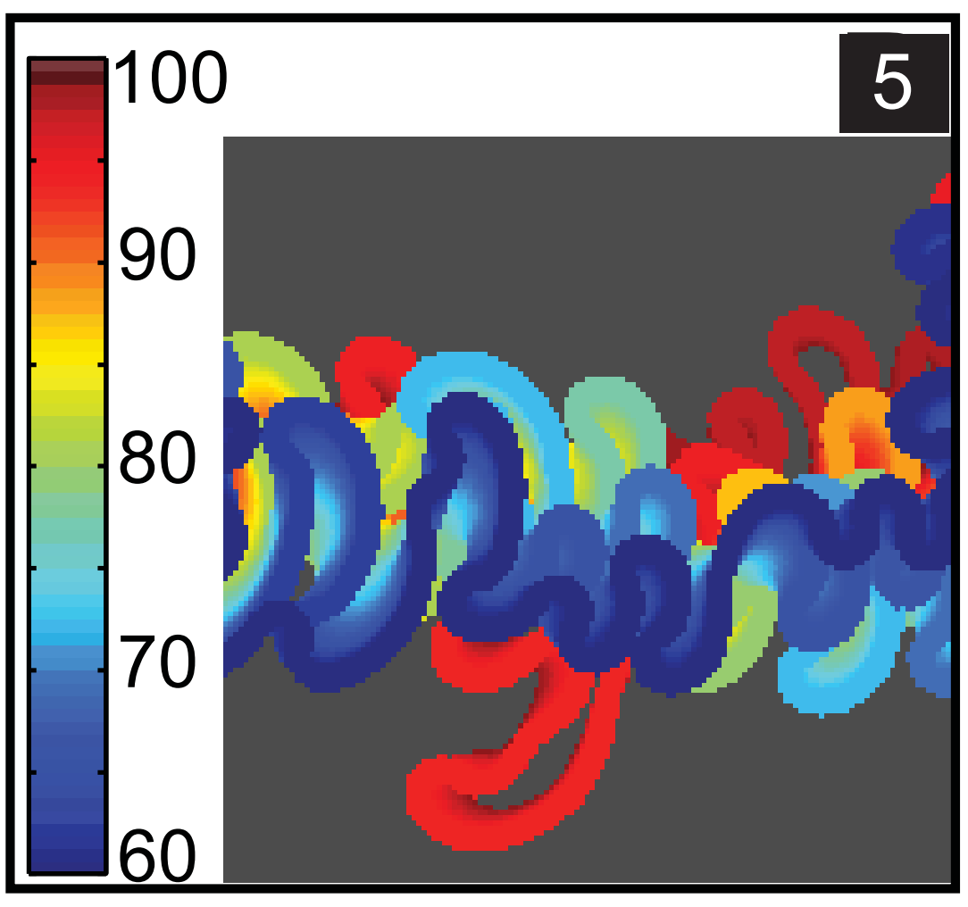

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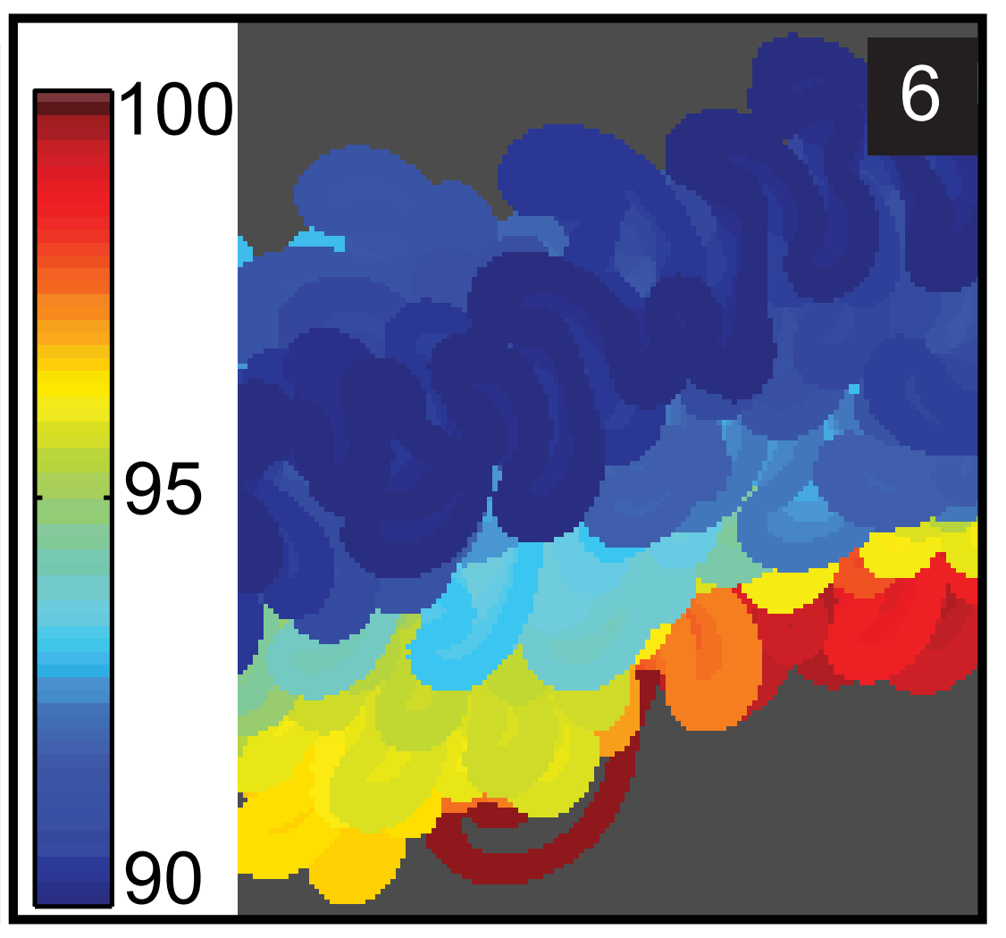

Simulations show that the model can produce deeply entrenched canyons with little terrace development for the case of low lateral:vertical erosion rate ratio (E_L/E_V), (Fig. 4), as well as broad terraces for the case of high E_L/E_V (Fig. 6), simular to field cases (Fig. 1 and 3, respectively). However, it is not possible to produce terraces that are constrained to the scale of individual meander bends with this model, except as remnants of cutoff loops, which are common in the field for cases with moderate E_L/E_V (compare Fig. 2 and 5). We hypothesize that this is because this model does not include spatial variability resistance to bank erosion which can feedback with meander migration.

Comparing cyclic and steady vertical incision cases

Figures 7-10 show results of simulations with cyclic and steady vertical incision, and steady lateral migration. Simulations suggest:

- **Terraces can be removed.** Compare Figures 7 and 8.
- **Paired terraces can form with steady vertical incision.** Terrace pairing and continuity are commonly argued to result only from pulses of vertical incision [5], but both occur in a simulation with steady vertical incision (Fig. 9).
- **The frequencies of terrace production by steady vertical incision and climate change may overlap.** Three dominant terrace levels form in simulations with both cyclic vertical incision (Fig. 7) and constant vertical incision (Fig. 9). With increased the frequency of cyclic incision (Fig. 10), the number of terrace levels increases enough to become distinct from the constant incision case.

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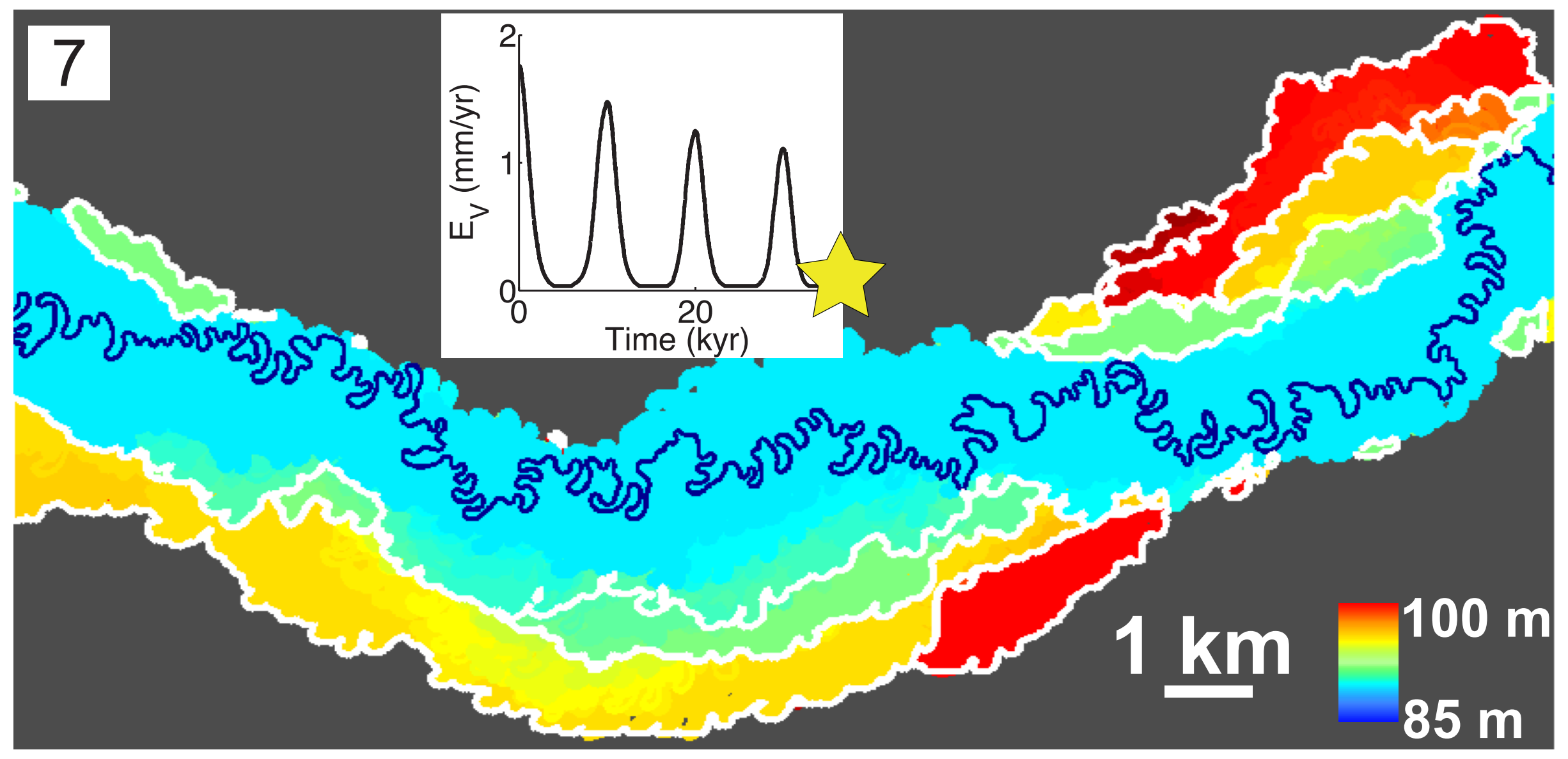

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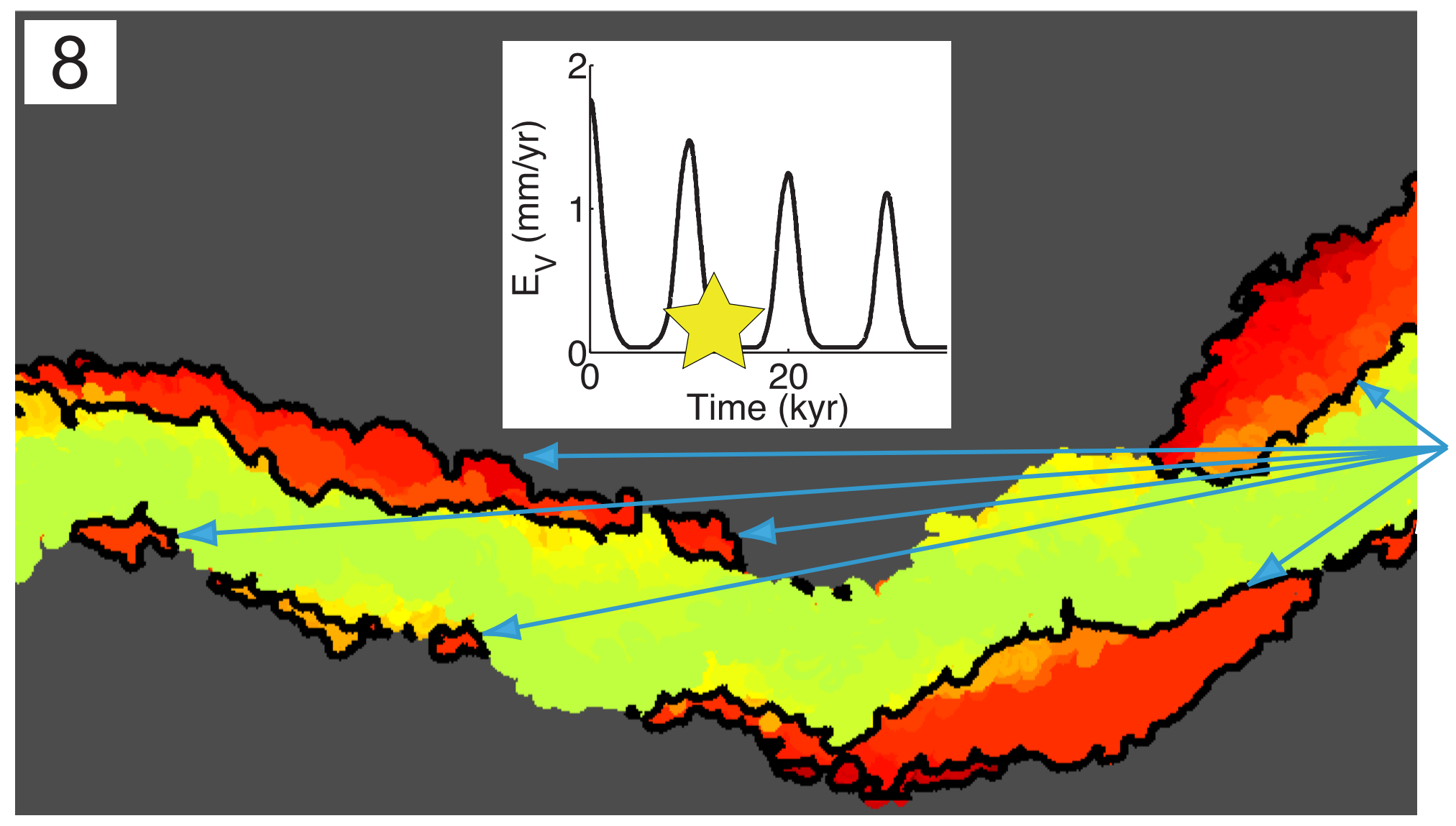

Previous extent of red terrace.

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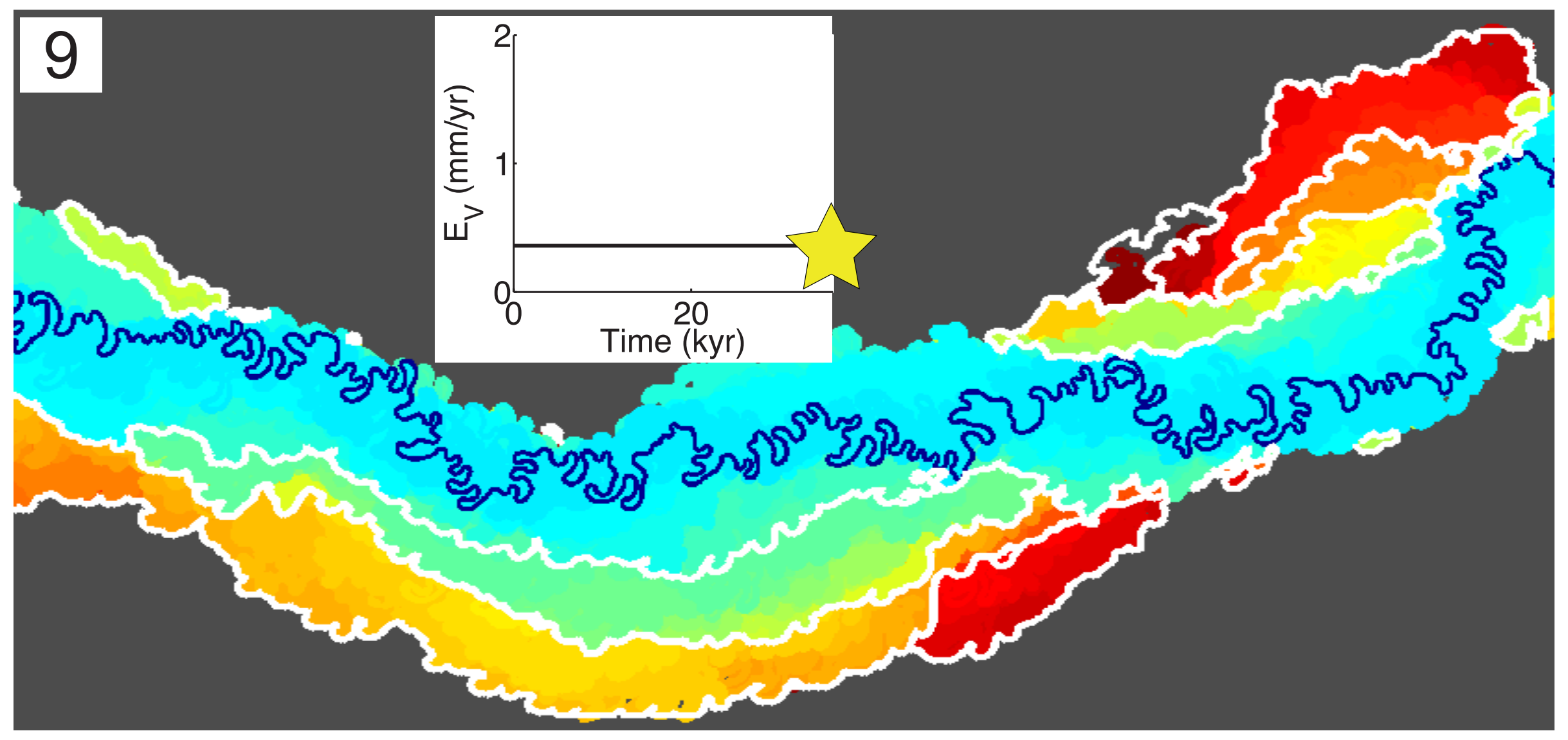

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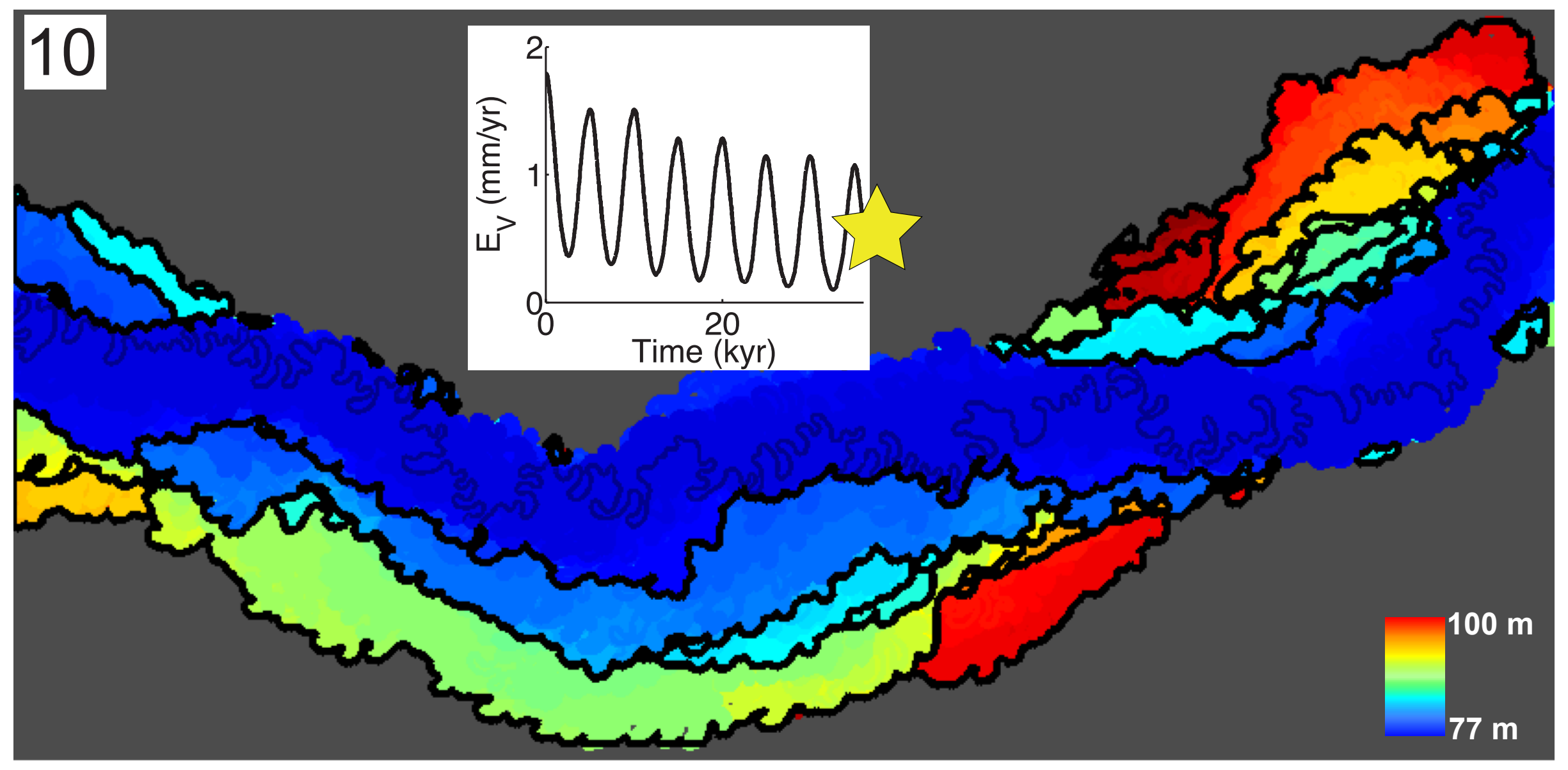
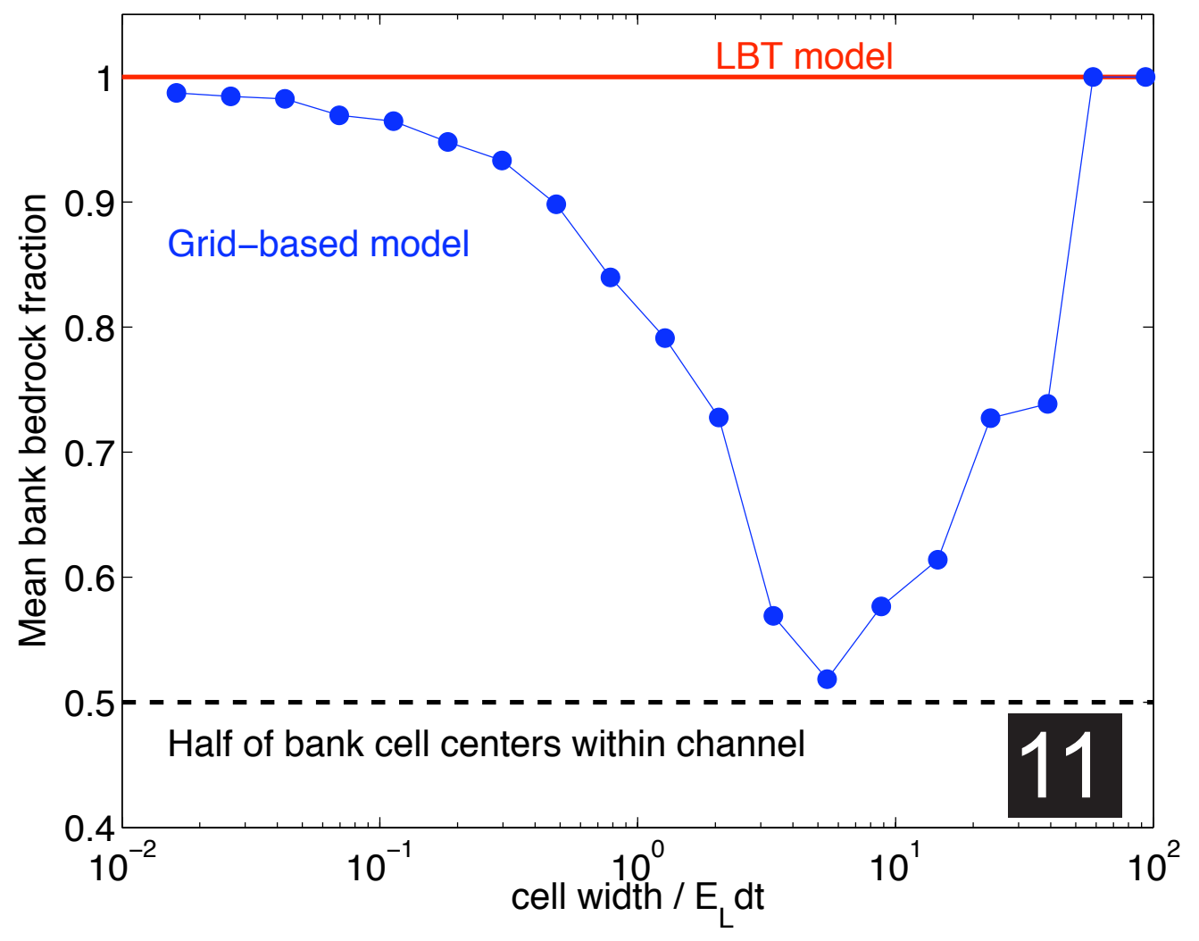


A new framework for modeling bank coupling

An accurate migration model requires feedbacks landscape feedbacks, by variations in suspectibility to erosion due to bank height or composition. Figure 11 illustrates the mean bank bedrock fraction sensed by a channel fully entreched in bedrock, which should be 1. However, the mean bank bedrock fraction depends strongly on the bedrock elevation of the cell closest to the bank, unless cell width is reduced to a small fraction of the typical bank migration distance in one timestep. Reducing cell width comes at a substantial cost in memory (Fig. 12).



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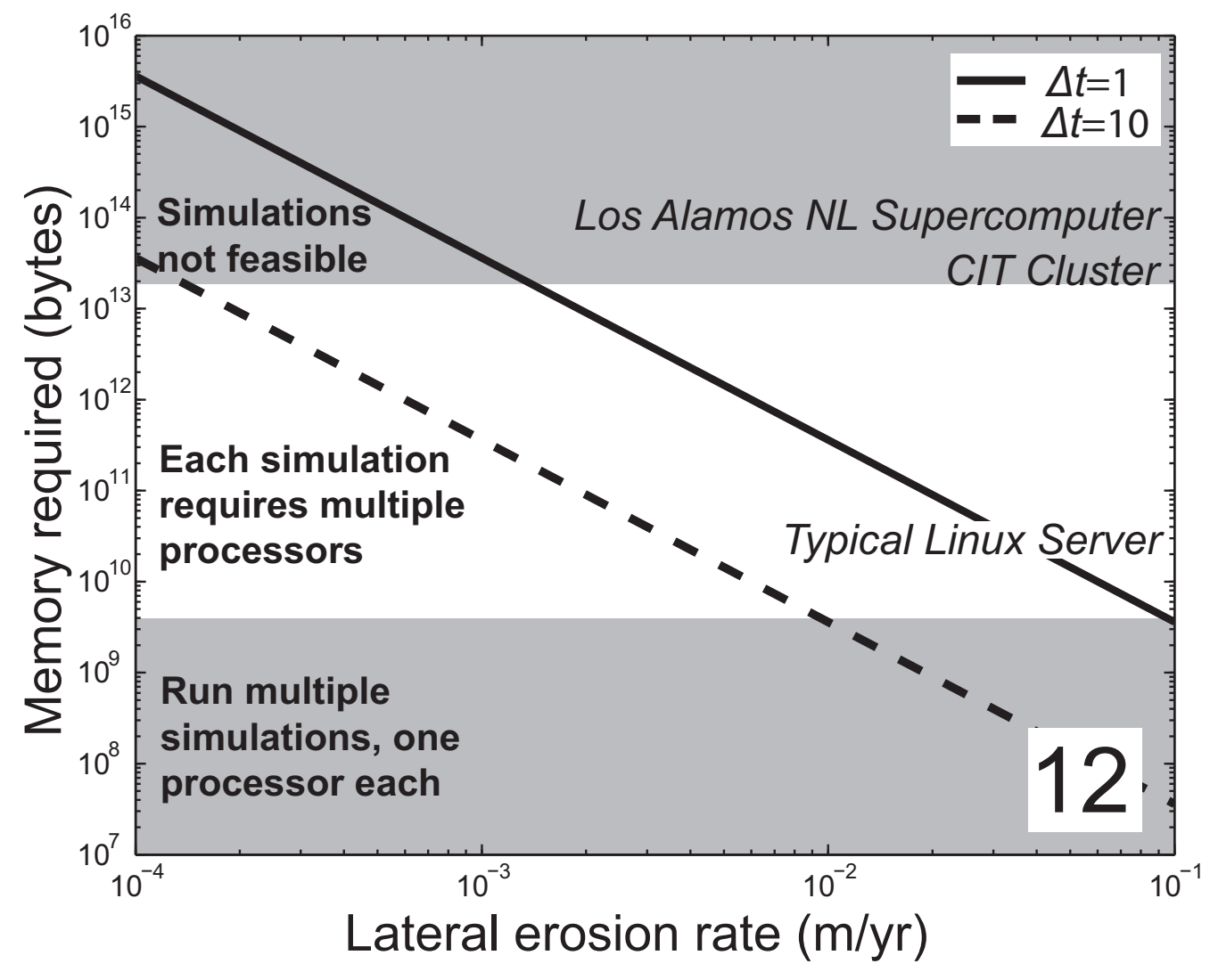

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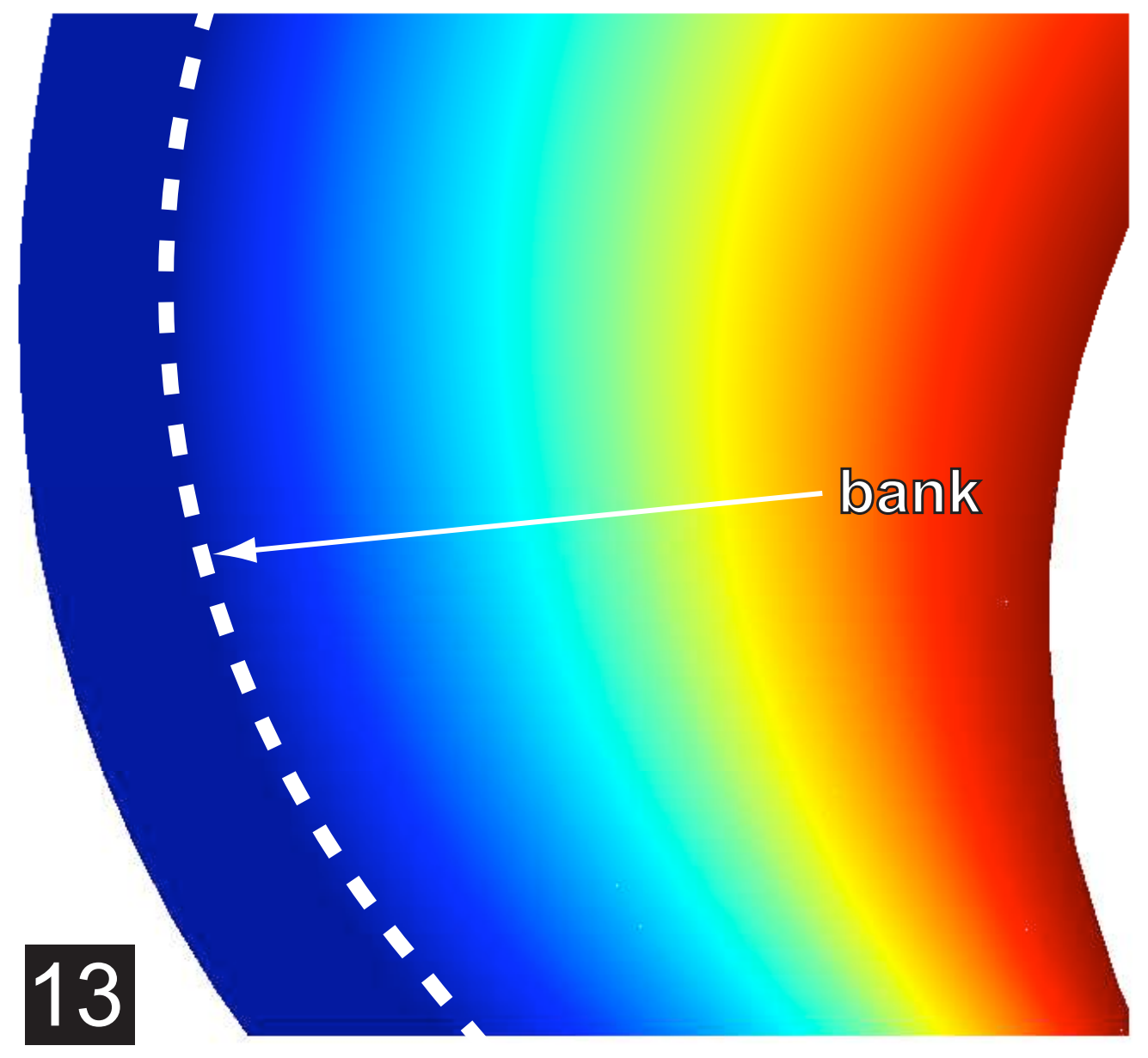
We have implemented a new method, Langrangian Boundary Tracking (LBT), which tracks bank position using an advancing front (Fig. 13), rather than as a boundary mapped onto a grid. For a typical model scenario, the LBT method uses ~1% of the RAM required for the grid-based approach, with ideal results for bank bedrock fraction (Fig 11).



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Testing for trends in terrace preservation and geometry

In continuing work, we are deploying the LBT model for a variety of channel geometries and erosion rates in order to determine controls on terrace geometry, age and preservation. As an example, Figures 14-16 show comparsion of terrace dip direction (with respect to valley centerline) and dip magnitude for field data and simulations based on the Mattole River, CA .

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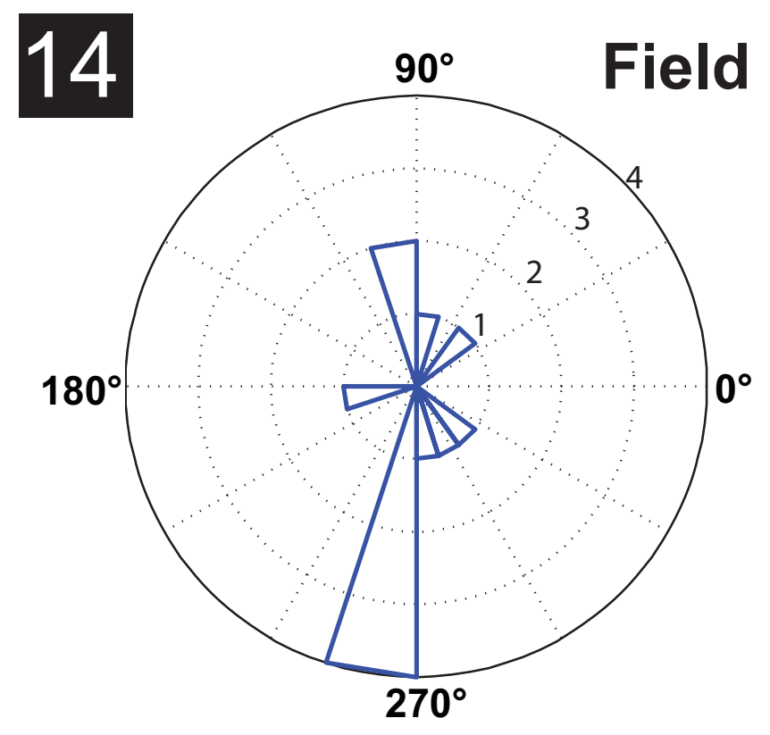

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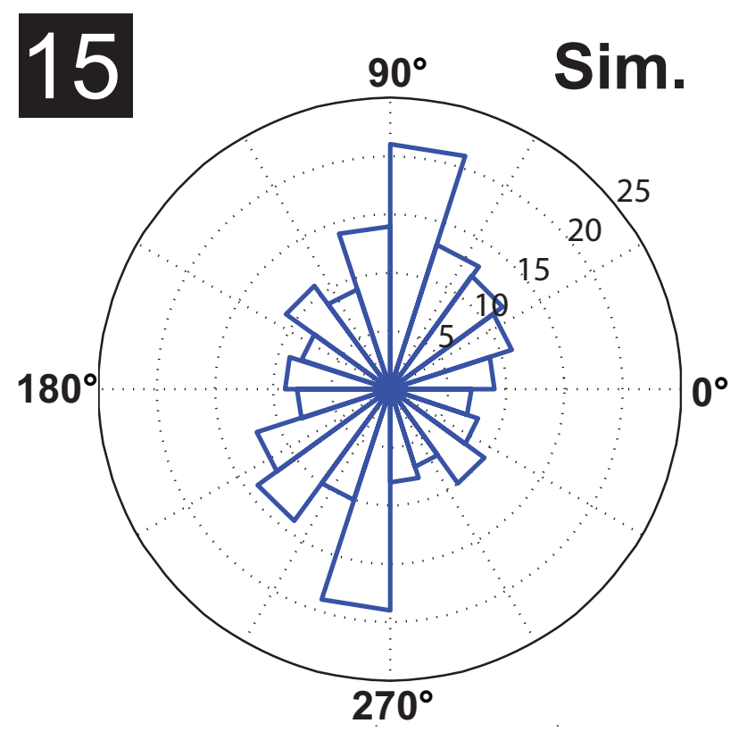

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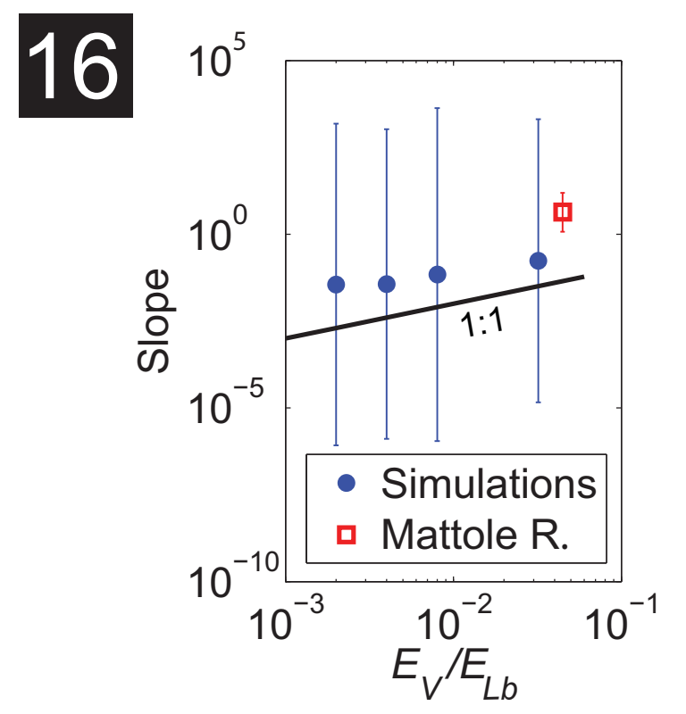

References

[1] Pazzaglia, F. J. (2011), River Terraces, in Wohl, E., ed., Treatise of Geomorphology, Elsevier.
[2] Bridgland, D., and R. Westaway (2008), Geomorphology 98, 285–315.
[3] Merritts, D. J., et al. (1994), J. Geophys. Res. 99(B7), 14,031-14,050.
[4] Howard, A. D., and T. R. Knutson (1984), Water Resources Res. 20(11), 1659-1667.
[5] Pazzaglia, F. J., et al. (1998), in *Rivers Over Rock: Fluvial Processes in Bedrock Channels*, ed. Tinkler, K. J., and E. E. Wohl, AGU, Washington.

Acknowledgments

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