RC3

Prediction of basin-scale river channel migration based on landscape evolution numerical simulation

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We are grateful to the reviewer for the insightful and constructive comments. We have carefully considered each point, provided a detailed point-by-point response below, and revised the manuscript accordingly. We believe these changes have improved the clarity and scientific rigor of the work, and we hope the revised manuscript now meets the publication standards of *Hydrology and Earth System Sciences* (HESS).

Note:

(1) In this response, the text in *italic type* is the original comments from the reviewers, and the text in blue, headed with "Reply", is the response from the authors.

(2) In the manuscript, the words in blue indicate the sentence is improved or revised. Some of them are mentioned in this response via the page and line number.

Response to Reviewers

Comments:

1. This study uses the average Hausdorff distance as an indicator to assess the difference between the simulated and the observed river channel, thereby evaluating the simulation accuracy. What is the justification for this indicator?

Reply: Thank you for raising this important question regarding the choice of evaluation metric. In this study, we use the average Hausdorff distance (H) to quantify the discrepancy between the simulated and observed channels, and its suitability is supported by the following considerations.

First, our focus is on basin-scale, long-term channel migration, rather than short-term hydrodynamics or reach-scale morphological details. The average Hausdorff distance (H) provides a direct measure of the planform geometric offset between two channel centerlines (see figure below). As a distance-based metric with clear physical meaning, it effectively characterizes the overall positional deviation of the simulated channel relative to the true channel, and is therefore well suited to our modeling objective.

In addition, the Hausdorff distance is a well-established measure of curve-to-curve spatial similarity, and has been widely used in studies of channel-shape matching, path comparison, and geomorphic feature analysis (Lei and Lei, 2022; Bogoya et al., 2019; Ranacher and Tzavella, 2014). Compared with metrics that evaluate discrepancies at individual points or local locations, the average Hausdorff distance (H) summarizes distances across all discretized points along the entire channel, thereby accounting for both the overall displacement and differences in channel curvature and planform geometry.

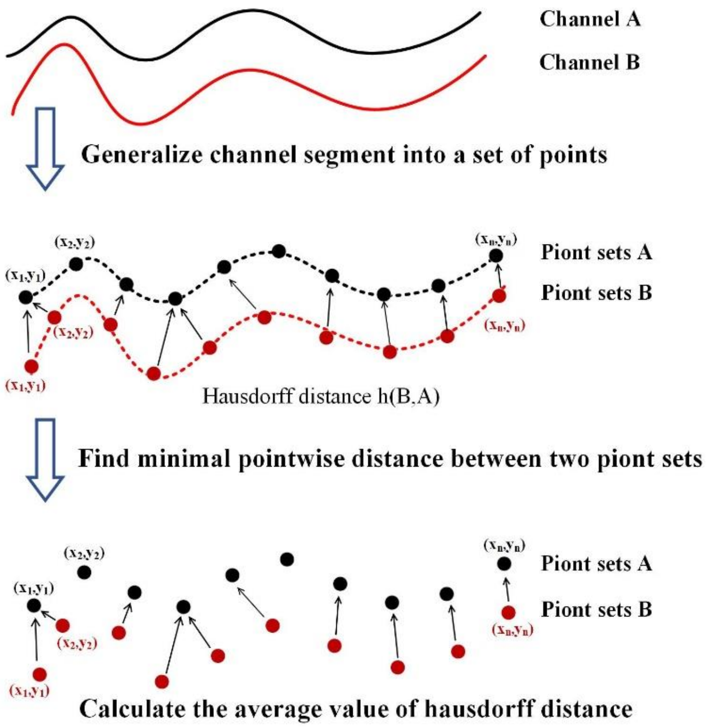

Figure R1. Schematic diagram of Hausdorff distance.

2. *The results of the parameter uncertainty analysis in Figure 10 show the posterior distribution histograms of model parameters, which are very useful. The significance of these posterior distributions could be further explained. I recommend to provide*

additional discussion on the posterior ranges.

Reply: We thank the reviewer for pointing out this issue. A more in-depth discussion of the posterior parameter distributions in Section 4.1.2 can help readers better understand model behavior and the mechanisms controlling channel migration in the basin scale.

The posterior distributions in Fig. 10 indicate that the inferred posteriors not only quantify uncertainty in parameter identification, but also reveal the relative importance of different geomorphic and hydrologic processes for reproducing channel migration in the basin scale. Specifically, several parameters—such as the vertical soil hydraulic conductivity (KVs), hillslope diffusion coefficient (K1), bare-bedrock weathering rate (P0), soil grain size (Ds), and vegetation fraction (VegFrac)—exhibit clear convergence to relatively narrow and concentrated posterior ranges after calibration. This suggests that channel-planform predictions are highly sensitive to these parameters, and that they exert strong control on basin-scale erosion–deposition balance and channel migration behavior. From a geomorphological perspective, these parameters directly regulate hillslope sediment supply, runoff generation, and fluvial sediment-transport capacity, and therefore constitute key controls on the magnitude of channel-position adjustment.

In contrast, the posterior distributions of some parameters—such as aquifer horizontal hydraulic conductivity (KHg), the weathering-law coefficient (α), and the tectonic uplift rate (U)—remain comparatively broad. This indicates that, given the spatial scale of this study and the available observational constraints, channel-planform position is less responsive to these parameters. Over the past 22 years, channel migration in the basin scale may have limited sensitivity to tectonic uplift, or the effects of uplift may be partially compensated by other parameters within the coupled hydro–geomorphic system.

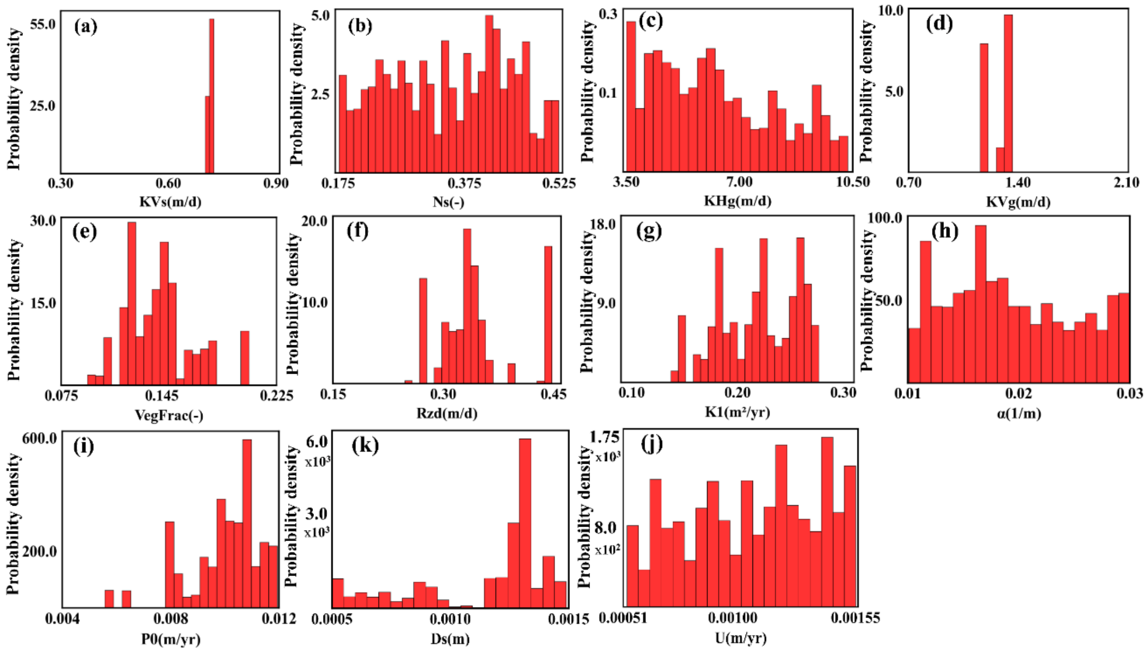

Figure 10. Calibrated posterior distributions of model parameters

3. *River channel migration at the basin scale is the result of landscape evolution processes. The manuscript proposes that LE-PIHM includes processes such as tectonics and hydrology. Could the authors provide more detailed explanations of the full-coupled multi-processes involved?*

Reply: Thank you to the reviewer for providing this important suggestion. LE-PIHM is a fully coupled watershed landscape-evolution model that integrates surface–subsurface hydrologic processes, snow accumulation and melt, hillslope and channel sediment transport, weathering and erosion, and tectonic uplift.

The hydrologic and geomorphic modules are tightly coupled within the same control volume through mass conservation and flux closure, and the state variables are updated synchronously at each time step. For each grid element (a Triangulated Irregular Network, TIN, control volume), the model simultaneously tracks seven state variables: canopy water storage, snowpack, surface-water depth, vadose-zone water storage, saturated-zone groundwater table, land-surface elevation (z), and bedrock-interface elevation (e). These state variables are assembled into a unified global system of ordinary differential equations (ODEs) and are solved concurrently. Within each TIN control volume, multiple fluxes—including infiltration, recharge, overland flow, groundwater flow, and sediment/weathering/uplift fluxes—coexist and are transported in a coupled manner across the entire TIN mesh domain.

Specifically, the hydrologic module represents the sequence of processes from precipitation to canopy interception/snowmelt, surface runoff generation and routing, infiltration, recharge to the vadose and saturated zones, lateral groundwater flow, and evapotranspiration. Overland flow is parameterized using the Manning equation, and lateral groundwater flow is represented using Darcy's law, with fluxes controlled by hydraulic-head gradients and unsaturated hydraulic conductivity. The geomorphic module updates land-surface elevation z and bedrock-interface elevation e based on mass conservation, with key controls including the tectonic uplift rate (U), bedrock weathering rate, and hydraulically driven sediment fluxes on hillslopes.

Topography elevation and bedrock elevation determine hydraulic slopes and head gradients, whereas hydrologic states (e.g., surface-water depth and groundwater level) govern shear stress and sediment-transport capacity. Sediment fluxes (qs), hillslope fluxes (qc), and uplift terms are solved in a coupled manner to update elevations, which in turn modify hydraulic gradients and flow-routing patterns. This two-way feedback implies that the evolving landscape constrains river dynamics, and river processes reshape the landscape, thereby forming a self-consistent loop of hydro–geomorphic co-evolution.

4. *For the parameter calibration of river channel migration model, the reliability of the validation data is crucial. How were the river channel location data acquired? The authors should specify if they originate from field surveys or remote sensing techniques.*

Reply: Thank you for pointing out this issue. We agree that the acquisition method and reliability of channel-position data are critical for parameter calibration of a channel-migration model. In this study, the observed river channel planform data were derived entirely from remote-sensing sources. Specifically, channel planform positions were obtained from high-resolution historical imagery available on the Google Earth platform. We selected imagery from several representative years (e.g., 2007, 2014, and 2021), which provides adequate spatial resolution and continuous coverage over the study area, allowing the channel centerline to be clearly identified.

For data processing, we first digitized (vectorized) the channel centerline in Google Earth and exported it as a KMZ file. The KMZ data were then imported into ArcGIS, where they were transformed into shapefile format and processed under a unified coordinate reference system. We further performed geometric correction, smoothing, and topology checks to ensure the consistency of channel geometry and spatial accuracy. The resulting planform coordinates were subsequently used for model calibration and validation.

We have added a detailed description of the channel-position data acquisition and processing workflow in Section 3.3 of the revised manuscript.

5. *Figure 11 illustrates that the distribution of channel sections is narrow in the upstream areas of the basin, whereas it widens in the downstream areas. An explanation for this spatial pattern is required.*

Reply: We thank the reviewer for pointing out this issue. In our study basin, the upstream area is mountainous, whereas the downstream area is a lowland plain. The relatively narrow migration envelope (i.e., lower uncertainty) in the upstream reach is primarily because this segment is confined within a canyon setting where the valley is topographically narrow and comparatively stable. As a result, the channel is strongly constrained laterally, and the channel-migration model exhibits lower predictive uncertainty in this reach, leading to a narrower simulated distribution of channel positions.

In contrast, parts of the downstream reach located on the plain show substantially larger predictive uncertainty. This is because the low-relief terrain provides fewer topographic constraints on lateral migration, and channel behavior is more strongly influenced by the combined effects of deposition, changes in flow hydraulics, and human activities. Consequently, the basin-scale river channel migration model is associated with greater uncertainty in the downstream plain, yielding a wider predicted channel distribution, indicating higher predictive uncertainty.

Minor Comments

1. To enhance the readability of the manuscript, it is advisable to add brief explanations for the technical terms, such as "Markov chain Monte Carlo" and "surrogate model".

Reply: We have revised and improved the corresponding section in the revised manuscript.

2. The use of "Equation" and "Eq." in the manuscript should follow a consistent format. In line 264, Equation (10) is missing a closing parenthesis.

The "H" in the first column of Table 6.

Reply: We have revised and improved the corresponding section in the revised manuscript.

Reference:

Lei, T. L. and Lei, Z.: Harmonizing full and partial matching in geospatial conflation: a unified optimization model, ISPRS Int. J. Geo-Inf., 11, 375, https://doi.org/10.3390/ijgi11070375, 2022.

Bogoya, J. M., Vargas, A., and Schütze, O.: The Averaged Hausdorff Distances in Multi-Objective Optimization: A Review, Mathematics, 7, 894, https://doi.org/10.3390/math7100894, 2019.

Ranacher, P. and Tzavella, K.: How to compare movement? A review of physical movement similarity measures in geographic information science and beyond, Cartogr. Geogr. Inf. Sci., 41, 286–307, doi:10.1080/15230406.2014.890071, 2014.

Schütze, O., Esquivel, X., Lara, A., and Coello, C. A. C.: Using the averaged Hausdorff distance as a performance measure in evolutionary multiobjective optimization, IEEE Trans. Evol. Comput., 16, 504–522, https://doi.org/10.1109/TEVC.2011.2161872, 2012.

Bogoya, J. M., Vargas, A., and Schütze, O.: The Averaged Hausdorff Distances in Multi-Objective Optimization: A Review, Mathematics, 7, 894, https://doi.org/10.3390/math7100894, 2019.