Numerical modeling of the evolution of fluvial networks on glaciated landscapes

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Background

Landscapes of Midwestern USA were impacted by repeated episodes of continental glaciation. Glaciations disrupted fluvial drainage networks and left low-relief and erosional landforms including moraines and valleys incised by glacial meltwater. The new landscape after deglaciation featured extensive uplands with little or no surface water connection to stream networks. What processes drive the expansion of fluvial networks on uplands are unclear.

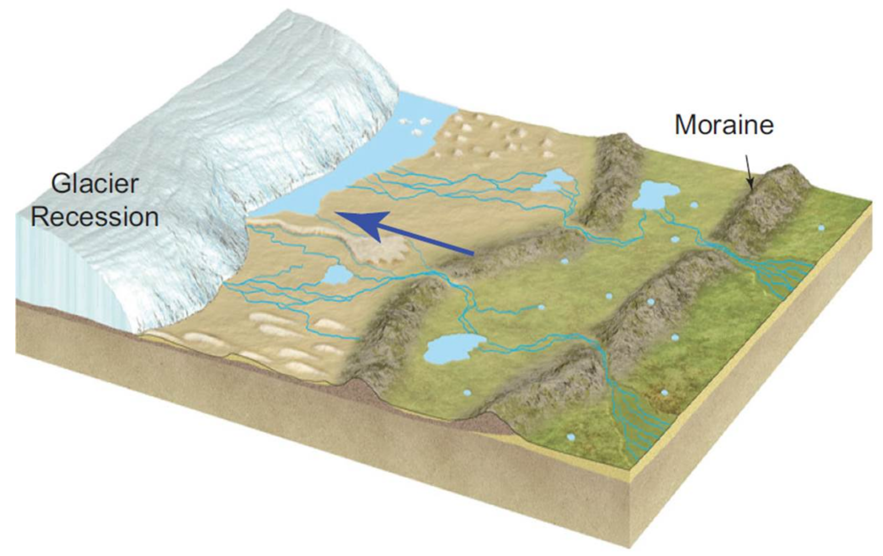

Fig. 1. *A typical post-glacial landscapes including moraines, uplands and incised valleys.*

Research Questions

What is the dominant process leading to hydrological connections between isolated upland basins and the valleys incised by meltwater?

- ❖ Headward erosion
- ❖ Filling and spilling of isolated upland basins

Methods

We build a 2D numerical model to explore the evolution of fluvial networks on formerly glaciated low-relief landscapes. We model fluvial process through stream power law and hillslope process is represented by linear diffusion.

$$\frac{\partial h}{\partial t} = k_d \nabla^2 h - k_{sp}(A^m S^n - \theta)$$

h	elevation
k_d	diffusivity
k_{sp}	fluvial incision constant
A	drainage area
S	slope
θ	threshold

Model Descriptions

Initial and boundary conditions

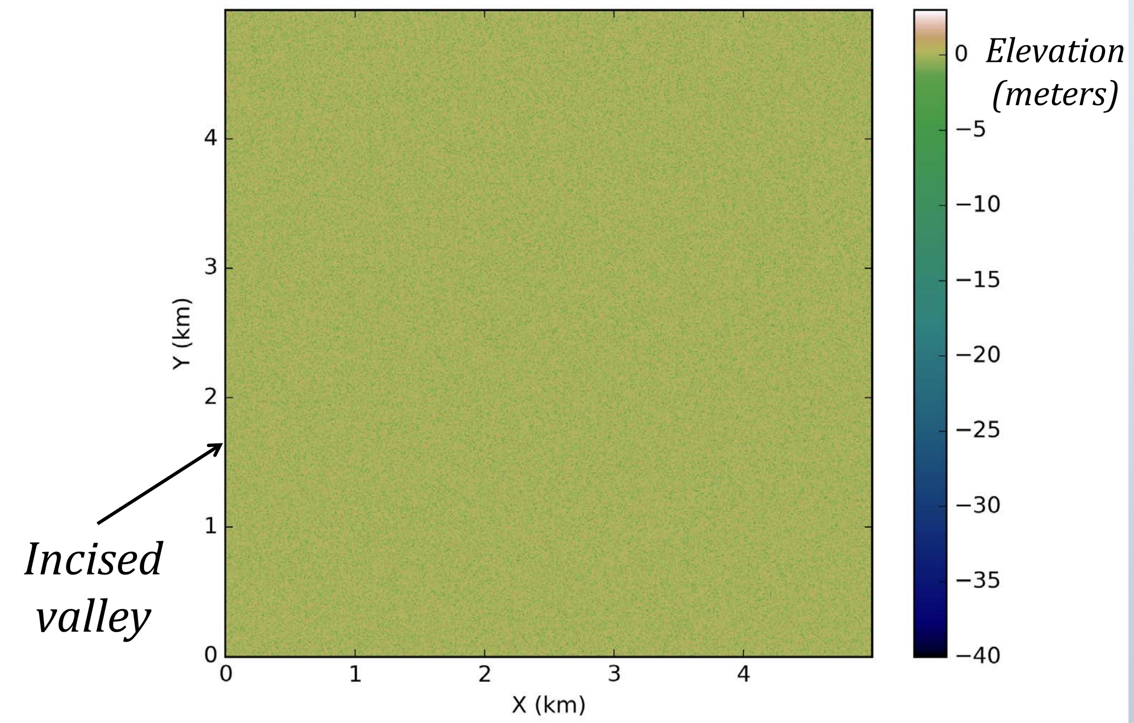

Fig. 2. *The domain is a 5 km by 5 km square. The cell size is 10 m. The left boundary of the domain is open in terms of flow routing, which means the water can flow across this boundary. This boundary represents a 40-m deep valley incised by meltwater. The other three boundaries are closed.*

Flow routing

Two end-member methods

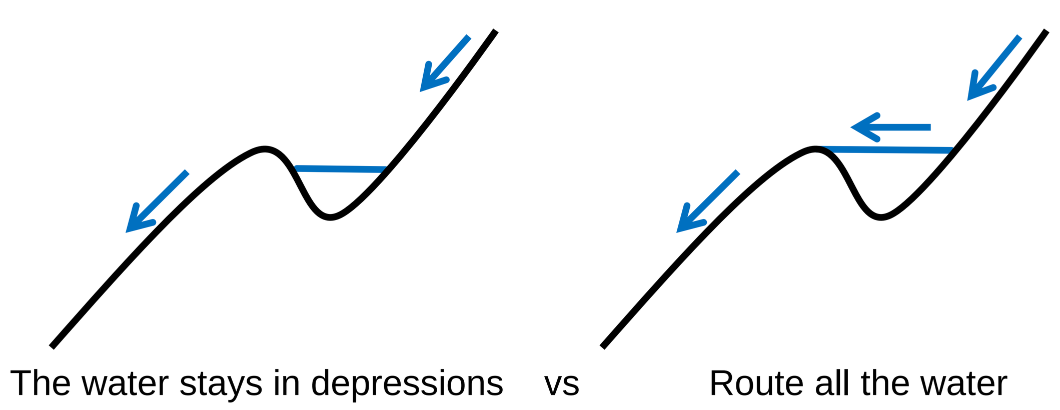

Fig. 3 *Two end-member flow routing methods. The left case assumes that precipitation falling on uplands is evaporated or lost to groundwater. The right panel represents the case when all depressions are filled and spilling.*

Results & Conclusions

Experiment 1. *Two end-member flow routing methods*

- ❖ The degree to which water is passed into the valley is a strong control on the rates of fluvial network organization. Filling and spilling of closed depressions allow for much higher rates of organization (Fig. 4).

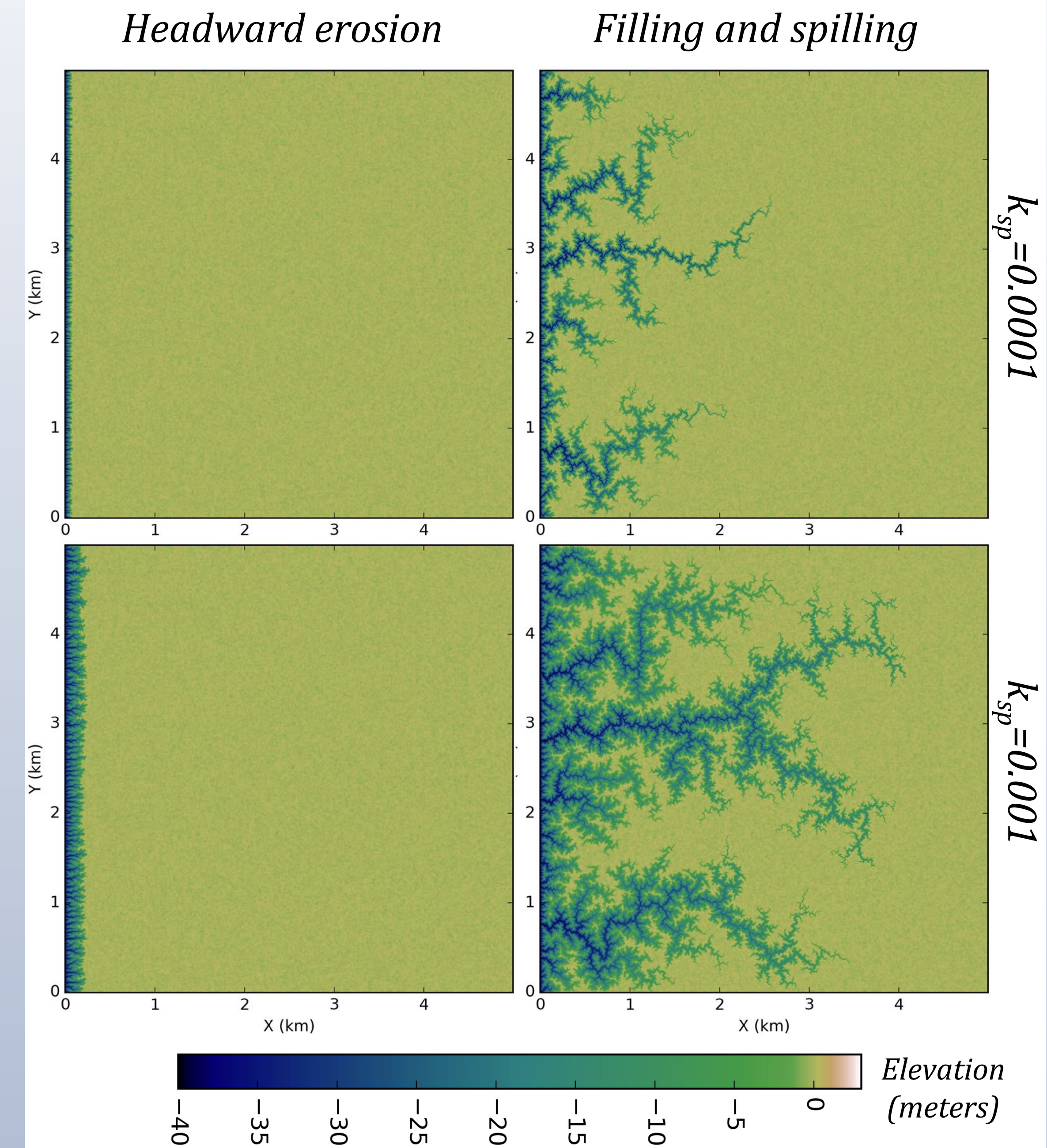

Fig. 4 *Modeled landscapes after 30,000 years of evolution. The left panel reflects the results when all of the water stays in closed depressions. Alternatively, when all the water from uplands is routed into the valley, the right panel is the results. The fluvial incision constant in the upper two cases is 0.0001. The lower two cases have a fluvial incision constant of 0.001.*

Experiment 2. *Filling through diffusion*

- ❖ Diffusion increases the size and decreases the depth of closed depressions as the landscapes evolve (Fig. 5).

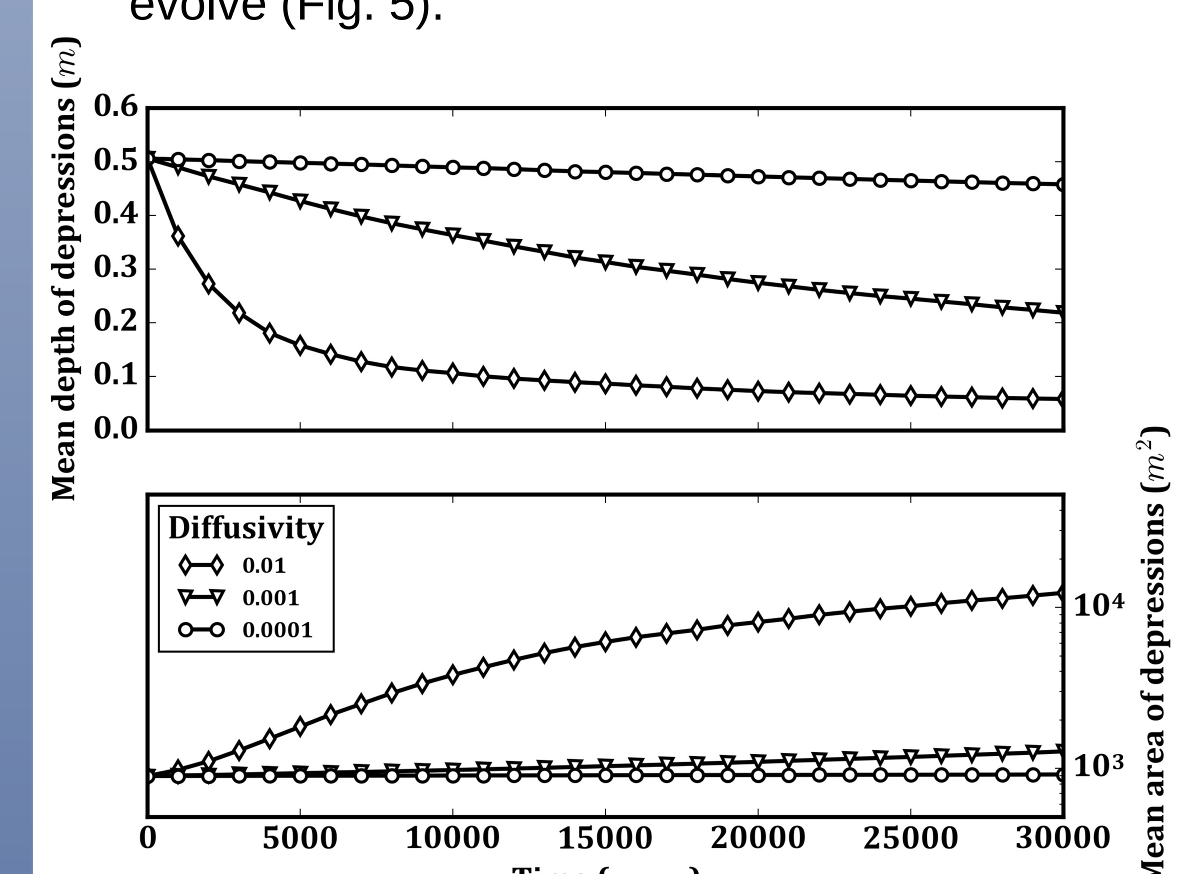

Fig. 5 *The evolution of depth and area of the depressions on the upland with different diffusivity values.*

Experiment 3. *Different initial conditions*

- ❖ Washboard moraines have a strong control on the orientation of channels (Fig. 6).

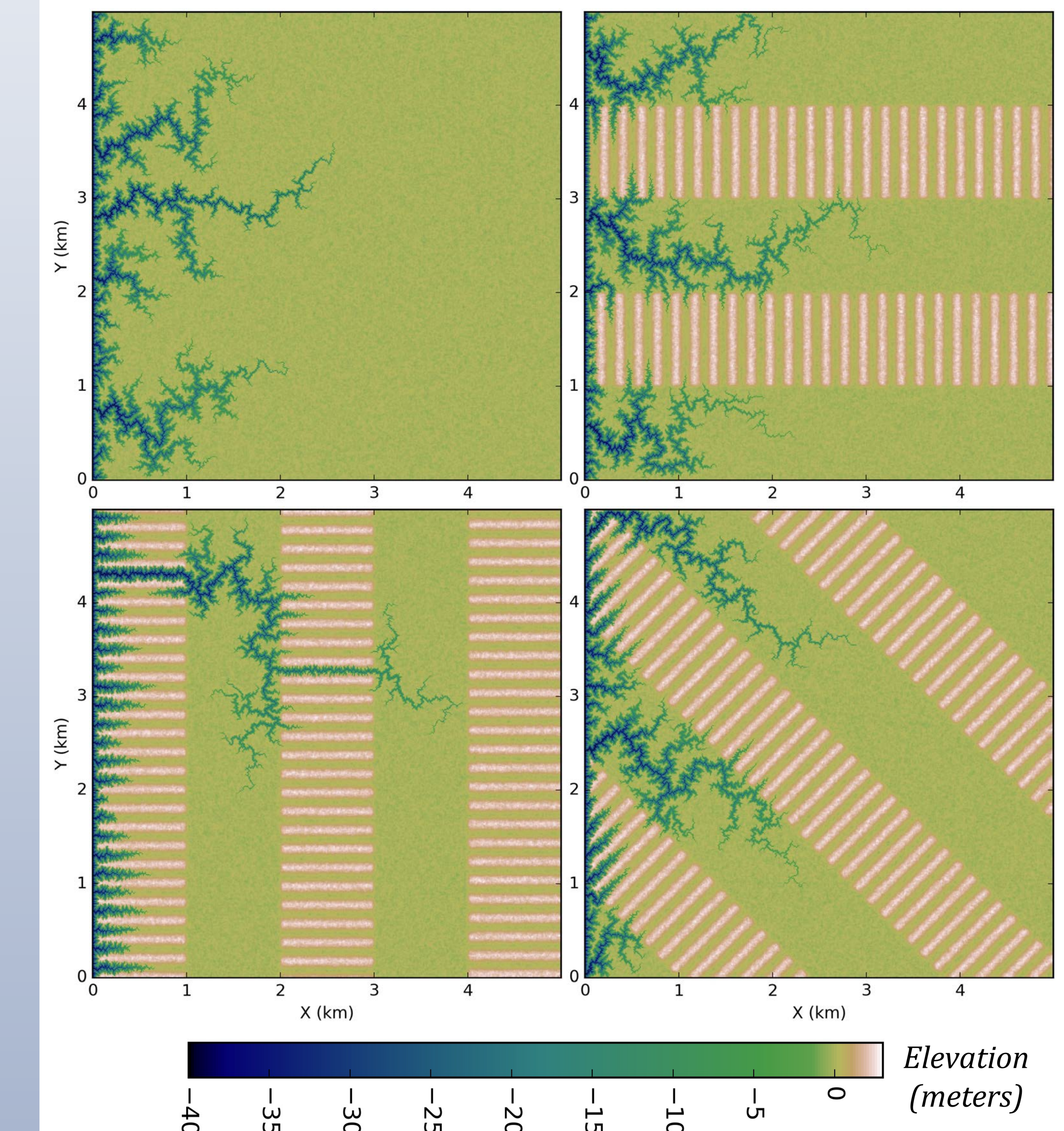

Fig. 6 *Modeled landscapes after 30,000 years of evolution with different initial topography. These initial conditions include glacial lake plain (upper left) and washboard moraines that are parallel (upper right), perpendicular (lower left) and diagonal (lower right) to the valley.*

Future Research

The temporal and spatial changes of climate and vegetation are not involved in this model. Climate and vegetation are most simply represented in the numerical model by varying the fluvial incision constant. Furthermore, filling and spilling are more likely to happen in wetter climate. In the future we plan to vary the fluvial incision constant and flow routing method in space and time.

Acknowledgements

IML-CZO

Landlab modeling platform