# A conduit evolution model built in Landlab: Coupling surface and subsurface processes

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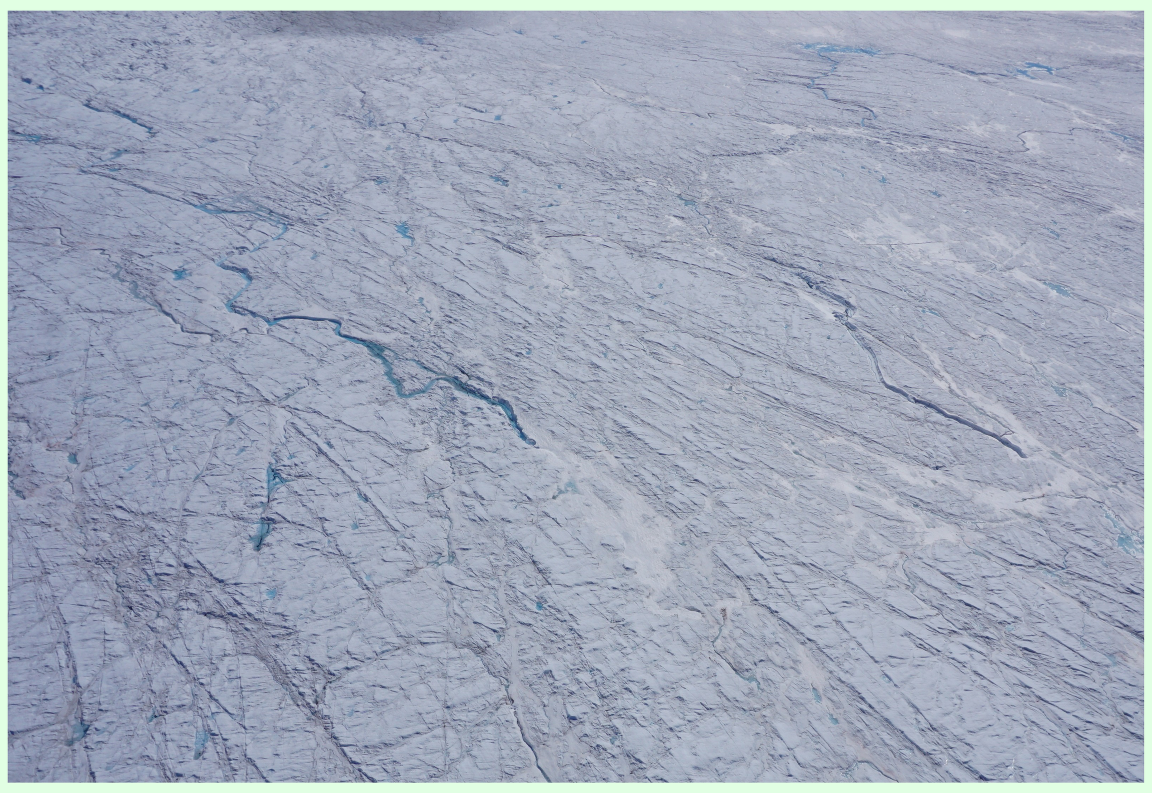
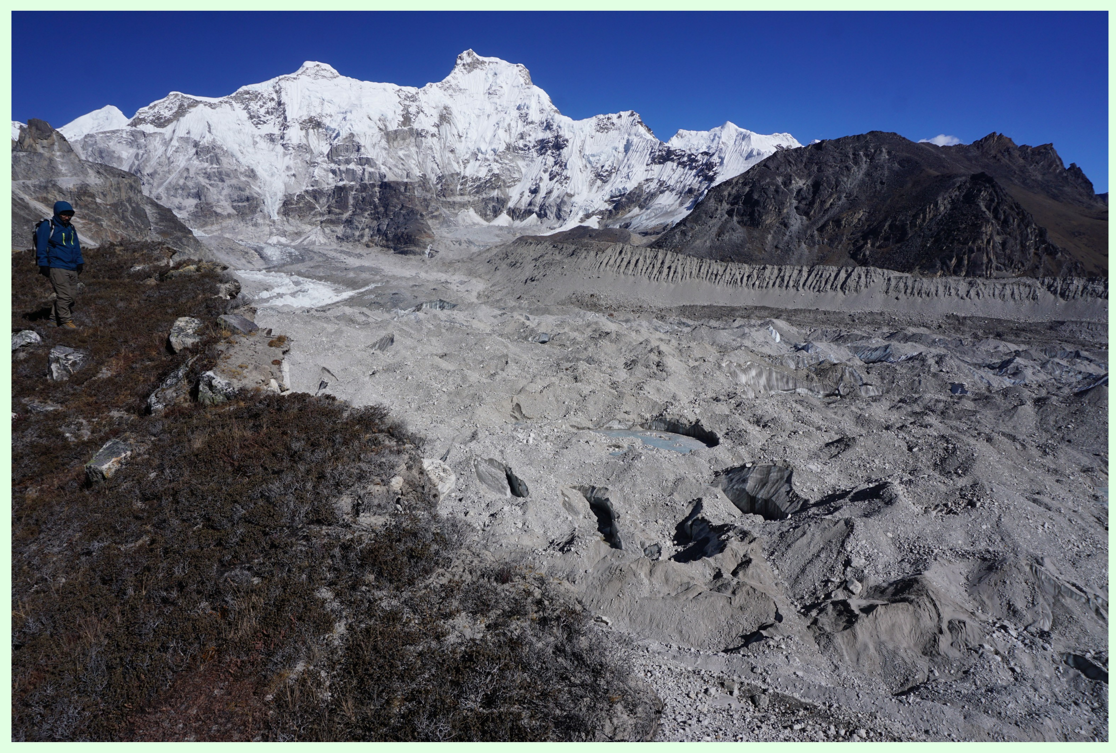
## Landscapes formed via coupling of surface and subsurface flow

Lidar hillshade from the classical karst region of Slovenia.



Stream channels in closed basins that flow into moulins on the Greenland Ice Sheet.



The topography that forms on debris covered glaciers in the Himalayas resembles cockpit karst.

## The Problem

A variety of landscapes on Earth, and possibly on other planets, develop through interactions between surface and subsurface flow paths. In some cases, models have been developed to simulate the subsurface development of flow systems, such as dissolution-driven models of speleogenesis (e.g. Dreybrodt et al. [2005]) or models of the development of subglacial flow systems (e.g. Schoof [2010]).

**However, very few models have examined the interactions between surface and subsurface systems that lead to the development of karst and similar landscapes.**

## Pressurized flow network solver

A pressurized flow solver is one of the key components needed to simulate subsurface flow through fractures or conduits, that is lacking within available landscape evolution models.

Here we develop such a solver for Landlab, using the Newton-Raphson Global Algorithm for water distribution networks described by Todini and Rossman [2013].

This approach solves for the unknown heads and discharges using a set of conservation of energy equations,

$$H_i - H_j - r_k |Q_k|^{\alpha-1} Q_k = 0$$

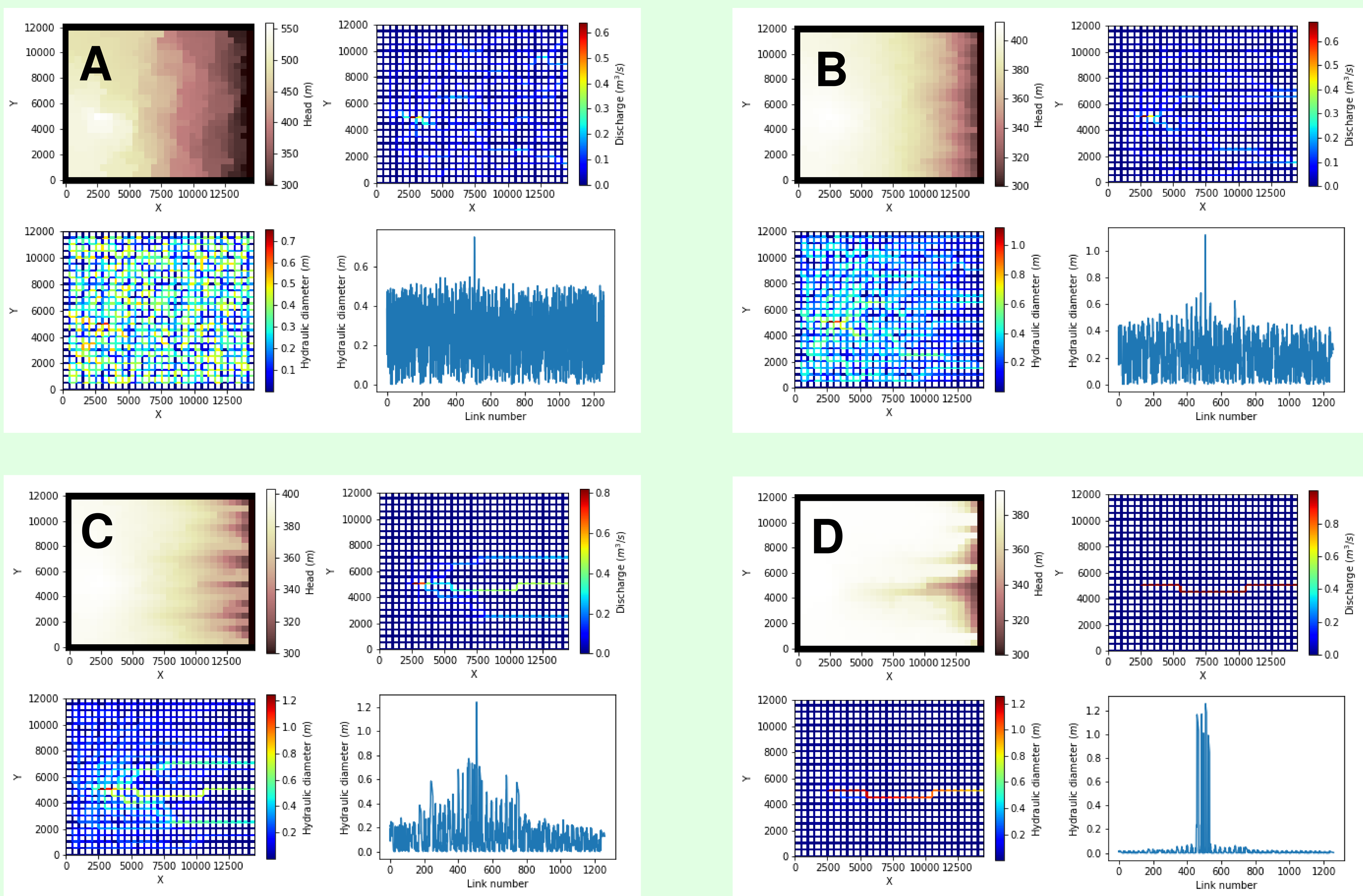
and conservation of mass equations,

$$\sum_{k=1}^{n_i} Q_{k_{i,j}} + q_i = 0$$

where $H_i$ and $H_j$ are the heads at the respective nodes, $Q_k$ is the discharge along the link connecting those notes, $r_k$ is the resistance factor for the node, which is a function of hydraulic diameter and other parameters, $\alpha$ is an exponent that depends on the chosen discharge equation, and $q_i$ is input discharge at the $i^{th}$ node.

The resulting sparse system is solved via Newton-Raphson iteration.

## Evolution of subglacial conduit system via melt and creep




In this example case, we combine the flow network solver with a subglacial conduit evolution component (time runs from A to D). Input is from a single moulin. Conduits begin with randomly distributed diameters (A) and gradually evolve toward an integrated flow system with a single primary conduit.

## plot_links()

There was no existing Landlab function for plotting values on links, rather than at nodes. Consequently, I added a plot_links() function to enable visualization of variables associated with links. This function plots all links as lines that run between two node centers. The lines are colored by the value being plotted (e.g. discharge, diameter). This function utilizes the PIL.ImageDraw module, which is much faster than manually drawing the lines in matplotlib.

## The Future

- **Develop transport and dissolution modules to enable simulation of karst conduit network development**
- **Couple conduit network and surface evolution models to examine how interactions between surface and subsurface processes impact landscape evolution within karst and glacier settings.**

### References

1. Dreybrodt, W., Gabrovšek, F., and D. Romanov [2015]. *Processes of Speleogenesis: A modeling approach.* Zalozhba, Ljubljana, 375 p.
2. Schoof, C. [2010]. Ice-sheet acceleration driven by melt supply variability, *Nature*, 468 (7325), 803.
3. Todini, E. and L.A. Rossman [2013]. Unified framework for deriving simultaneous equation algorithms for water distribution networks, *J. Hydraulic Engineering*, 139(5), 511-526.

### Acknowledgments

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Link to development fork on Github:

https://github.com/speleophysics/landlab/tree/add-pressurized-flow-network-solver

Or QR code on the right.