Modeling landscape evolution and climate: how erosion and precipitation are linked in active orogens (preliminary results)

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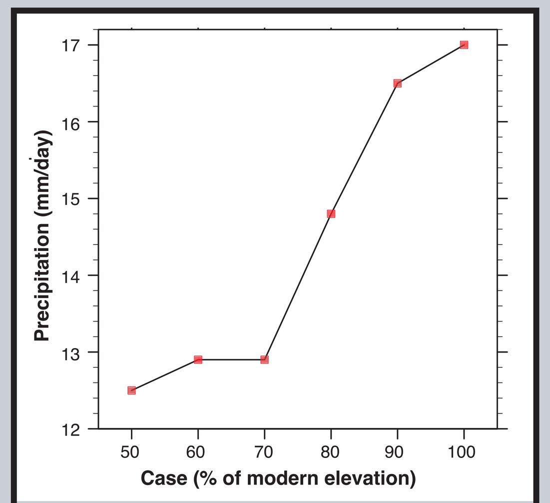
Abstract: The tectonic history and the climate driven erosional processes acting in a region are the primary controls on the evolution of a landscape. Quantifying these controls is essential to our understanding of uplift and erosion histories in mountain ranges. While tectonic processes are generally dependent on the location of plate boundaries, the controls on erosion are less constrained. We implement a numerical modeling approach to investigate these processes by coupling a high-resolution climate model, Weather Research and Forecasting Model (WRF), and a landscape evolution model, Landlab. The Andes act as the climatic setting for this study, due to the variation in climate along the length of the orogen, and serve as a natural laboratory to test controls on erosion. With the help of the hydrologic model WRF Hydro, we pass discharge and topography data between the models, which allows for a feedback relationship to form between topography and precipitation. We will test these feedbacks between topography and climate by monitoring topographic metrics and erosion histories. This work provides a necessary next step in landscape evolution modeling by using an actively evolving climate to model real precipitation dynamics. This next step allows for modeling more accurate representations of precipitation and the role orography and precipitation play in shaping one another.

Motivation:

- Landscape evolution involves complex feedbacks between climate and tectonics over time and space.
  - Topography acts as a control on climate by disturbing atmospheric circulation and causing orographic precipitation.
  - Climate acts as a control on topography by eroding material off of the landscape.
- Understanding the coevolution of climate and tectonics together will further our knowledge of what controls are most important for landscape evolution.



Modeling results using Andean topography showing the strong influence of topography on precipitation. (Poulsen et al., 2010)

Approach:

We couple a high-resolution climate model to a landscape evolution model to study the coevolution of climate and tectonics. Climate characteristics will be created based on the topography produced in the landscape evolution model and the land surface will be modified through tectonics and precipitation induced erosion allowing for complete climate-topography interactions.

Models:

Landlab: A Python-based landscape evolution model.

1) Calculates erosion (E) at each cell using bedrock erodibility (K), discharge provided from WRF-Hydro (Q), and slope (S).

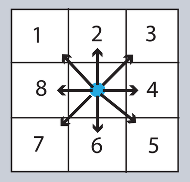
$$E = K Q^m S^n$$

2) Updates elevations using erosion and uplift.

$$Elevation = Uplift - Erosion$$

WRF (Weather Research Forecasting): A Fortran-based weather prediction model that produces precipitation maps input into WRF-Hydro.

WRF – Hydro: A Fortran-based hydrologic model that routes precipitation from WRF through the topography provided by Landlab using the D8 flow routing methodology and diffusive wave formulation.



D8 flow routing is a 1-D routing methodology in which water moves from a cell to one of the 8 surrounding cells with the steepest slope.

Model Coupling:

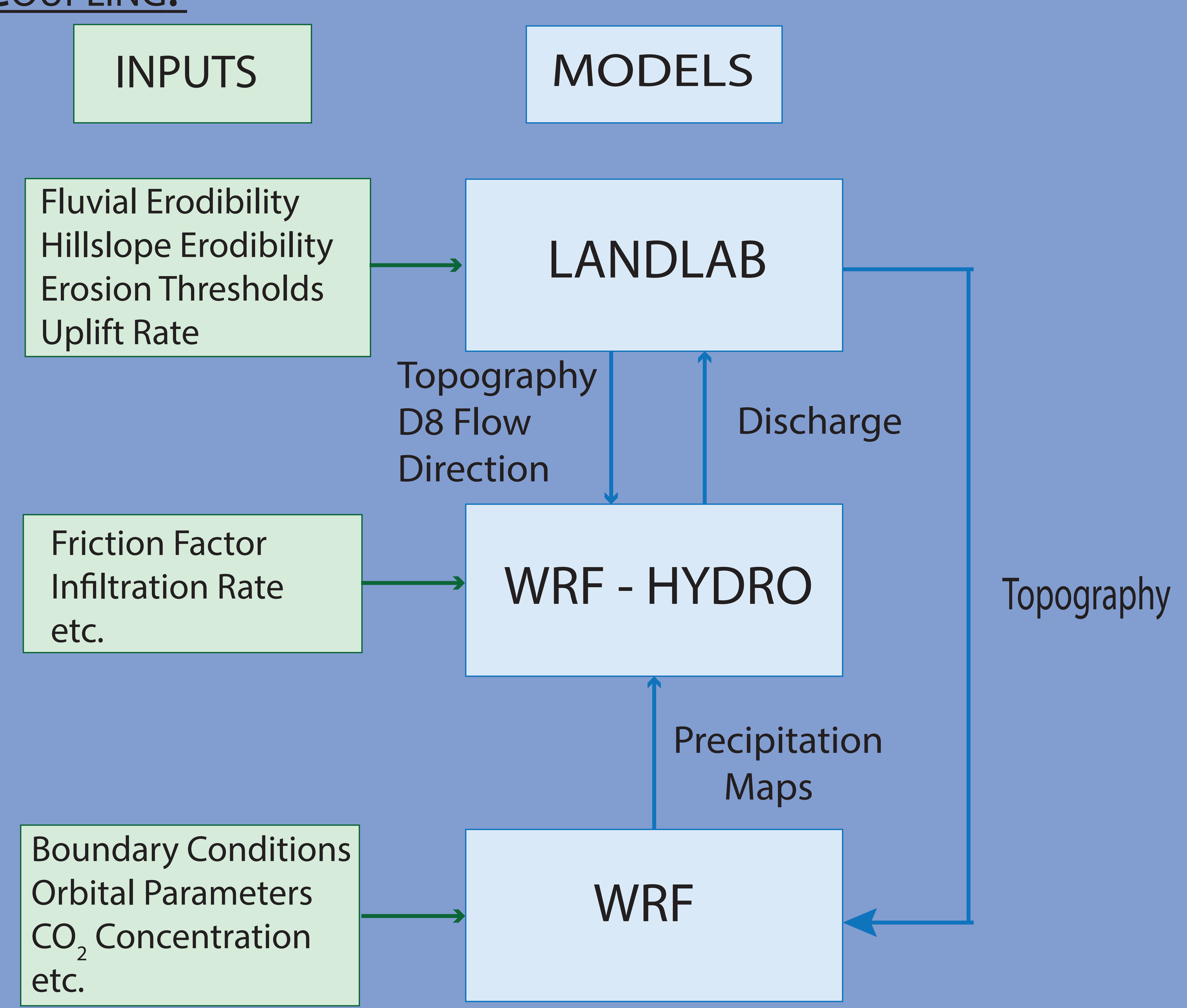


Figure 1: Flow chart depicting model coupling and input parameters. Blue squares and arrows represent model relationships and green squares and arrows represent model inputs. Coupling will be asynchronous to accommodate for the variable timesteps required for each model component.

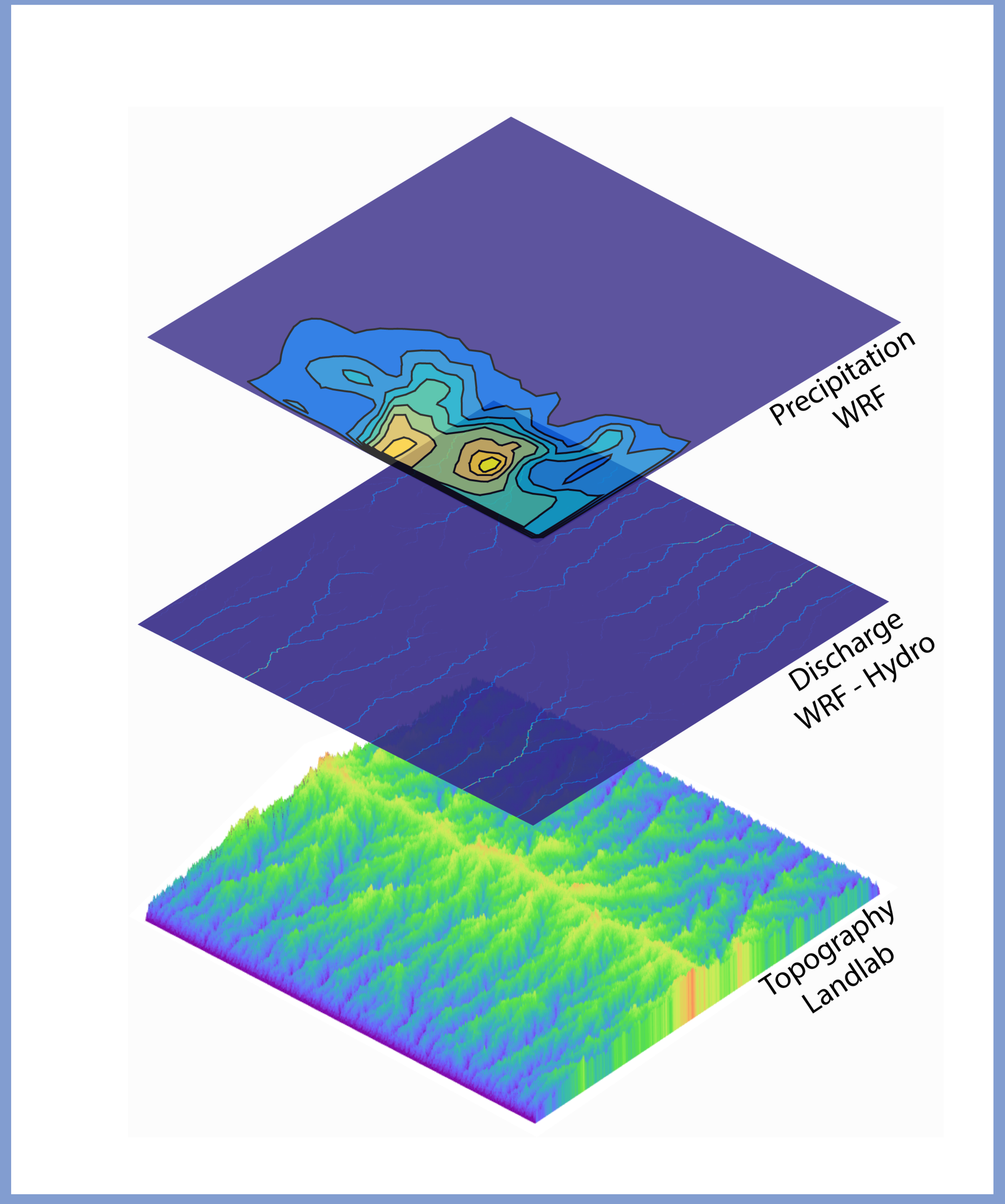


Figure 2: Conceptual design of the model coupling process. WRF creates a precipitation map from a climate model run using Landlab topography as an input. WRF - Hydro creates discharge maps by routing precipitation through the Landlab topography. Discharge maps are input into Landlab, this discharge causes erosion and Landlab updates topography, which is fed back into WRF.

Model Domain:

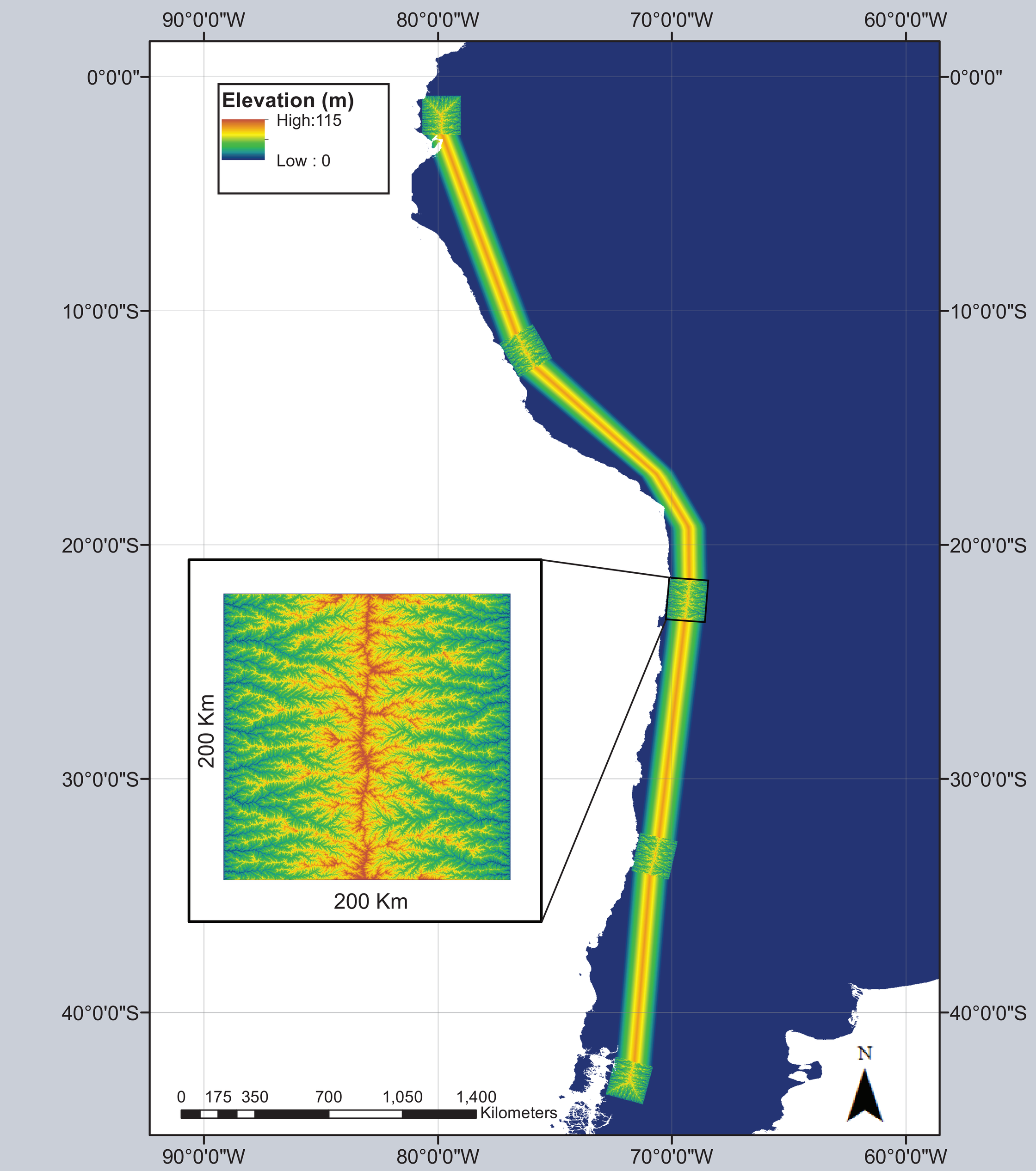


Figure 3: Initial topography input into WRF. Five low elevation, low relief topographies created in Landlab are placed at varying latitudes and climate regimes along South American coast. Elevations between each Landlab topography are interpolated to create a continuous mountain range and avoid atmospheric circulation around the base of each simulated mountain.

Future Work:

The next steps will be to run sensitivity tests and initial runs to determine appropriate values for:

- *erodibility*
- *uplift rate*
- *erosion threshold*
- *simulation length*
- *model communication frequency*

Once appropriate parameter values are finalized we will begin performing fully coupled model runs and analyze results to answer:

1. How do different climate regimes affect developing topographies?

2. How do landscape and climate coevolve during the development of topography?

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Citations:

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