Integrating glaciers and isostatic deformation with Landlab, a computational framework for Earth-surface systems, and GRASS GIS

Andrew D. Wickert[1*], William Colgan[2], Leif S. Anderson[1], Daniel Hobley[1], Robert S. Anderson[1], and Gregory E. Tucker[1]

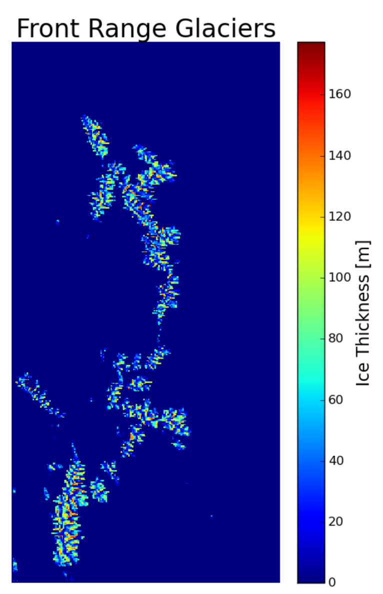
[1]University of Colorado Boulder
[2]Geological Survey of Denmark and Greenland
[*]wickert@colorado.edu

Abstract

Landlab is a new modeling framework to integrate components of the Earth-surface system and understand their interactions. Here we add two new components: (1) a mechanical ice flow model and (2) a model of Earth's flexural isostatic response to surface loads. The two are fully coupled, as large ice masses produce significant deflections of the surface. The mechanical ice flow model calculates 2D (depth-averaged) horizontal ice fluxes in response to an evolving surface mass balance parameterization and prescribed isothermal ice temperature. Solving depth-integrated ice velocity under prescribed ice temperature provides sufficient computational efficiency, relative to a fully 3D thermo-mechanical ice flow model, to explore glacier form and flow on geologic timescales. The flexure model ingests load distributions and a prescribed map of lithospheric elastic thickness to produce surface deflections. These connect with GRASS GIS to act as a database and platform for data–model integration and bypass the need to prepare input files. We explore the fully-transient interplay between ice overburden and lithospheric flexure using as a case study the evolution of the Yellowstone ice cap over the last glacial cycle, which covered an area of ~40,000 km2 at the Last Glacial Maximum (~26.5–19.5 ka).

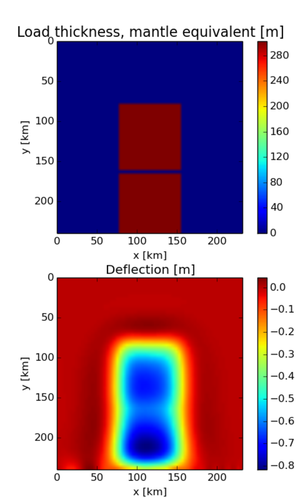
IceFlow

Originally written by Liam Colgan in Matlab before being ported to Python and modified for this project, IceFlow is uses a semi-implicit technique to solve the shallow ice approximation for glacier deformation. This technique is computationally efficient and ideal for investigations of past glaciers, where time scales are long and knowledge of the details of past ice conditions can be limited.



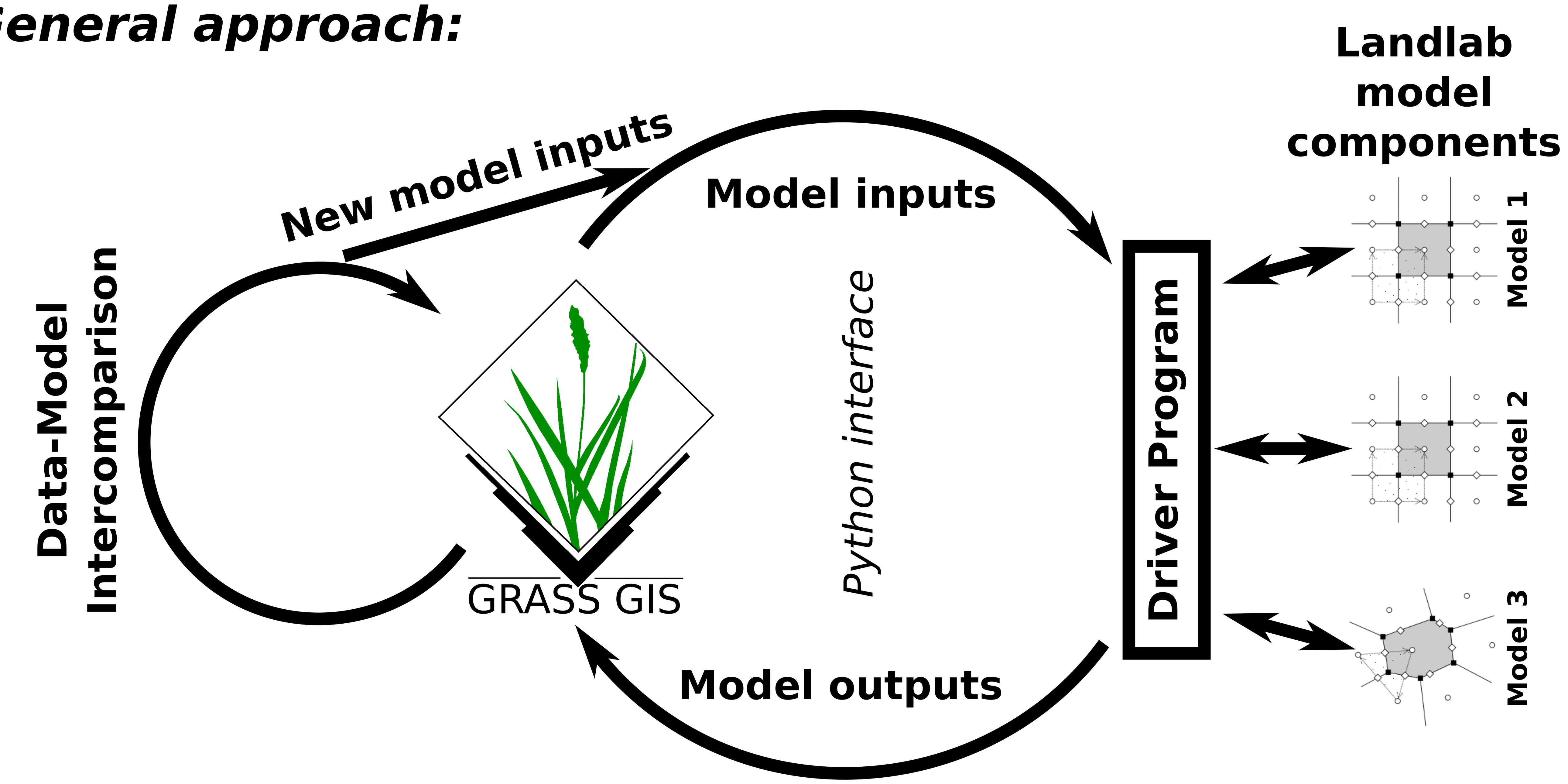
Flexure

Flexure, written by Andy Wickert, provides a finite-difference matrix solution for the bending of a 2D elastic plate. This is used here to simulate lithospheric deformation under a time-variable ice load, with the temporal response of the lithosphere provided by 1-dimensional viscous relaxation time scales at each cell.

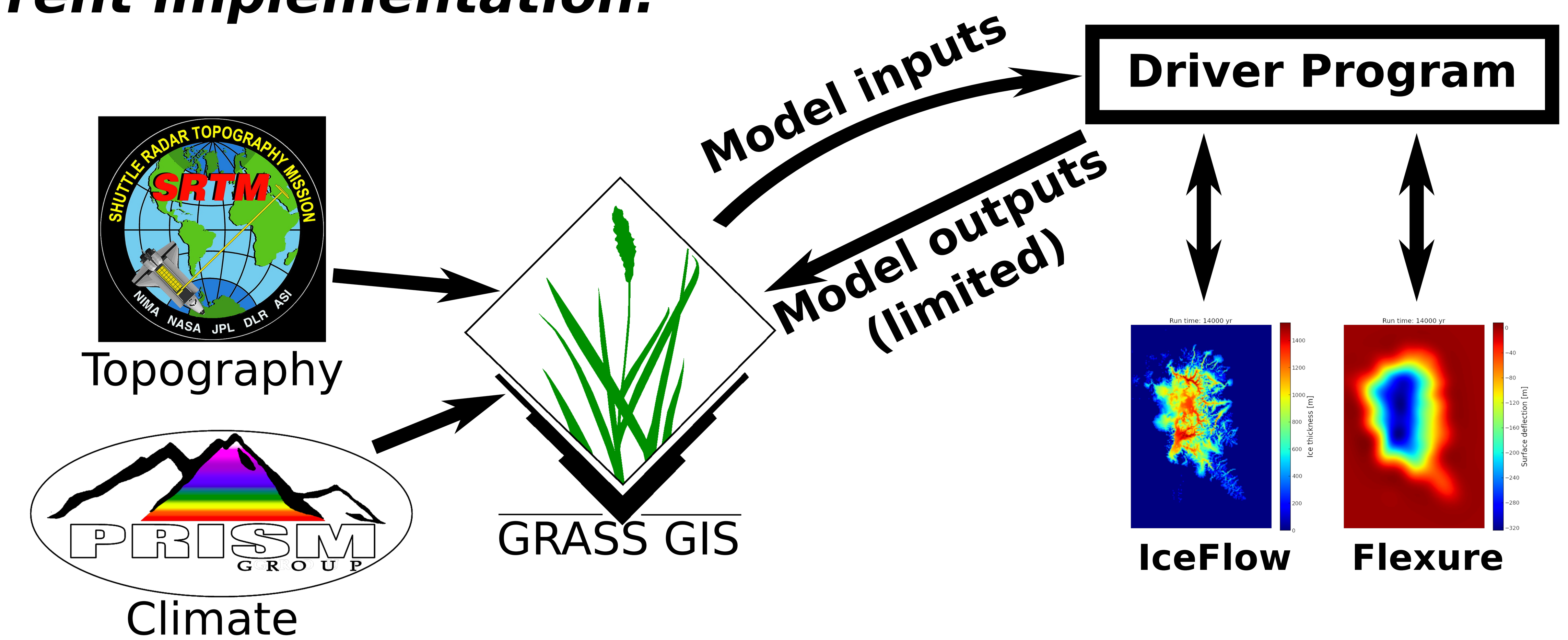


Integration: Python, GRASS GIS, and Landlab

General approach:



Current implementation:



Case Study: Yellowstone Ice Cap

At the Last Glacial Maximum, Yellowstone was covered by a thick, extensive ice cap. We model the advance of this ice cap from the mountains to the east into the Yellowstone caldera. The great mass of this ice means that flexural isostatic deformation of the Earth's surface is significant to unraveling its history.