EGU2016-9981

Landlab: a new, open-source, modular, Python-based tool for modelling Earth surface dynamics

Daniel E.J. Hobley[1], Gregory E. Tucker[1,4], Nicole M. Gasparini[2], Jordan M. Adams[2], Sai Nudurupati[3], Erkan Istanbulluoglu[3], Eric Hutton[4], and Jenny Knuth[1]

1 - Cooperative Institute for Research in Environmental Sciences (CIRES) and Department of Geological Sciences, University of Colorado at Boulder.
2 - Department of Earth and Environmental Sciences, Tulane University. 3 - Department of Civil and Environmental Engineering, University of Washington, Seattle
4 - Community Surface Dynamics Modeling System (CSDMS), University of Colorado at Boulder

http://landlab.github.io

ABSTRACT

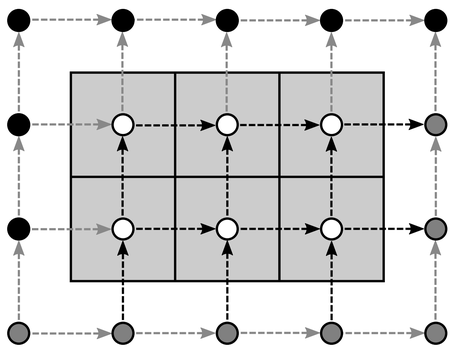
The ability to model surface processes and to couple them to both subsurface and atmospheric regimes has proven an invaluable tool in the Earth and planetary sciences. However, creation of a new model typically demands a very large investment of time, and modification of an existing model to address a new problem typically means the new work is constrained to its detriment by model adaptations for a different problem. Landlab is a new software framework explicitly designed to accelerate the development of new process models by providing: 1. a set of tools and existing grid structures to make development of new process components faster and easier; 2. a suite of stable, modular, and interoperable process components onto which new components can be added; and 3. a set of example models built with these components. Landlab's structure makes it ideal not only for fully developed modelling applications, but also for model prototyping and classroom use. Here we illustrate some of Landlab's capabilities, emphasizing its breadth of application and ease of use.

What is Landlab?

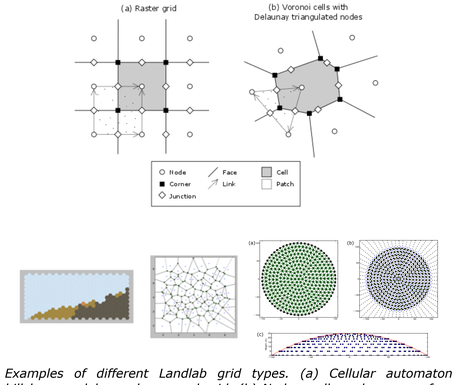
- An open-source, Python-language library that helps geoscience researchers efficiently develop 2D grid-based numerical models
- A set of pre-built model *components*, each of which models a particular landscape process (see examples)
- A framework for combining components into multi-process models
- Learn more at **http://landlab.github.io**

GRIDS

Grids are built from primitives such as *nodes, links,* and *cells.*



Different grid types

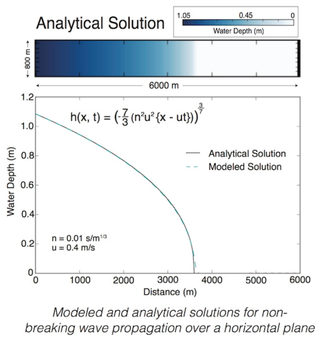


Examples of different Landlab grid types. (a) Cellular automaton hillslope model on a hexagonal grid. (b) Nodes, cells and corners of an irregular Voronoi-Delaunay grid. (c) Radial grid with z decreasing radially from the central node.

COMPONENTS

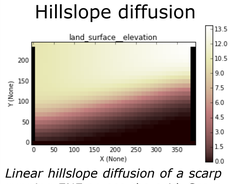
- Standard design
- Sharing data through grid object
- Coupling with driver script

Shallow-water flow over terrain



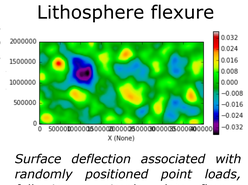
Modeled and analytical solutions for non-breaking wave propagation over a horizontal plane

Hillslope diffusion



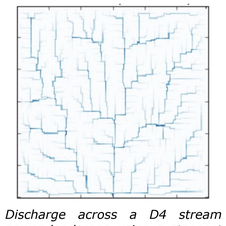
Linear hillslope diffusion of a scarp running ENE across the grid. Scarp was vertical at t=0.

Lithosphere flexure



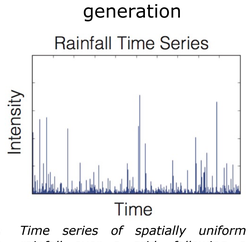
Surface deflection associated with randomly positioned point loads, following a simple plate flexure model.

DEM flow routing



Discharge across a D4 stream power landscape using a steepest descent flow router (following Braun & Willett 2013).

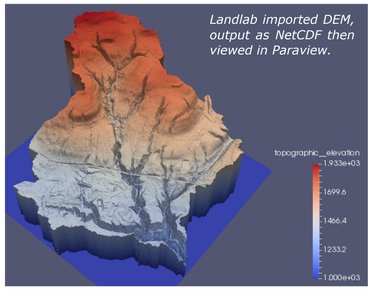
Stochastic rainfall generation



Time series of spatially uniform rainfall over a grid, following a modified Poisson pulse model (Eagleson, 1978), as also in CHILD.

UTILITIES

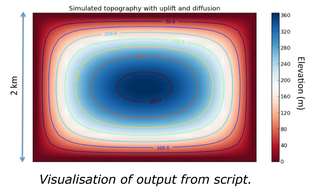
- Import ESRI Arc AsciiGrid format digital elevation data
- Read and write netCDF files
- Read model parameters from formatted text files
- Suite of plotters, including data overlay



SCRIPTING

Example: a nine-line diffusion model

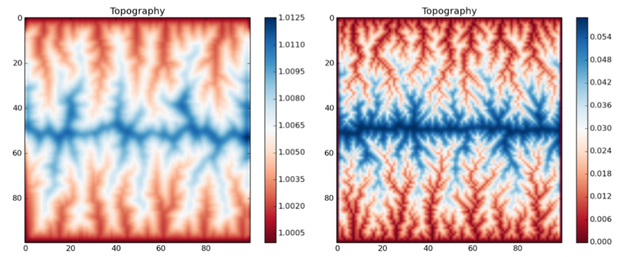
```
mg = landlab.RasterModelGrid(numrows, numcols, dx)
z = mg.add_zeros('node', 'land_surface__elevation')
core_nodes = mg.core_nodes()

for i in range(0, num_time_steps):   # main loop
    g = mg.calculate_gradients_at_active_links(z)  # slope
    qs = -kd*g   # sediment flux
    dqsds = mg.calculate_flux_divergence_at_nodes(qs)
    dzdt = uplift_rate - dqsds
    z[core_nodes] += dzdt[core_nodes] * dt
```



Visualisation of output from script.

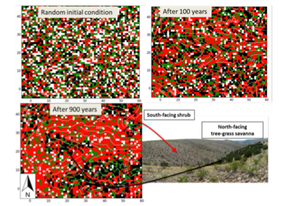
EXAMPLES

Landform Evolution



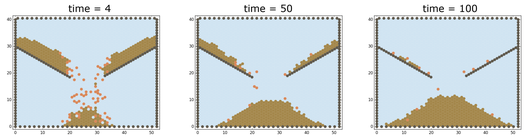
Steady state uplifting stream power landscapes in Landlab both with (left) and without (right) additional superimposed hillslope diffusion. Colourbar is elevation (model km); horizontal unit is also model km.

Vegetation dynamics



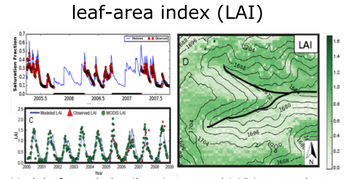
Cellular model of vegetation type sensitivity to hillslope aspect. Colours denote different vegetation types; white is bare earth.

Granular mechanics (lattice-grain model)



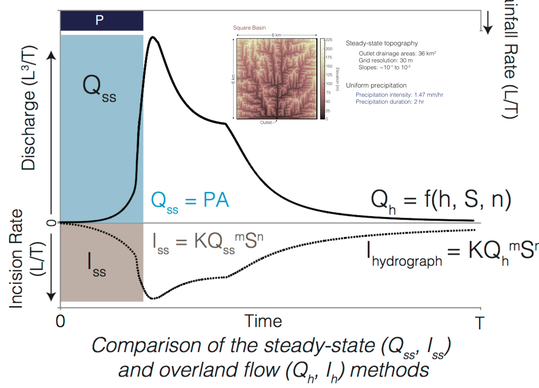
Lattice-grain cellular automaton ssimulating granular mechanics in an hourglass-like simple test. Grey is a fixed cell; brown a currently immobile grain; and orange a moving grain. Landlab has extensive support for CA models.

Soil moisture and leaf-area index (LAI)



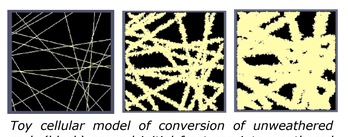
Model of coupled soil moisture and LAI in a catchment across several years, compared to observations.

Rainfall, runoff, and erosion



Comparison of the steady-state (Q_{ss}, I_{ss}) and overland flow (Q_h, I_h) methods

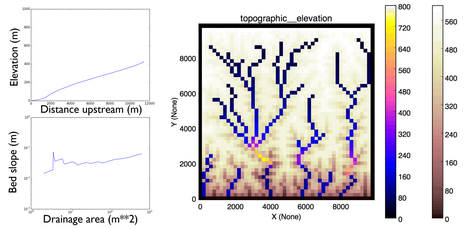
Fractured rock weathering



Toy cellular model of conversion of unweathered rock (black) around initial fractures into weathered material (yellow).

Model coupling rainfall to shallow water overland flow (following deAlmeida et al., 2012) and shear-stress-dependent erosion on a synthetic stream power landscape. Rainfall occurs at a constant rate during the period marked "P" over the illustrated catchment. Figure illustrates the resulting hydrograph and incision rates at the network outlet. The overland flow model generates a realistic lag in peak discharge.

Sediment flux dependent channels and steepness indices



Steepness indices (bright colours) during channel response to a large increase (x20) in uplift rate, in a fluvial landscape controlled by a tools-and-cover-like erosion rule. Topographic elevations are shown in brown shades (m). A time slice is shown from shortly into the transient response, as a knickzone begins to sweep backwards from the outlet into the catchment. The knick is wildly oversteepened compared to both up- and downstream reaches.

Also shown are the long profile and slope-area responses of the longest channel in the landscape at the same time slice.

For more on this topic: K1, Wednesday at 11am!

Development of Landlab is supported by NSF (ACI-1450409 and ACI-1147454)