Steps for building a watershed model in ParFlow

ParFlow Short Course

1. Gridded Inputs

Meteorology*

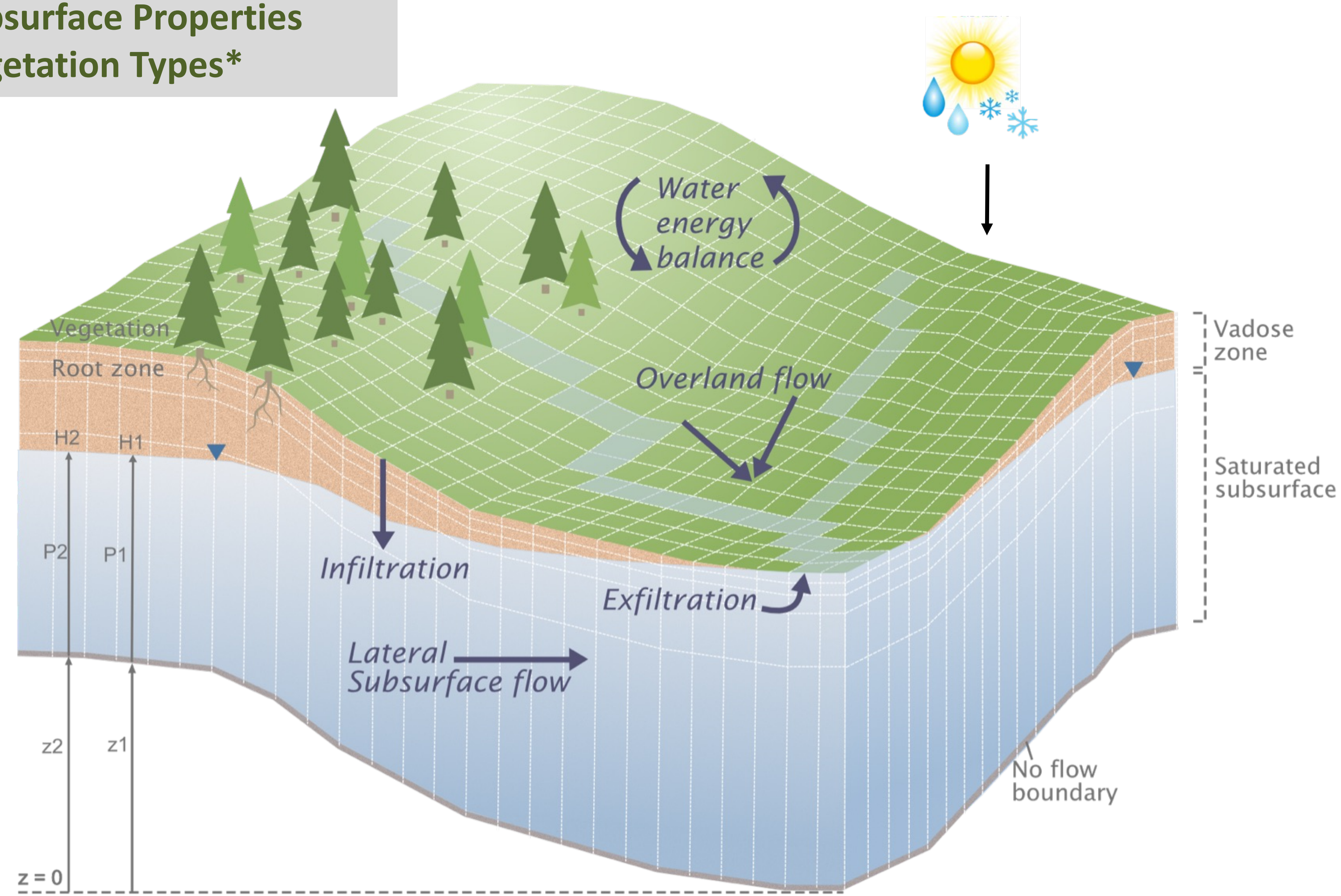
Topography

Subsurface Properties

Vegetation Types*

2. Boundary Conditions

3. Initial Conditions



Workflow Outline

1. Evaluate available model inputs
2. Determine your domain configuration
3. Process topography
4. Setup the subsurface
5. Initialize the model (i.e. spinup)
6. Additional setup for PF-CLM

This is also outlined in [Setting Up a Real Domain] in the manual

1. Evaluate available model inputs

- Land surface
  - Digital Elevation Model -> slopes
  - Mannings roughness coefficients
- Subsurface configuration: hydrologic properties for soil and and deeper geologic units
  - Permeability
  - Porosity
  - Specific storage
  - Relative permeability
  - Saturation

1. Evaluate available model inputs

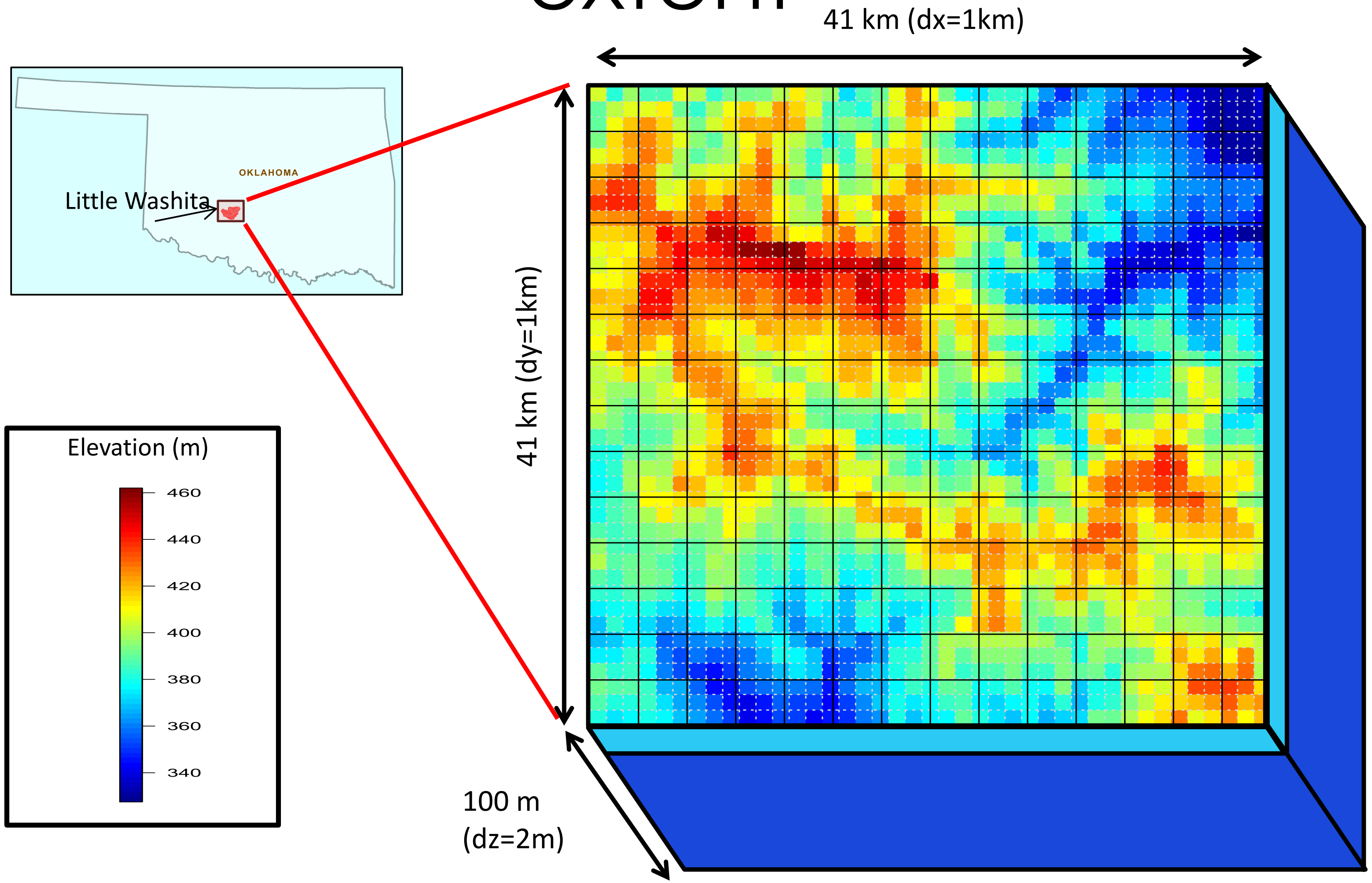
- Atmospheric forcings:
  - ParFlow: moisture flux for surface
  - ParFlow CLM: precipitation, air temperature, wind, incoming short and longwave radiation, atmospheric pressure, specific humidity
- Land cover: vegetation types and properties (for ParFlow-CLM)

2. Determine your domain configuration

1. *What are the questions you want to answer with your model?*

2. *What kind of inputs do you have available to build your model with?*

Lateral resolution and domain extent



Setting up the subsurface model

- Computational Grid (variable dz?)
- Geometries
- Domain
- Parameters
  - Permeability
  - Porosity
  - Specific storage
  - Relative permeability
  - Saturation
  - Toposlopes
  - Mannings coefficient

- Timing
- Time steps
- Time cycles

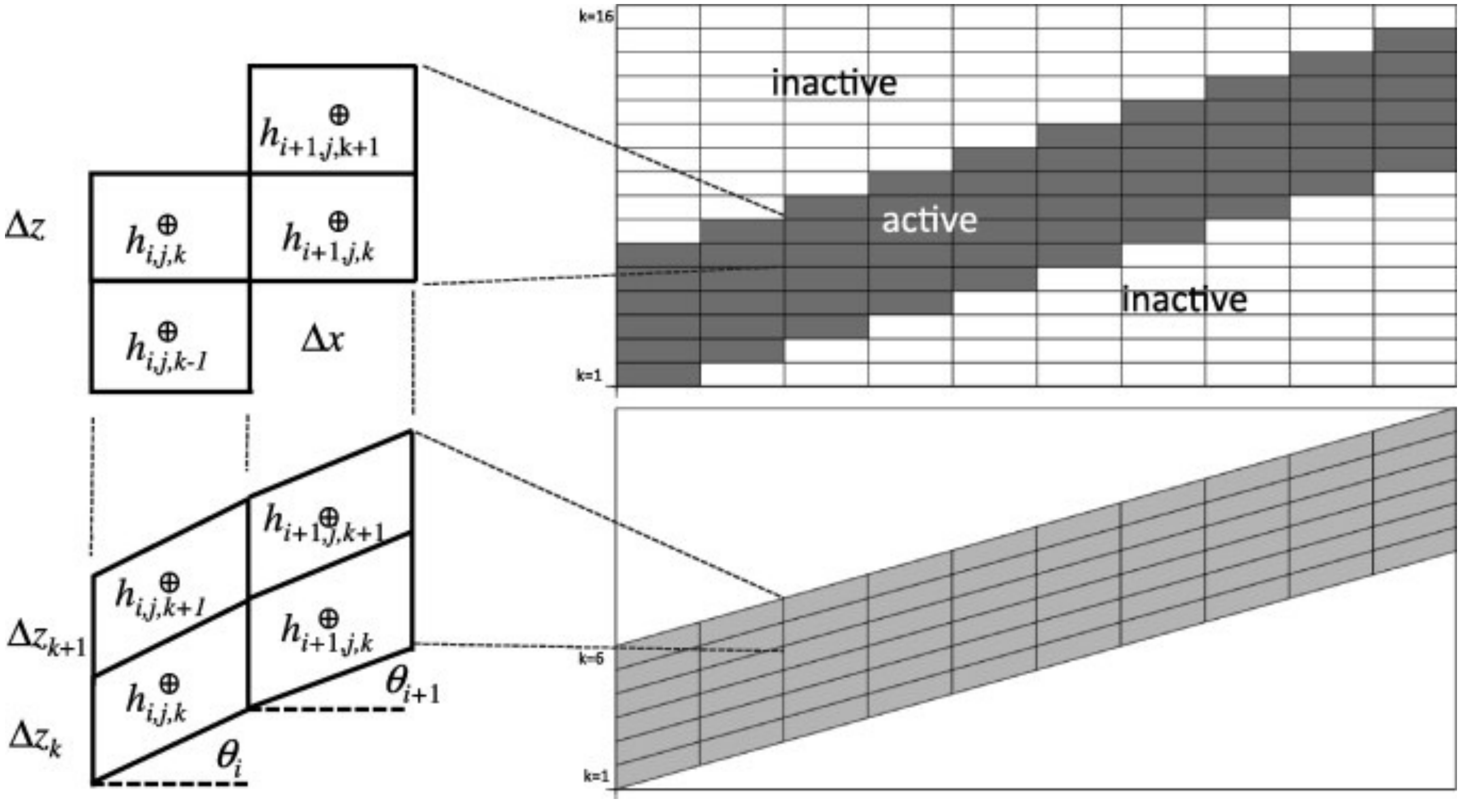
- Boundary Conditions
- Initial Conditions

- CLM (yes/no)
- Terrain following grid (yes/no)
- Solver settings

Subsurface configuration:

– Domain thickness

– Terrain following grid or orthogonal grid

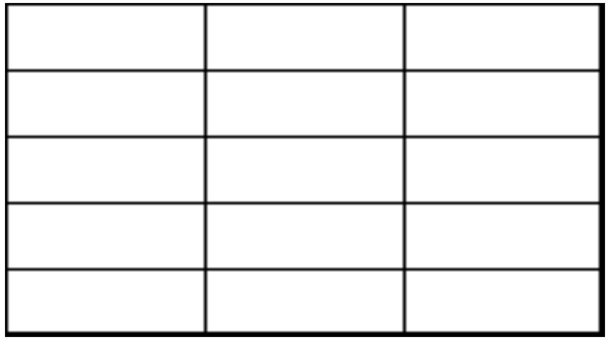


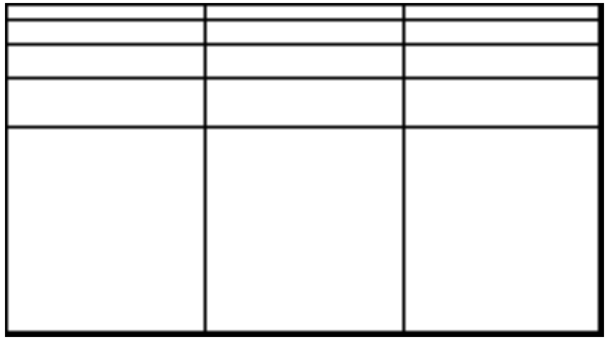
Maxwell, 2013

http://parflow.blogspot.com/2015/08/domain-options-terrain-following-vs.html

Subsurface configuration:

- Constant or variable layer thickness (dz)





- Variable dz allows for thin layers at the surface and thicker layers at the bottom of the domain to maintain high resolution in the upper layers and total domain thickness without too many layers

Boundary Conditions

- Boundary conditions must be set for all of the external patches on the domain
- 12 types of pressure boundary conditions (*BC Pressure in manual*):
  1. DirEquilRefPatch: pressure will be in hydrostatic equilibrium with reference pressure
  2. DirEquilPLinear: pressure will be in hydrostatic equilibrium with piecewise line at elevation z=0
  3. FluxConst: Constant flux (L/T) normal to the patch
  4. FluxVolumetric: Constant volumetric flux normal to the patch
  5. Pressure File: Defines hydraulic head boundary conditions. Only the values on the specified patch will be used
  6. FluxFile: Flux boundaries read in from a pfb file
  7. OverlandFlow: Turns on fully-coupled overland flow routing for uniform fluxes (e.g. rainfall or ET over the entire domain)
  8. OverlandKinematic: Turns on fully-coupled overland flow routing with upwinding and interface centered-fluxes
  9. OverlandDiffusive: Turns on fully-coupled overland flow routing with diffusive wave approximation
  10. SeepageFace: Turns on a seepage face boundary condition
  11. OverlandFlowPFB: Turns on fully-coupled overland flow routing for uniform fluxes with grid based spatially variable fluxes read in from a pfb
  12. Exact Solution: Exact know solution applied as a Dirichlet boundary condition on the patch

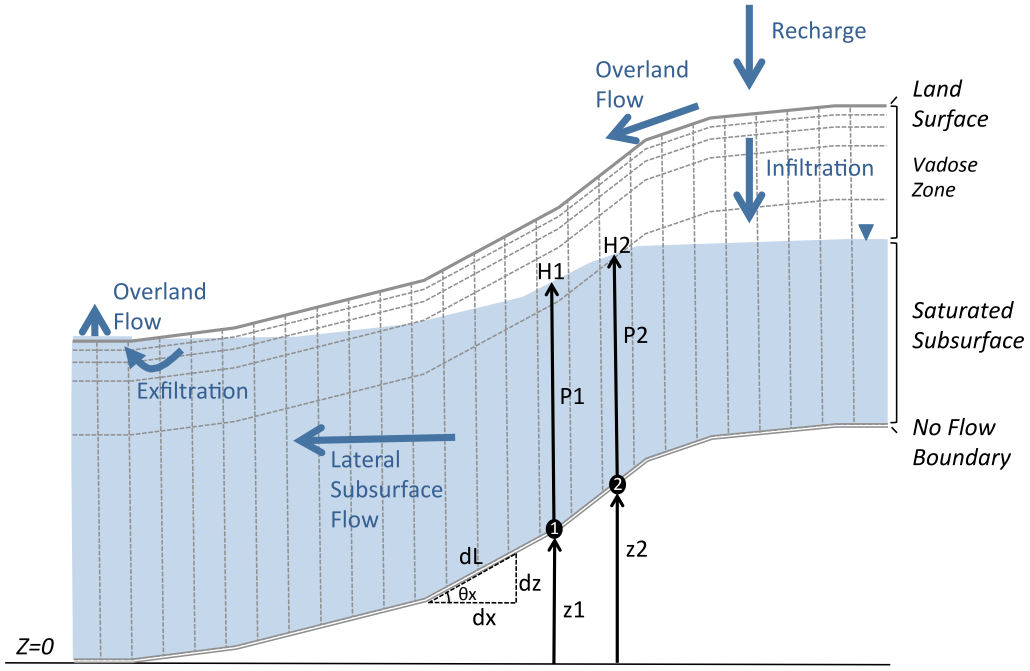
- Internal Dirichlet boundary conditions can also be defined by setting the pressure at internal points in the domain (*Internal BCs in manual*)

3. Processing Topography

Convert from a digital elevation model to slopes and adjust values to ensure a realistic drainage network

Processing Topography

- ParFlow requires <u>slopes</u> not elevations



Built in PFTools commands can be used to calculate slopes from elevations, but this is **<u>not</u>** the recommended approach for watershed domains.

Processing Topography: Why shouldn’t you use slopes from your raw DEM directly?

- When you calculate slopes from DEMs you are not guaranteed to get a fully connected drainage network
- This is particularly problematic for lower resolution DEMS

This is a well known problem and there are many approaches to address this

Contents lists available at ScienceDirect
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Routing overland flow through sinks and flats in interpolated raster terrain surfaces☆

Frank Kenny *, Bryce Matthews, Kent Todd
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HYDROLOGICAL PROCESSES
Hydrol. Process. **30**, 846–857 (2016)
Published online 20 September 2015 in Wiley Online Library
(wileyonlinelibrary.com) DOI: 10.1002/hyp.10648

Efficient hybrid breaching-filling sink removal methods for flow path enforcement in digital elevation models

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EARTH SURFACE PROCESSES AND LANDFORMS
Earth Surf. Process. Landforms **41**, 658–668 (2016)

Published online 13 January 2016 in Wiley Online Library
(wileyonlinelibrary.com) DOI: 10.1002/esp.3888

The practice of DEM stream burning revisited

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Received 27 July 2015; Revised 7 December 2015; Accepted 7 December 2015

Contents lists available at ScienceDirect
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Priority-flood: An optimal depression-filling and watershed-labeling algorithm for digital elevation models

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Hydrol. Earth Syst. Sci., 14, 1153–1165, 2010
www.hydrol-earth-syst-sci.net/14/1153/2010/
doi:10.5194/hess-14-1153-2010

Hydrology and Earth System Sciences

On the uncertainty of stream networks derived from elevation data: the error propagation approach

T. Hengl[1], G. B. M. Heuvelink[2], and E. E. van Loon[1]

WATER RESOURCES RESEARCH, VOL. 34, NO. 4, PAGES 897–901, APRIL 1998

Extraction and representation of nested catchment areas from digital elevation models in lake-dominated topography

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HYDROLOGICAL PROCESSES
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Pit filling algorithms ensure drainage and can achieve globally optimal solutions but may not match the drainage network

The practice of DEM stream burning revisited

Computers & Geosciences

journal homepage: www.elsevier.com/locate/cageo

Stream burning methods match the spatial configuration of the drainage network but can result in deeply incised channels that alter the terrain attributes of the DEM

, APRIL 1998

On the uncertainty of stream networks derived from elevation data: the error propagation approach

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Processing Topography: GRASS Workflow

- GIS tools can help you evaluate your drainage network
- Example workflow using the watershed analysis tool in grass is documented on the ParFlow Blog (http://parflow.blogspot.com/2015/08/terrain-processing.html)
- This uses the A* algorithm to ensure that every cell n the domain drains out
- Make sure to look closely at the drainage network developed by GRASS to ensure its consistent with what you expect.

Processing Topography: PriorityFlood Tool

GitHub Repo

https://github.com/lecondon/PriorityFlow

README.md

PriorityFlow

PriorityFlow is a toolkit for topographic processing for hydrologic models. This repo contains a set of R Functions and example workflow scripts.

Development Team

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- Reed Maxwell (rmaxwell@mines.edu)

Citation

For more details on the model and if you use PriorityFlow in published work please cite the following reference:
Condon, LE and RM Maxwell (2019). Modified priority flood and global slope enforcement algorithm for topographic processing in physically based hydrologic modeling applications. Computers & Geosciences,

Computers & Geosciences
Volume 126, May 2019, Pages 73-83

Modified priority flood and global slope enforcement algorithm for topographic processing in physically based hydrologic modeling applications ☆

Laura E. Condon [a], Reed M. Maxwell [b]

- Modified priority flood algorithm for depression filling and stream enforcement
- Slope processing tools and workflows for D4 and D8 routing
- Options for stream network smoothing
- Additional options for handling primary and secondary flow directions
- More control of DEM Processing and generated PF Consistent slope outputs

Parking lot test

- Make your domain impervious, rain on it and look at the drainage network

4. Setup the subsurface

Developing a gridded representation of subsurface

Subsurface inputs

1. Identify unique subsurface units and provide subsurface geometries to ParFlow
   - Either using solid files or indicator files

2. Assign the hydrologic properties to each unit
   - permeability, specific storage, porosity and van Genuchten parameters

http://parflow.blogspot.com/2015/08/subsurface-setup-options.html

5. Initializing the model (spinup)

Determining the starting groundwater configuration for your simulations

Spinup

- Goal: develop a domain that is stable and solving nicely before you start making runs to answer questions
- There is no best practice for spinup, results and approaches will vary depending on your domain and the questions you want to answer with your model
- Groundwater is the slowest moving part so its often easiest to start with a simplified system and get a stable water table before adding in land surface processes

http://parflow.blogspot.com/2015/08/spinning-up-watershed-model.html

One Approach to Spinup

1. Initialize your water table somewhere
   – Completely saturate the domain
   – Make it completely dry
   – Make an intelligent guess about where you think the water table should be
2. Run for a long time with a constant or periodic forcing at the land surface until you get a ‘stable’ configuration

6. Additional setup for PF-CLM

Additional Inputs needed:

1. Land cover type
2. Properties of each land cover type (IGBP land cover classifications already setup)
3. Meteorological forcing data which can be spatially heterogeneous or homogeneous
   - Visible or short-wave radiation [W/m2]
   - Long wave radiation [W/m2]
   - Precipitation [mm/s]
   - Air Temperature [K]
   - East-west wind speed [m/s]
   - South-to-North wind speed [m/s]