Implementing Hillslope Hydrology in CLM

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1 NCAR

2 RUTGERS

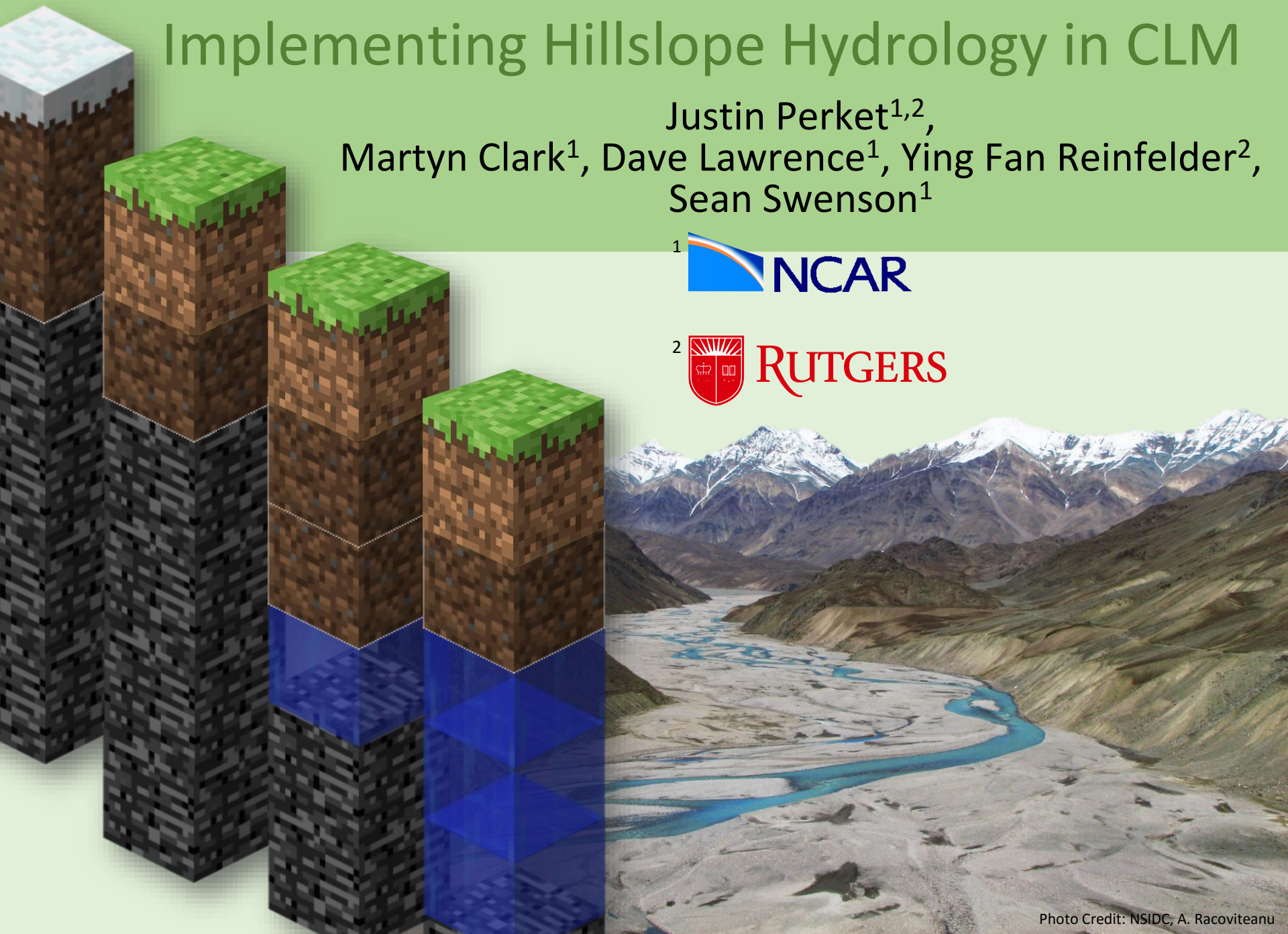
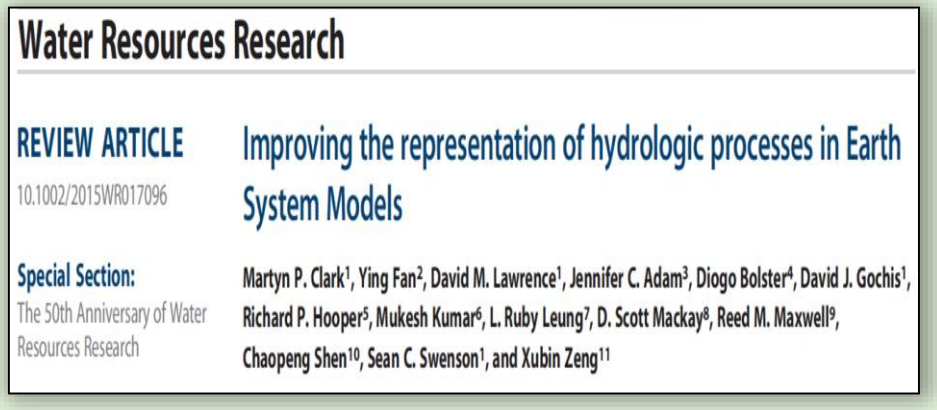


Photo Credit: NSIDC, A. Racoviteanu

CUAHSI-NCAR collaboration

- CUAHSI (Consortium of Universities for the Advancement of Hydrologic Science, Inc.)

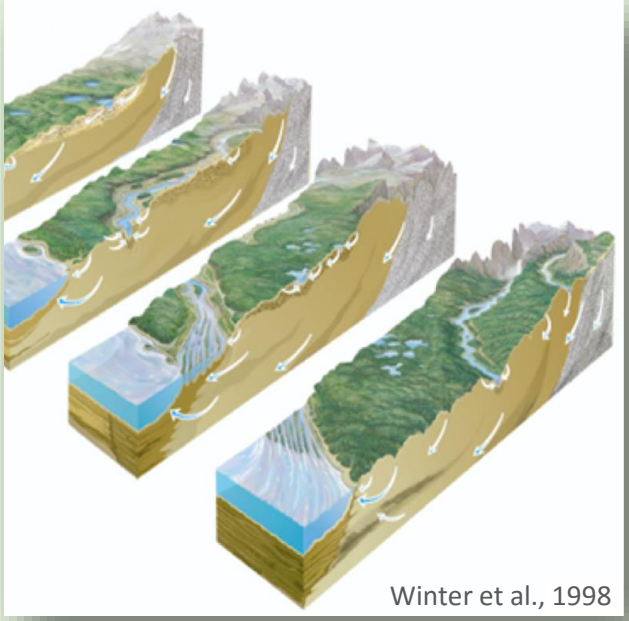
- CUAHSI / NCAR initiative to improve representation of hydrologic processes in ESMs
  - Hillslope hydrology
  - Plant hydrodynamics



Motivation

- Land water strongly influence surface energy & BGC fluxes, exchanges with atm/ocean
  - ET affects boundary layer heat/moisture and dynamics
- Climate influences freshwater availability/quality

- Lateral subsurface flow critical to represent terrestrial water, but missing from most ESMs
- Need efficient representation of hillslope hydrology dynamics for global water cycle interactions with climate

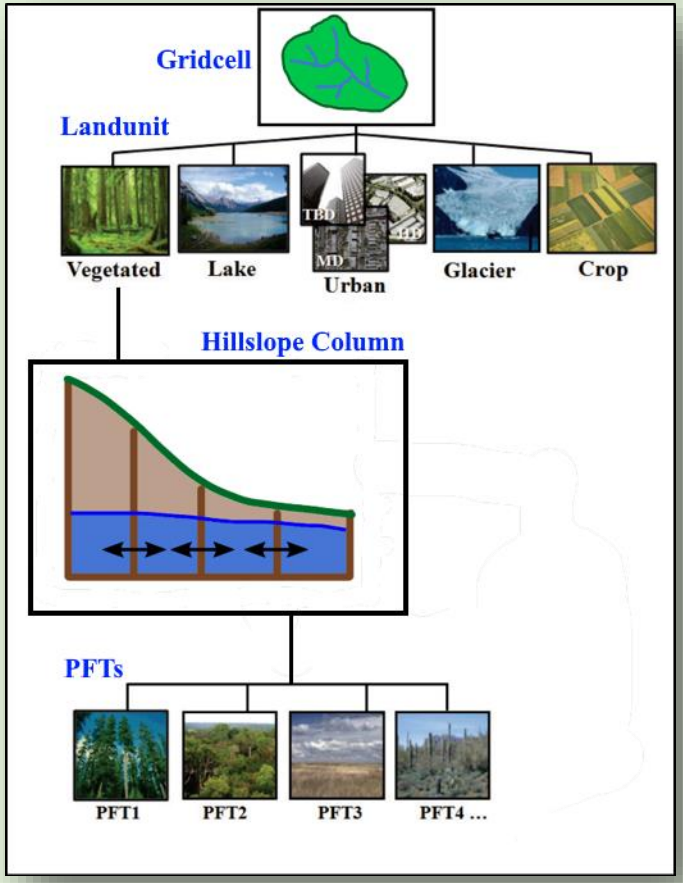


Winter et al., 1998

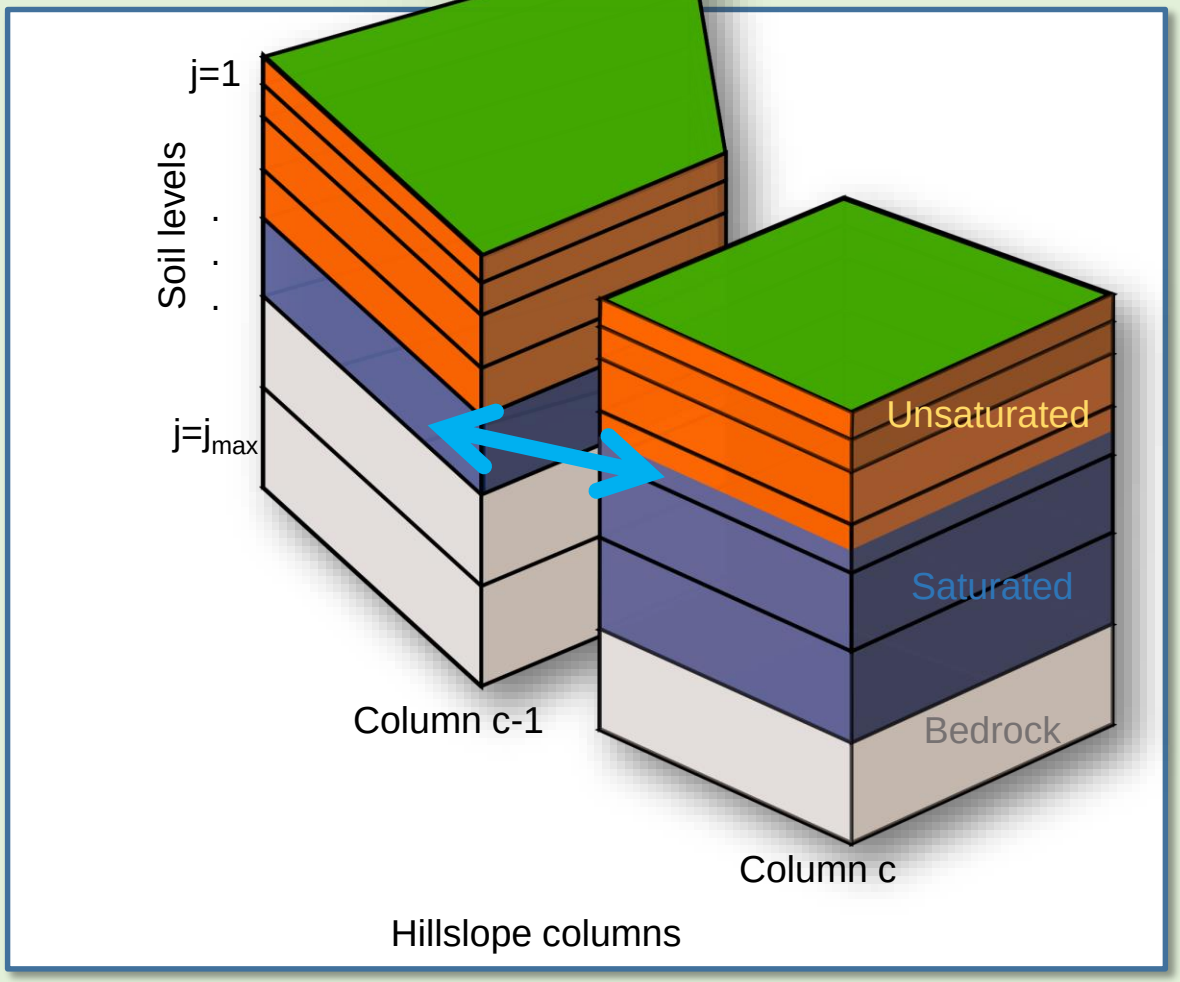
Implemented Intra-Gridcell Hillslope Representation

- Gridcell level assumes role of drainage basin
- Few representative hillslopes per basin (if not singular)
- Lateral connections between neighboring columns in hillslope

Modified CLM Hierarchy

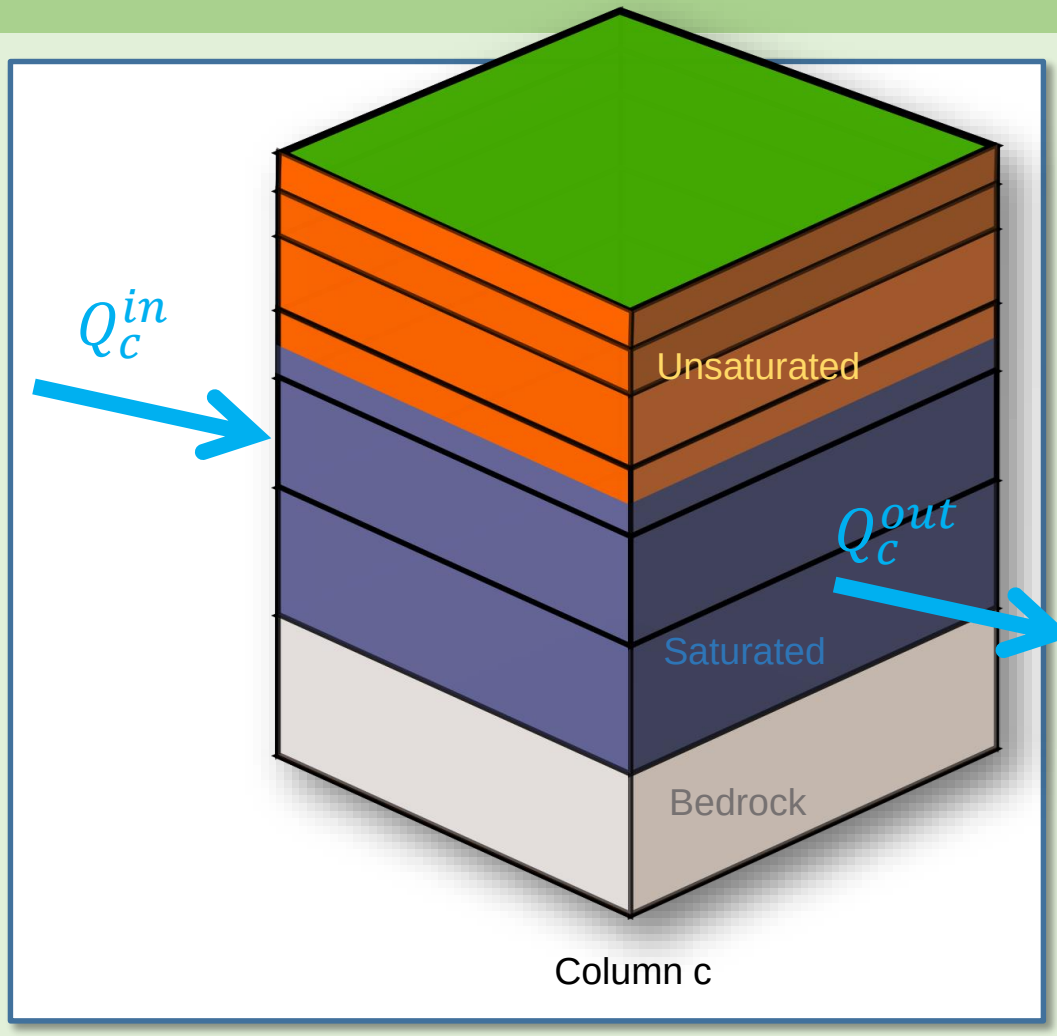


Implemented Hillslope Lateral Flow



- Columns have distinct:
  - Elevations
  - Slopes
  - Surface areas
  - Bedrock depths
- Lateral saturated flow between columns based on:
  - Topographic height
  - Water table slope

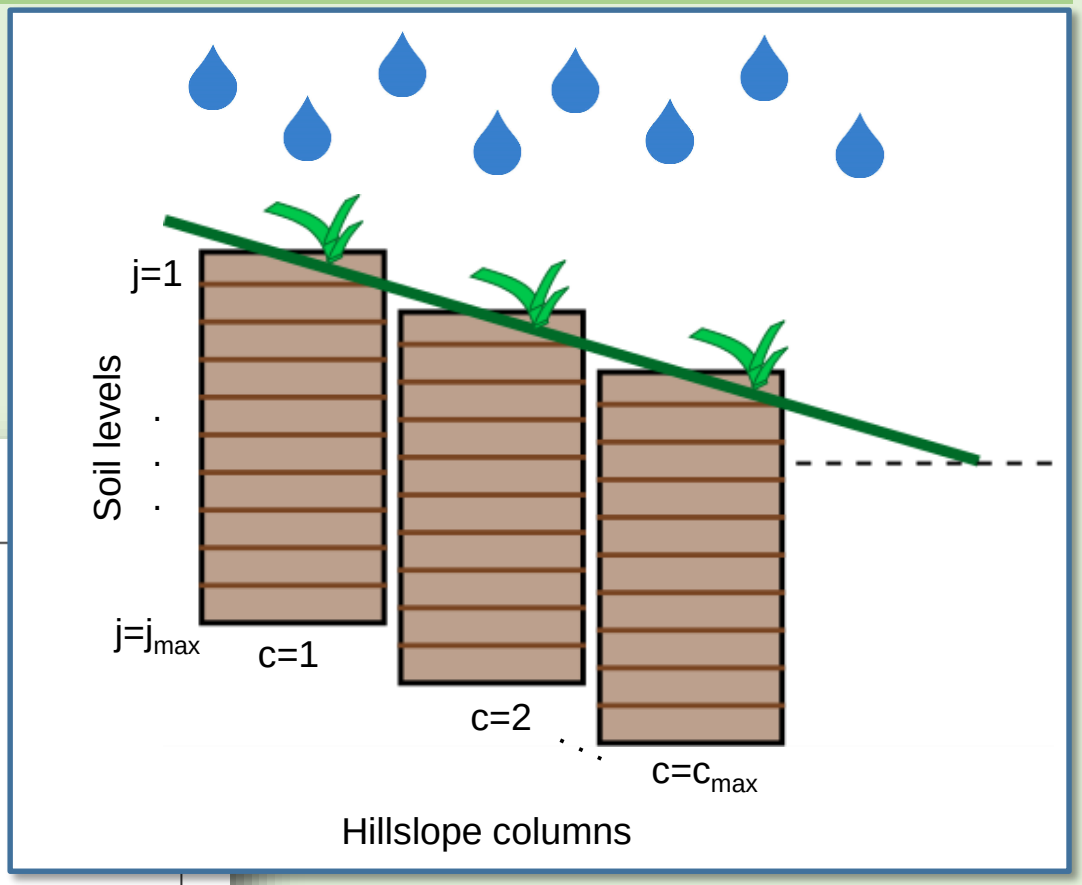
Implemented Hillslope Lateral Flow

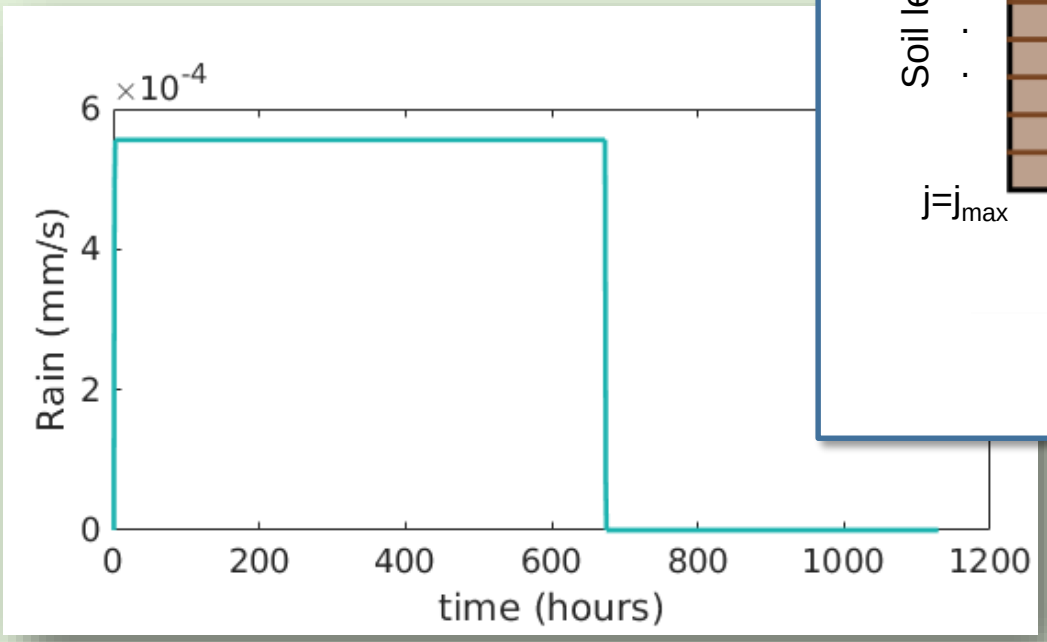


- $Q_c^{out} = \frac{-K_0 * depth * \tan(slope)}{n}\left(1 - \frac{wt}{depth}\right)^n$
- Checks to prevent soil moisture < specific yield in any layer
- Withdraws from deeper layers if needed
- Q_c^{in} adds to water table layer
- $Q_c^{net} = Q_c^{out} - \underbrace{\frac{Area_{(c-1)}}{Area_c} Q_{c-1}^{out}}_{Q_c^{in}}$

Synthetic Test Cases

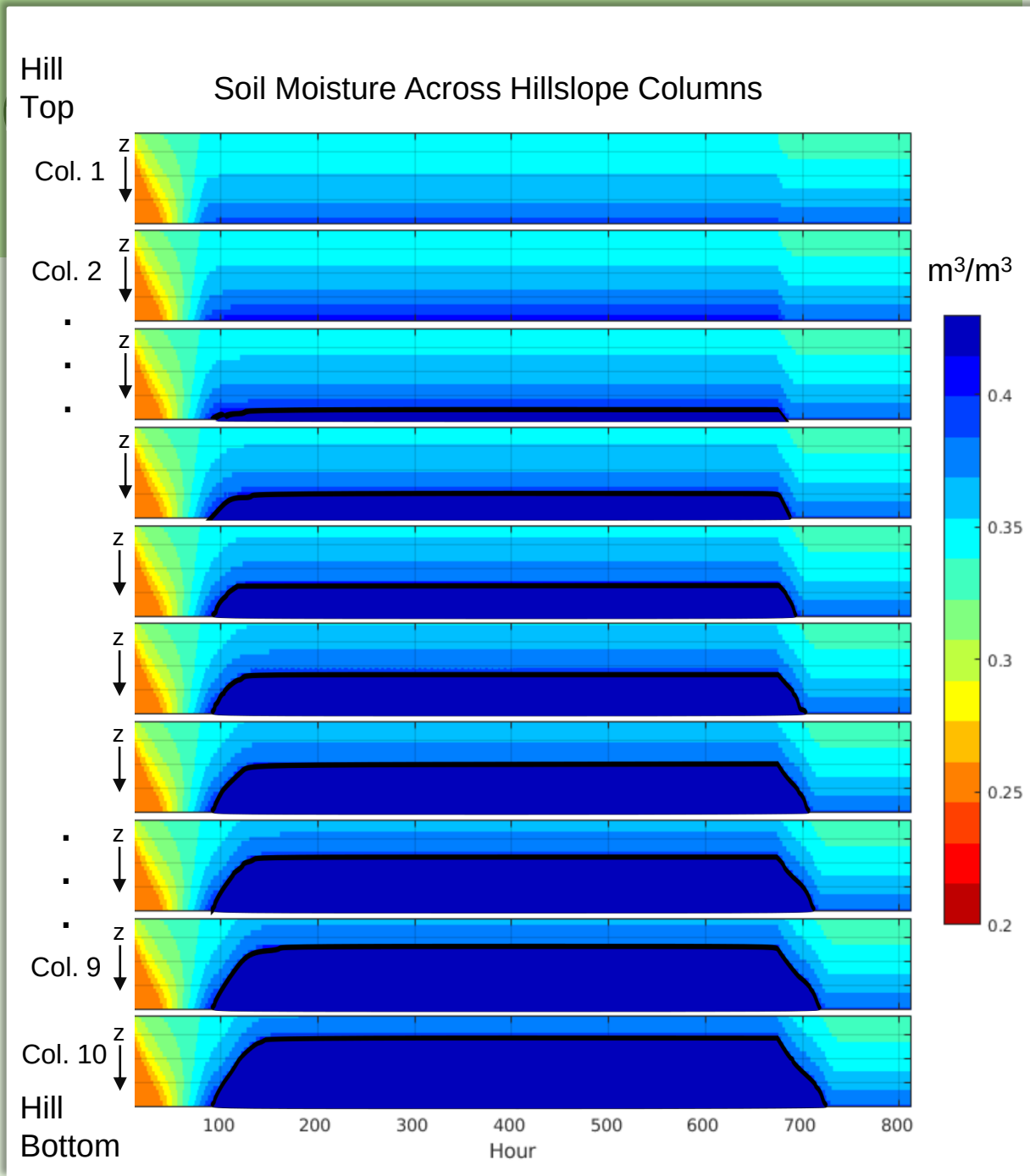
- Flat constant slope w/ 700 hour constant rain
- Compared to simple analytical & numerical solns.





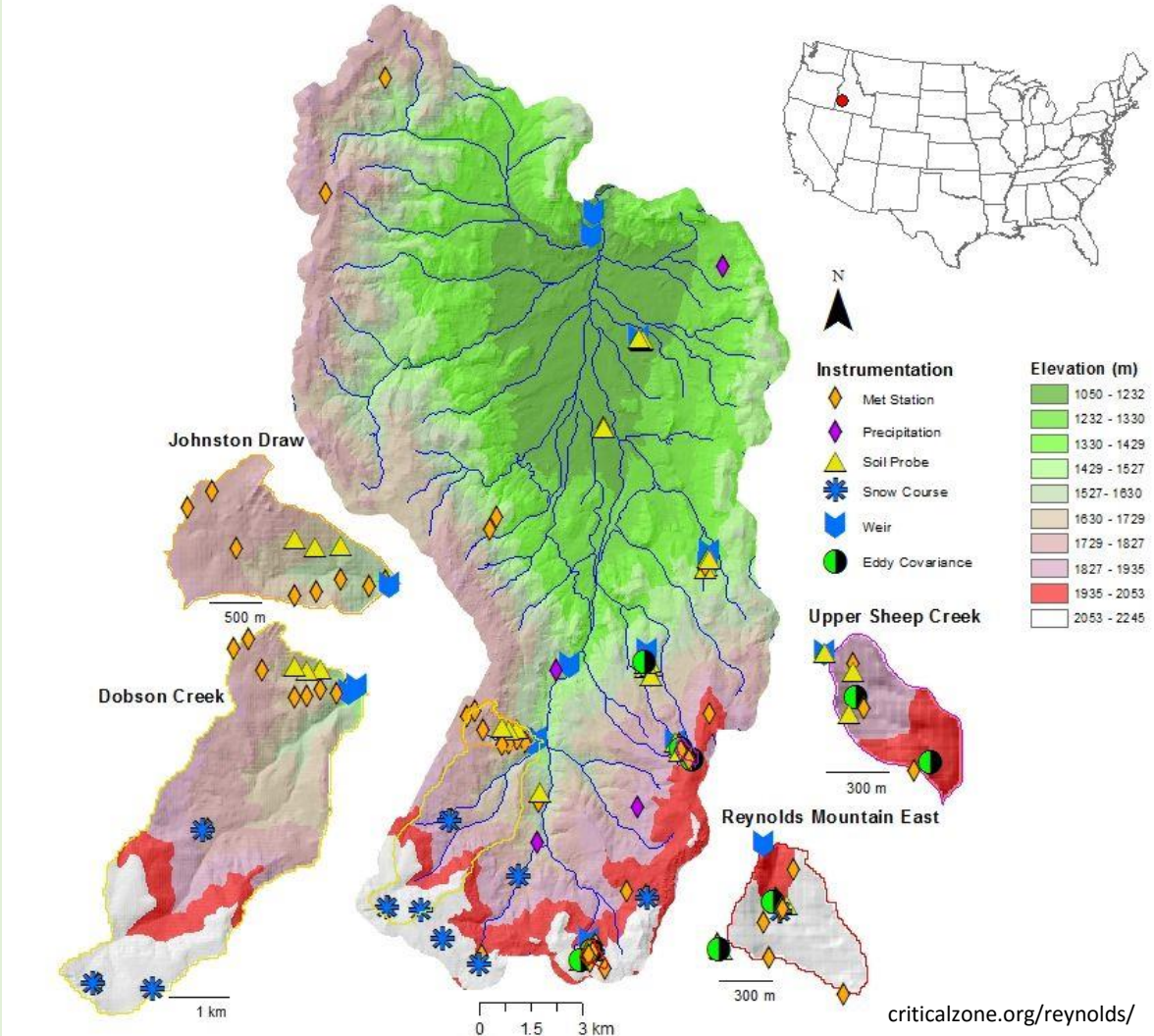
Synth

- Flat constant slope w/ 700 hour constant rain
- Increased water storage, higher water table going downhill

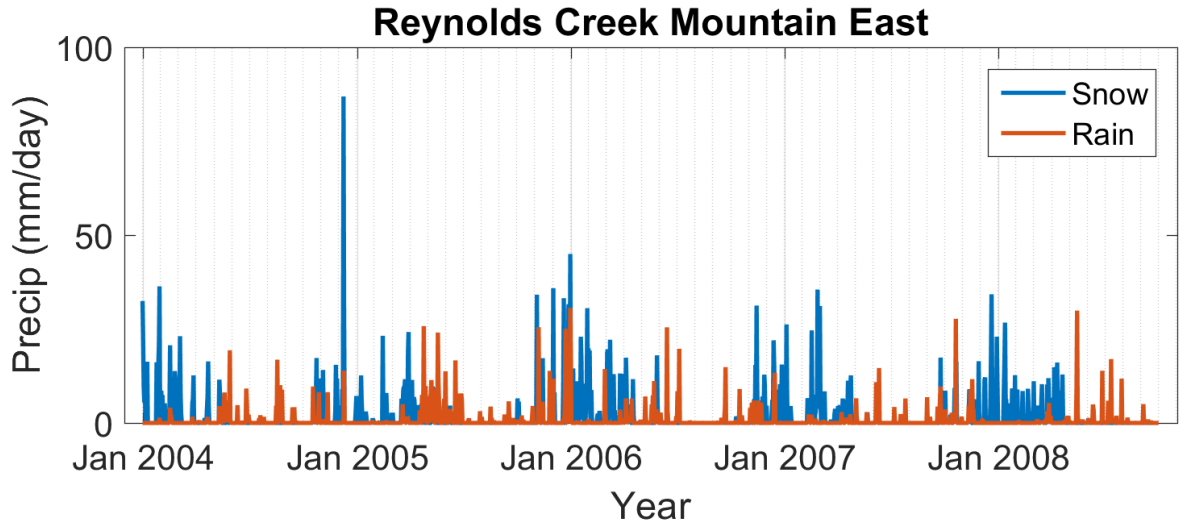


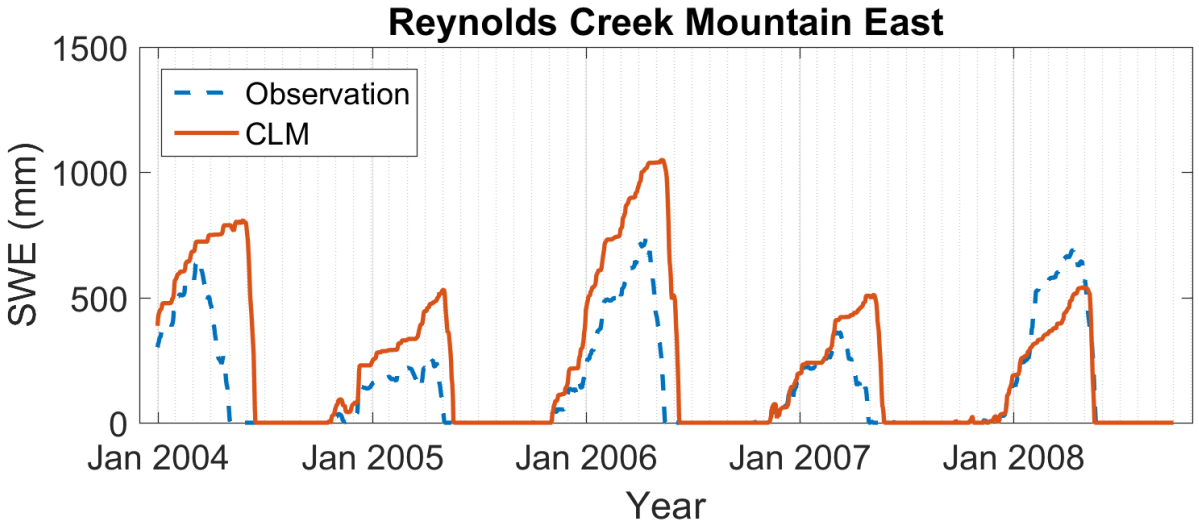
Reynolds Creek Watershed

- Compared Single Point CLM w/ site forcing to Critical Zone Observatory measurements

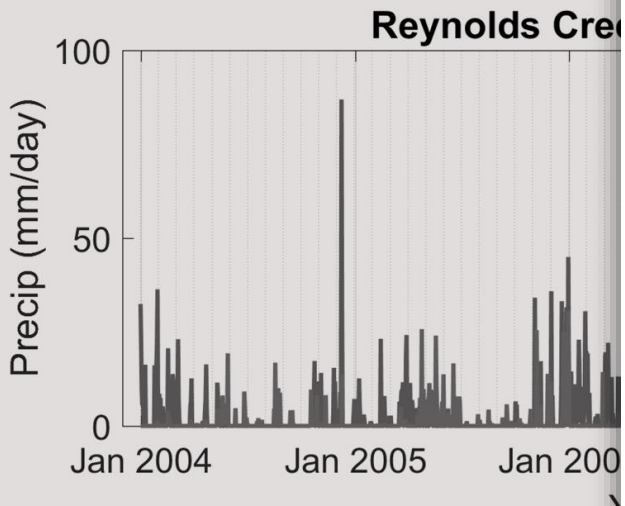


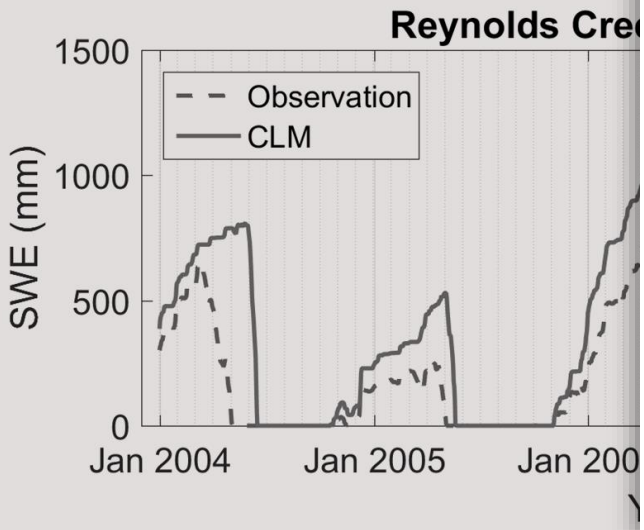
Reynolds Creek Watershed

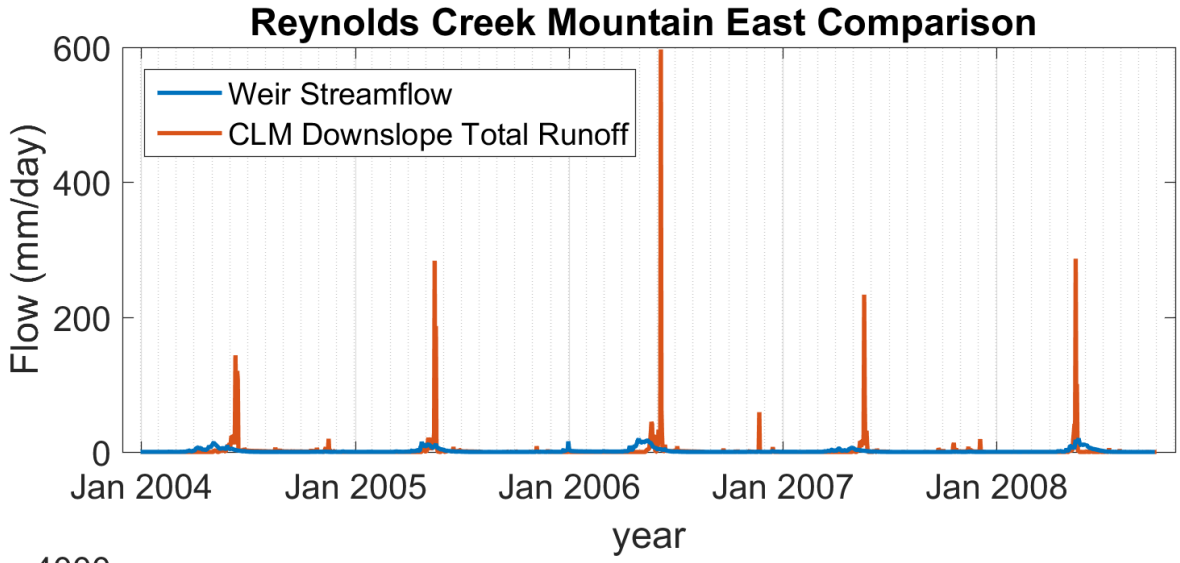


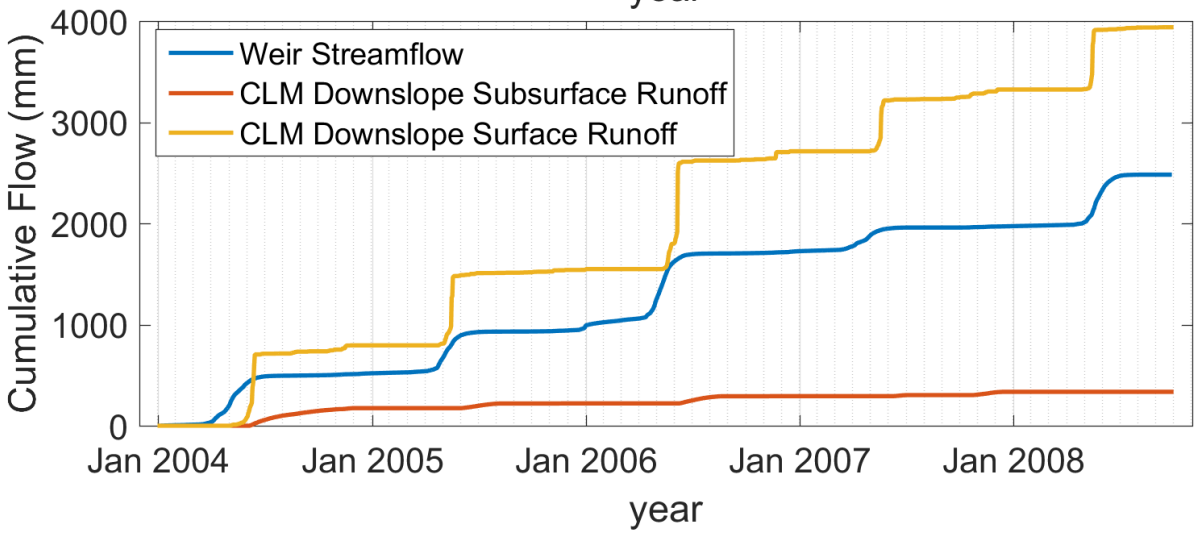


Reynolds Creek Watershed





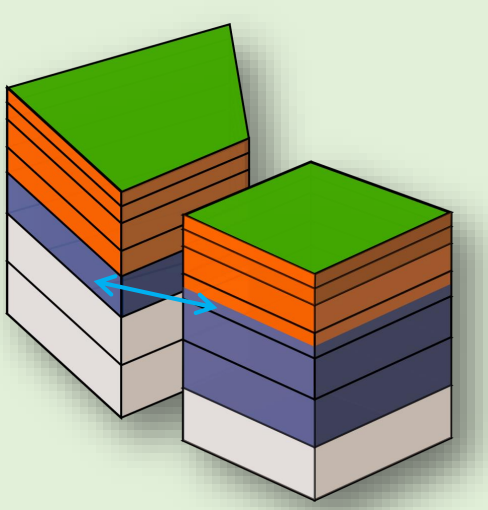




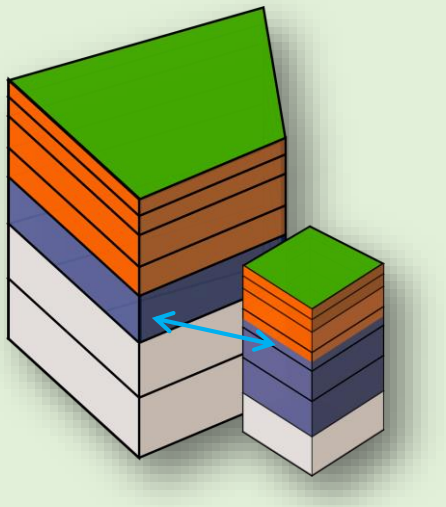
Parameter Variation

- Control:
  - 1m soil depth
  - 10 % slope
- 2 columns: upland & lowland
- Trial Series 1: converging basin

Trial #	Parameter Varied	Column	
		Upslope	Downslope
1a	Area (relative to 1st col.)	1	1/2
1b	Area (relative to 1st col.)	1	1/4
1c	Area (relative to 1st col.)	1	1/8



Control

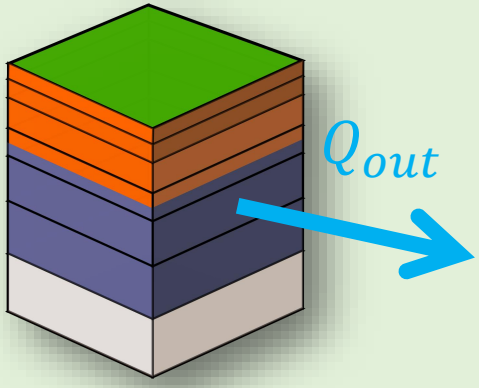


Shrinking Downslope Area

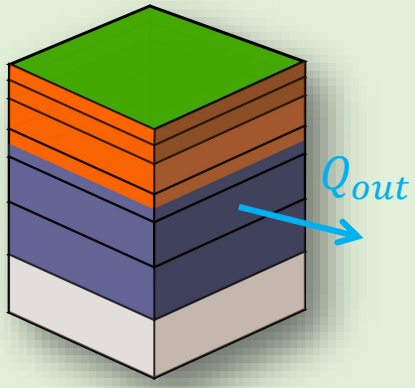
Parameter Variation

- Control:
  - 1m soil depth
  - 10 % slope
- 2 columns: upland & lowland
- Trial Series 2: Slowing slope downhill

Trial #	Parameter Varied	Column	
		Upslope	Downslope
1a	Area (relative to 1st col.)	1	1/2
1b	Area (relative to 1st col.)	1	1/4
1c	Area (relative to 1st col.)	1	1/8
2a	Baseflow strength	1	0.5
2b	Baseflow strength	1	0.25
2c	Baseflow strength	1	0.125
2d	Baseflow strength	1	0.01



Control

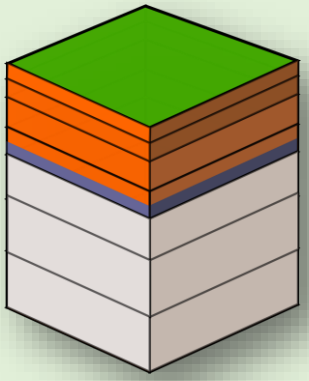


Smaller Downslope Lateral Flow

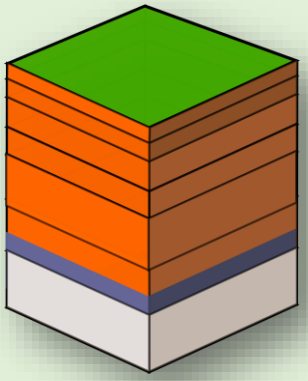
Parameter Variation

- Control:
  - 1m soil depth
  - 10 % slope
- Trial Series 3: deepening soil downhill

Trial #	Parameter Varied	Column	
		Upslope	Downslope
1a	Area (relative to 1st col.)	1	1/2
1b	Area (relative to 1st col.)	1	1/4
1c	Area (relative to 1st col.)	1	1/8
2a	Baseflow strength	1	0.5
2b	Baseflow strength	1	0.25
2c	Baseflow strength	1	0.125
2d	Baseflow strength	1	0.01
3a	Soil Depth (m)	1	2
3b	Soil Depth (m)	1	4
3c	Soil Depth (m)	1	8



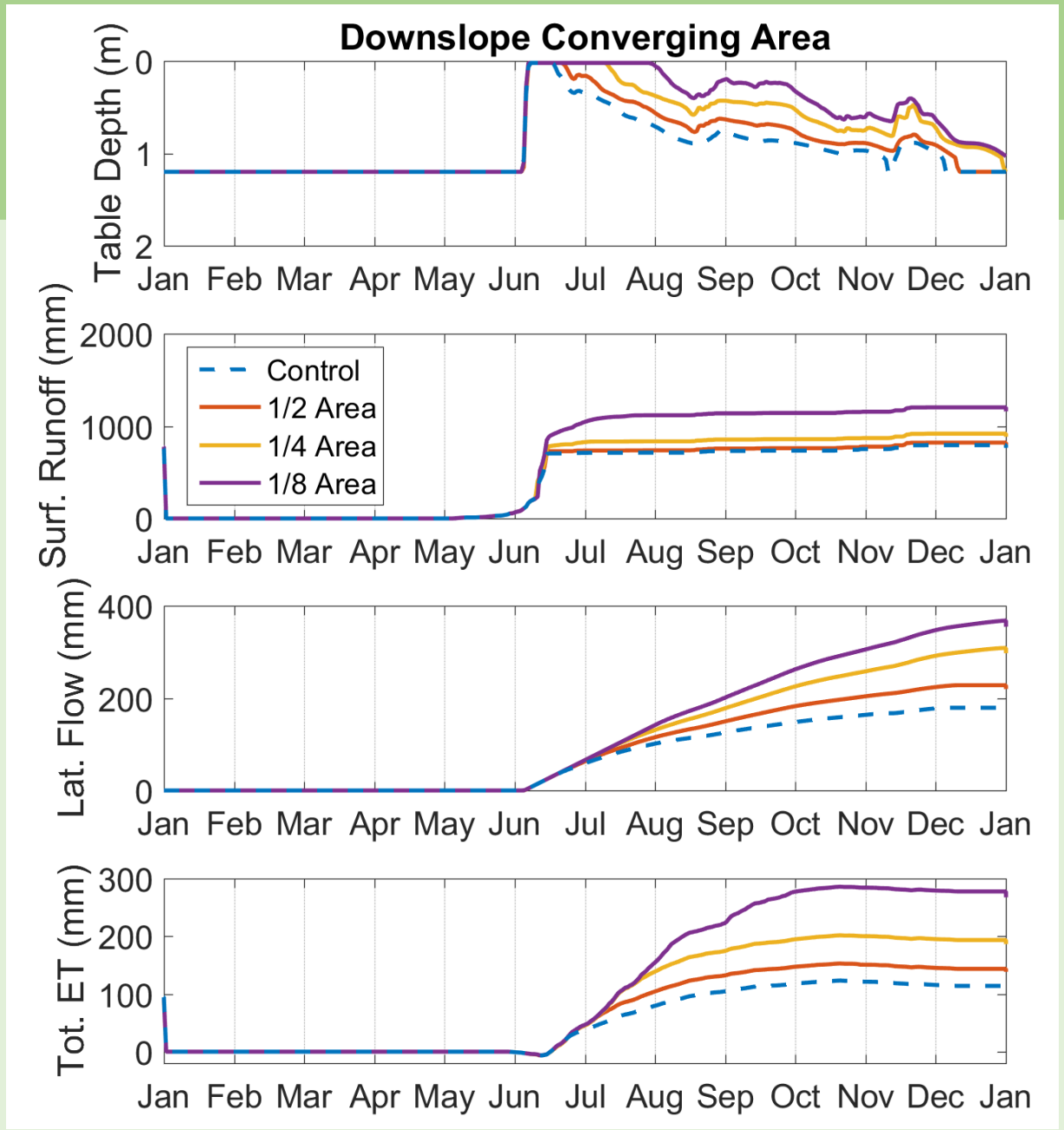
Control



Deeper Downslope Soil

Parameter Variation: **Converging Area**

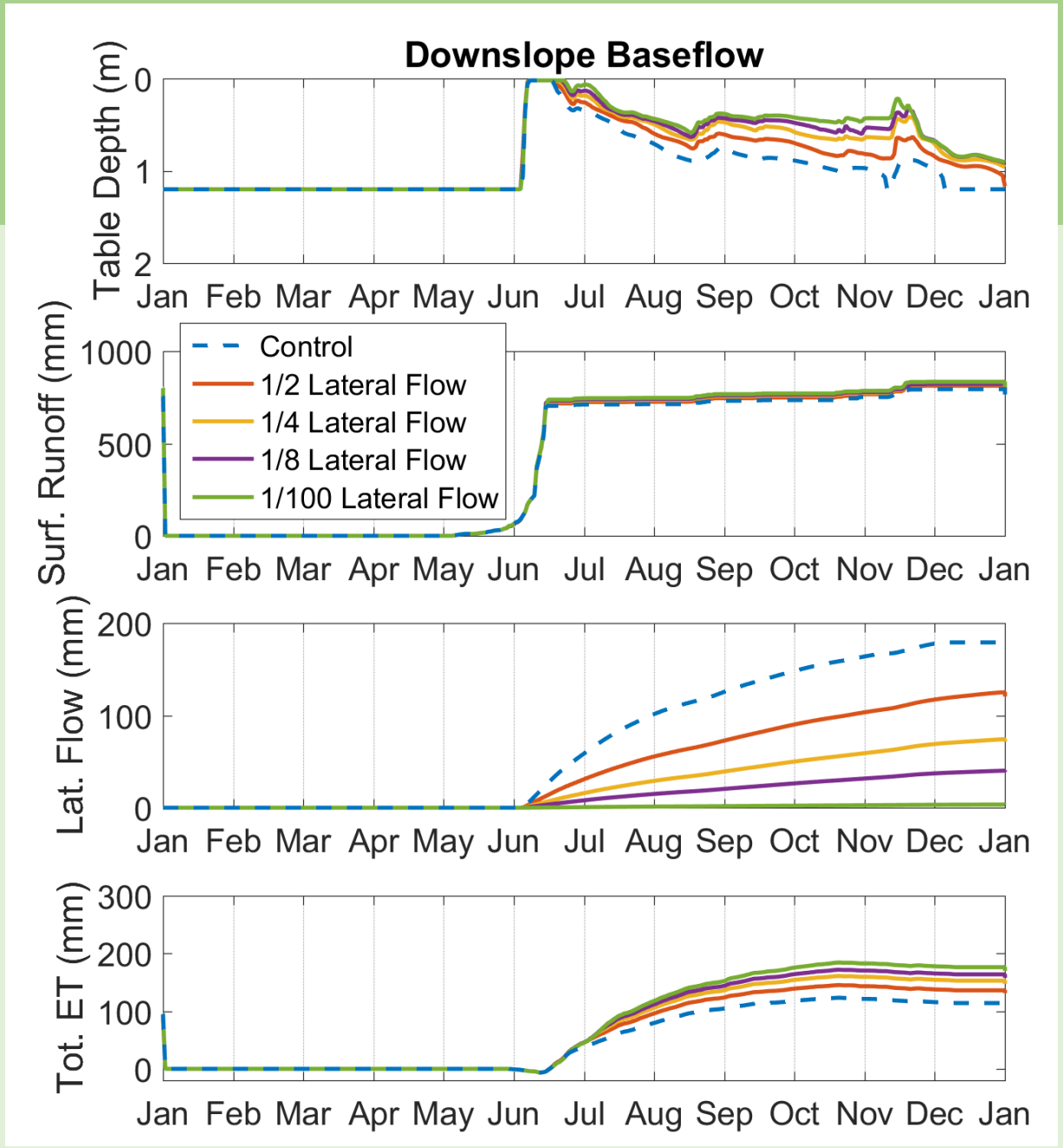
- Representative Year 2004, Cumulative fluxes
- Control:
  - 1m soil depth
  - 10 % slope
- Converge to 1/2th, 1/4th, 1/8th area



Parameter Variation:

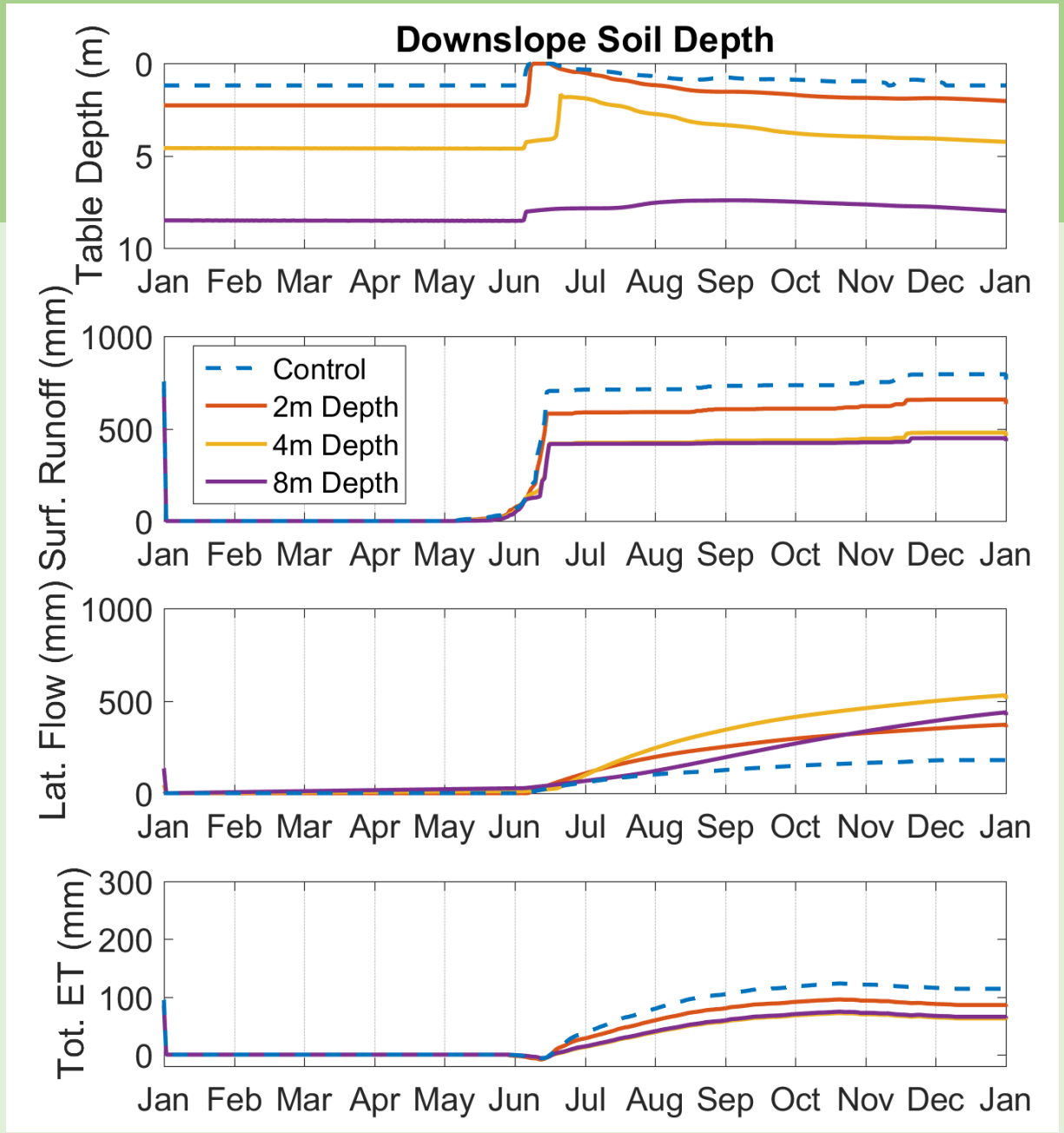
Lateral Subsurface Flow /Slope

- Representative Year 2004,
  Cumulative fluxes
- Control:
  - 1m soil depth
  - 10 % slope
- 1/2, 1/4, 1/8, 1/100 lateral flow



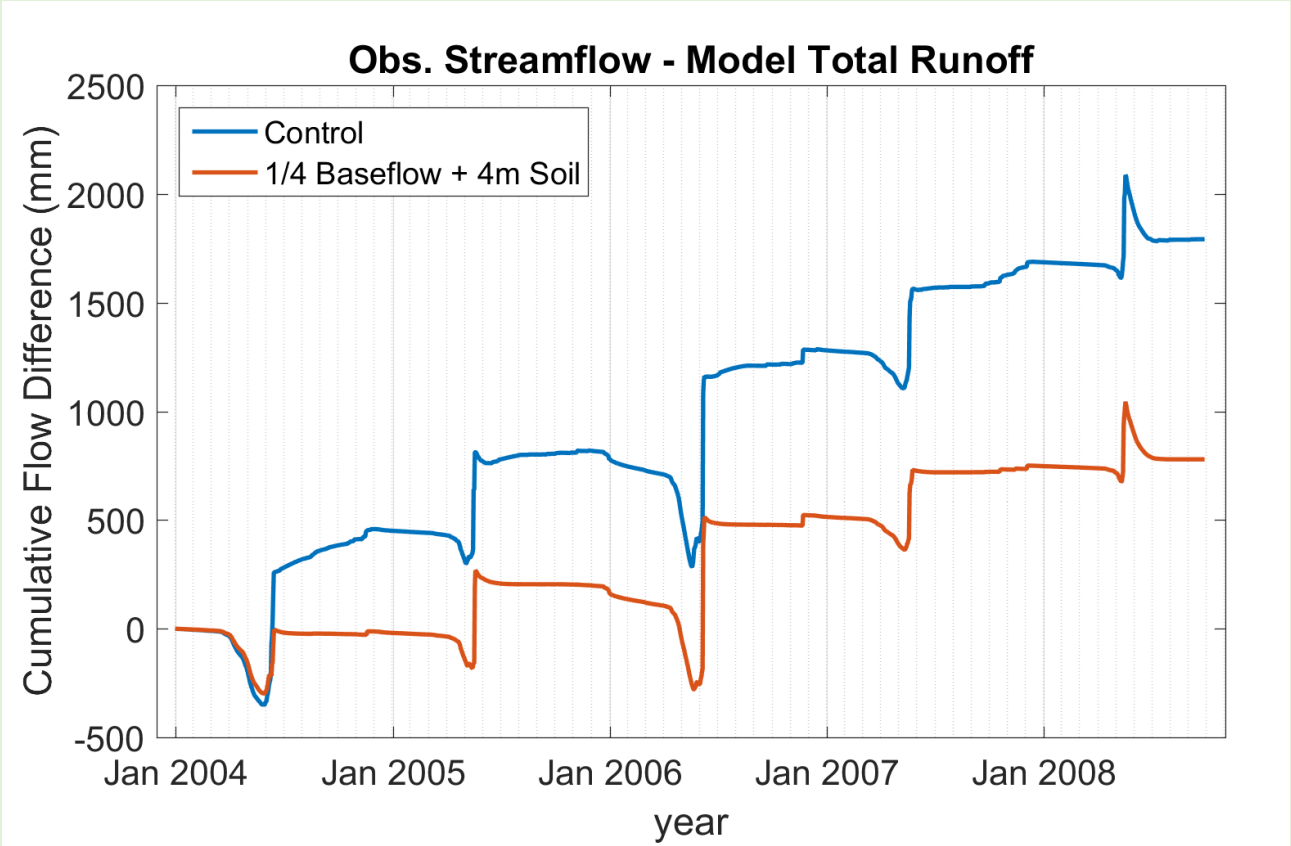
Parameter Variation:
Soil Depth

- Representative Year 2004, Cumulative fluxes
- Control:
  - 1m soil depth
  - 10 % slope
- Depth to bedrock: 2m, 4m, 8m



Reynolds Creek Watershed

- Combo Trials
- More realistic hillslope geometries



Next Steps

- Vegetation sensitivity
- Unique PFT distributions between columns
- Hillslope hierarchical structure
- Global simulations, using Topo30 and bedrock depth datasets