Hillslope Hydrology in CLM

CESM Joint Meeting

Wed., Feb. 10

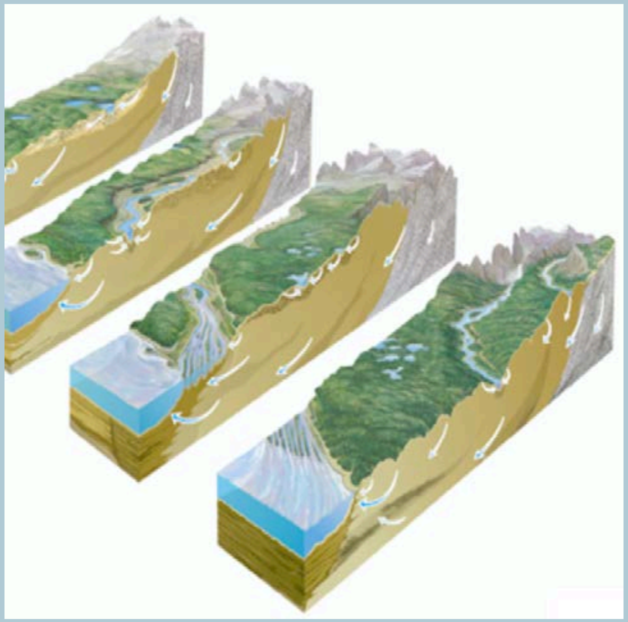
Martyn Clark, Dave Lawrence, Justin Perket, Ying Fan Reinfelder, Sean Swenson

CUAHSI-NCAR collaboration

CUAHSI
UNIVERSITIES ALLIED FOR WATER RESEARCH

- CUAHSI (Consortium of Universities for the Advancement of Hydrologic Science, Inc.) supports/enables community activities to advance hydrologic science

- New CUAHSI / NSF initiative to improve representation of hydrologic processes in ESMs
  - Accelerate implementation of state-of-art hydrologic understanding into large-scale land models
  - Emphasis on model evaluation / benchmarking utilizing catchment-scale observations
  - Initial focus on CLM
    - Hillslope hydrology
    - Plant hydrodynamics



Winter et al., 1998

Water Resources Research

REVIEW ARTICLE
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Special Section:
The 50th Anniversary of Water Resources Research

Improving the representation of hydrologic processes in Earth System Models

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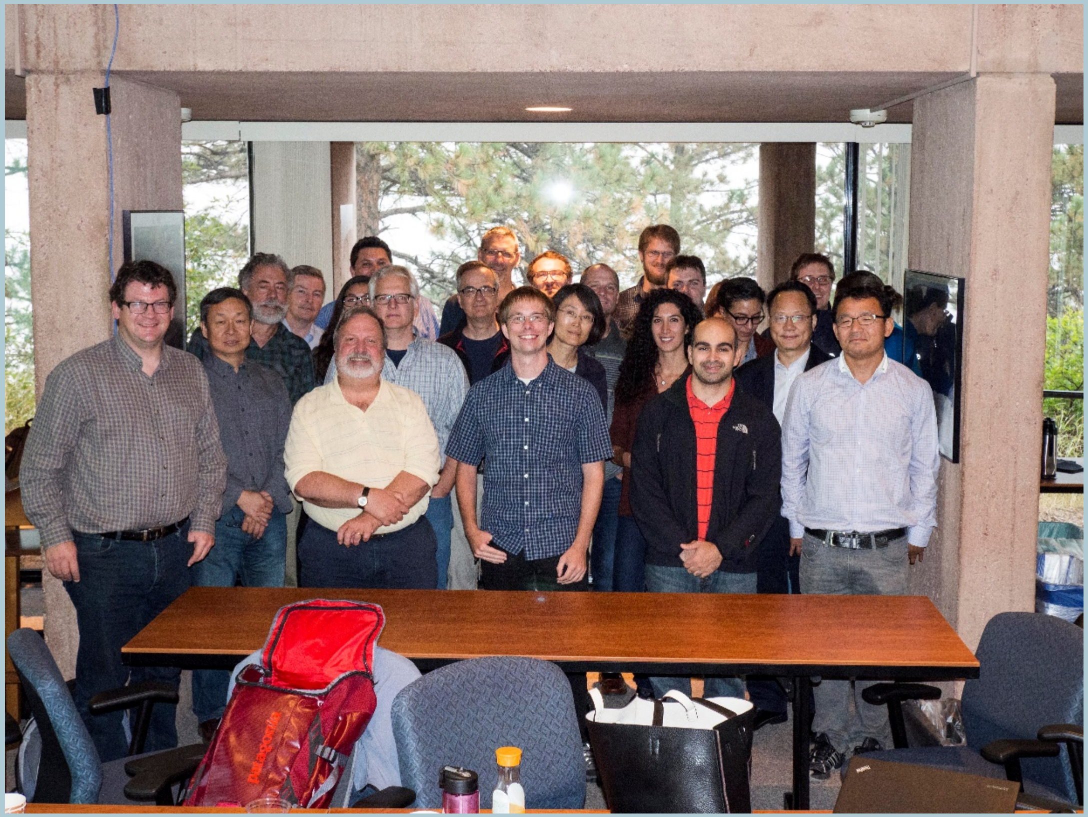
CUAHSI-NCAR collaboration

- Oct. workshop of hydrologists and LSM modelers



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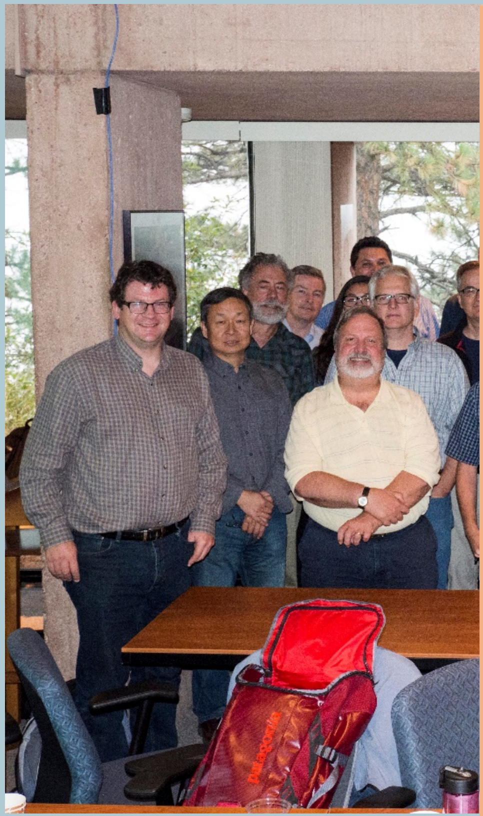

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Zhenghui Xie (Chinese Academy of Science)
Xubin Zeng (U of Arizona)
Qinghuan Zhang (CU Boulder)

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- Agreed:
  - Global simulation model grids still can't resolve subgrid variability which affect average hydro. stores & fluxes
  - Need to find and implement efficient methods to represent sub-grid heterogeneity, structure and hydraulic connectivity for large-scale climate
  - There's need for 2-way data/knowledge exchanges between catchment science and the ESM communities

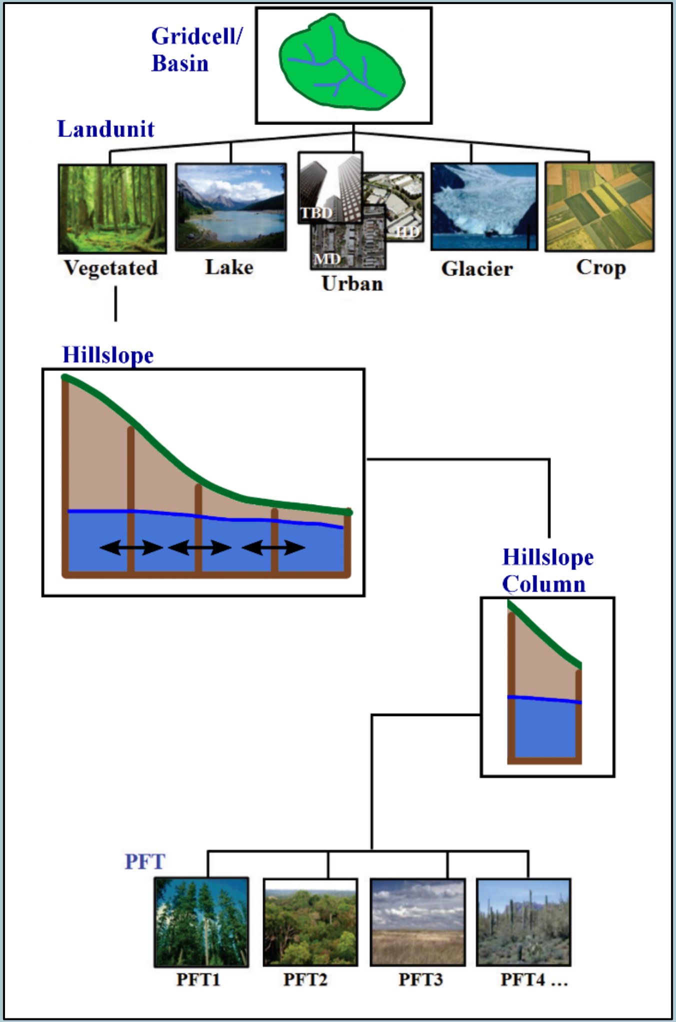
CUAHSI-NCAR collaboration

- Recommendations:
  - Implement hillslope representation, lateral connectivity between multiple columns
  - Focus on intra-gridcell, since inter-gridcell connectivity largely accounted by river flow routing
  - Use observations from Critical Zone Observatories and other research watersheds (as well as remote sensing, i.e., GRACE) for performance evaluation
  - Assemble test cases and data sets for benchmarking

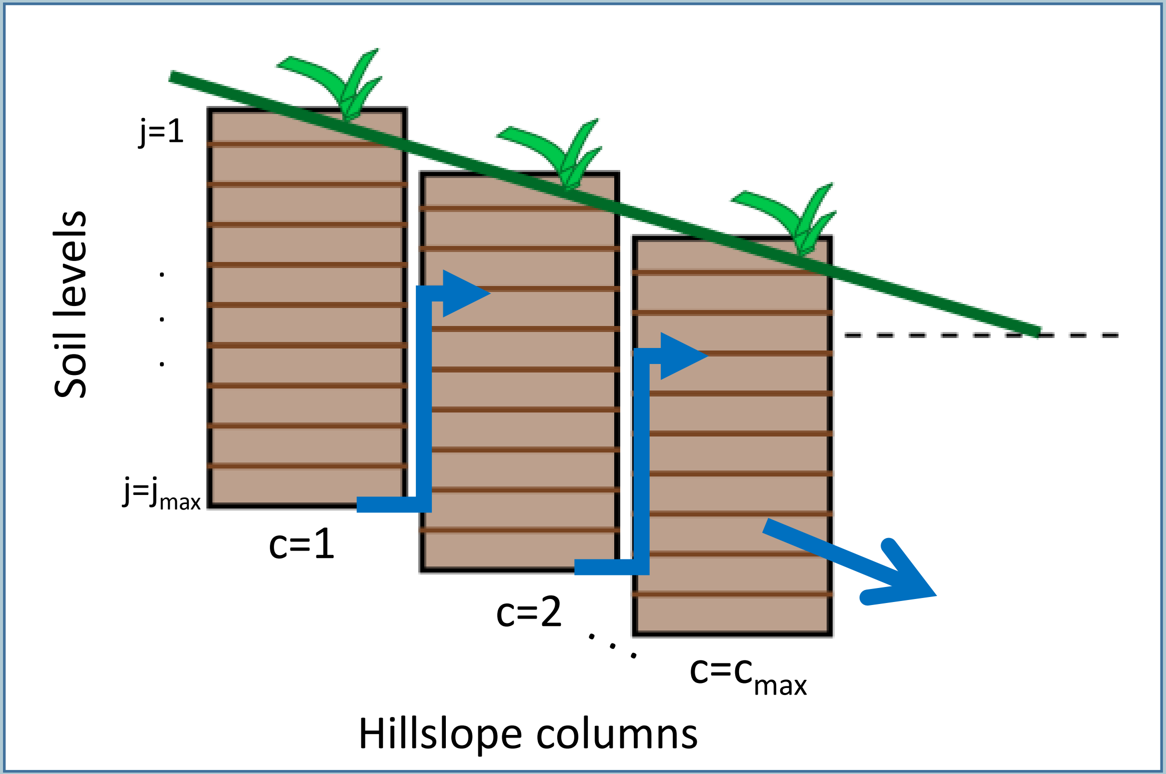
criticalzone.org

Proposed CLM Hillslope Structure

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



Implemented Hillslope Lateral Flow



- Column connections in existing CLM structure
- Currently upslope neighbors' subsurface runoff connected to next column's infiltration
- Only lowest column's drainage connected to RTM

Implemented Hillslope Lateral Flow

…

HydrologyNoDrainage

- SnowWater
- SurfaceRunoff
- Infiltration
  - *Lateral transfer from upslope neighbor (from last time step) added to infiltration flux*
- SoilWater (Richards Eqn. between layers)
- Calc. water table height
- …

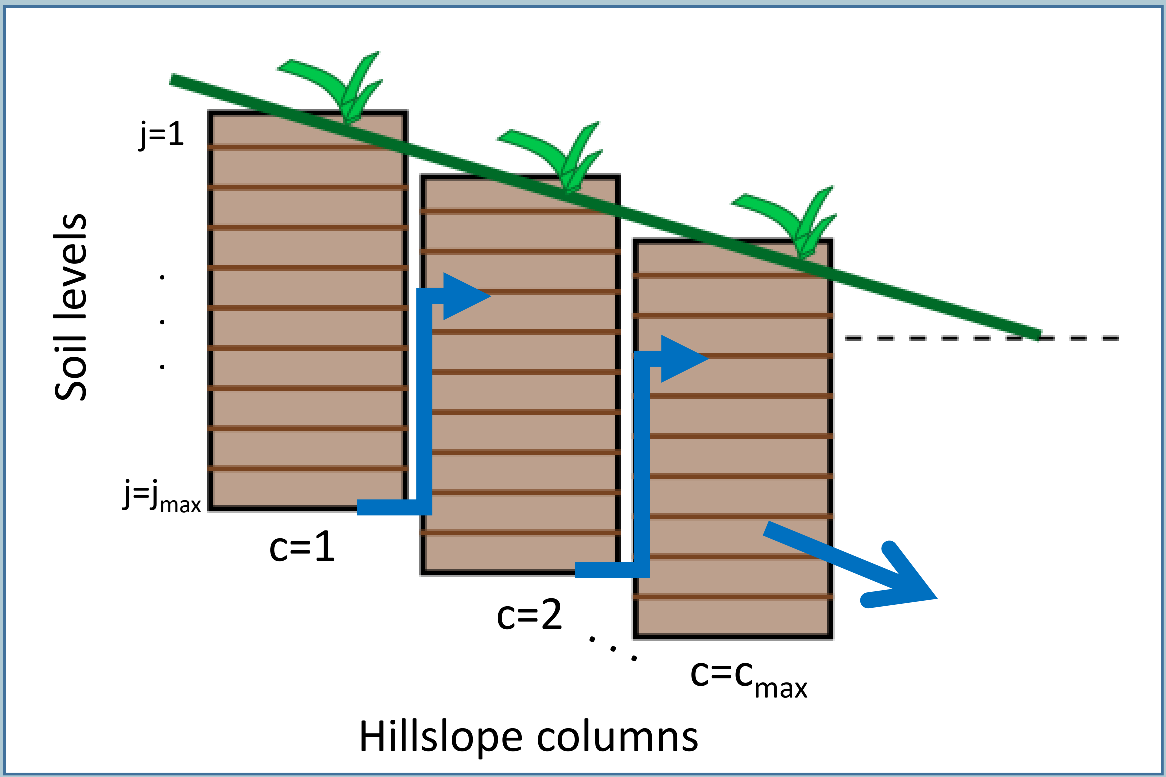
…

HydrologyDrainage

- Drainage (Aquifer Layer), or LateralFlowPowerLaw
  - *Calcs. transfer due to water table height differential (kinematic assumption), adds to subsurface runnoff*
- *Subsurface runnoff reassigned to new lateral transfer flux*
- …

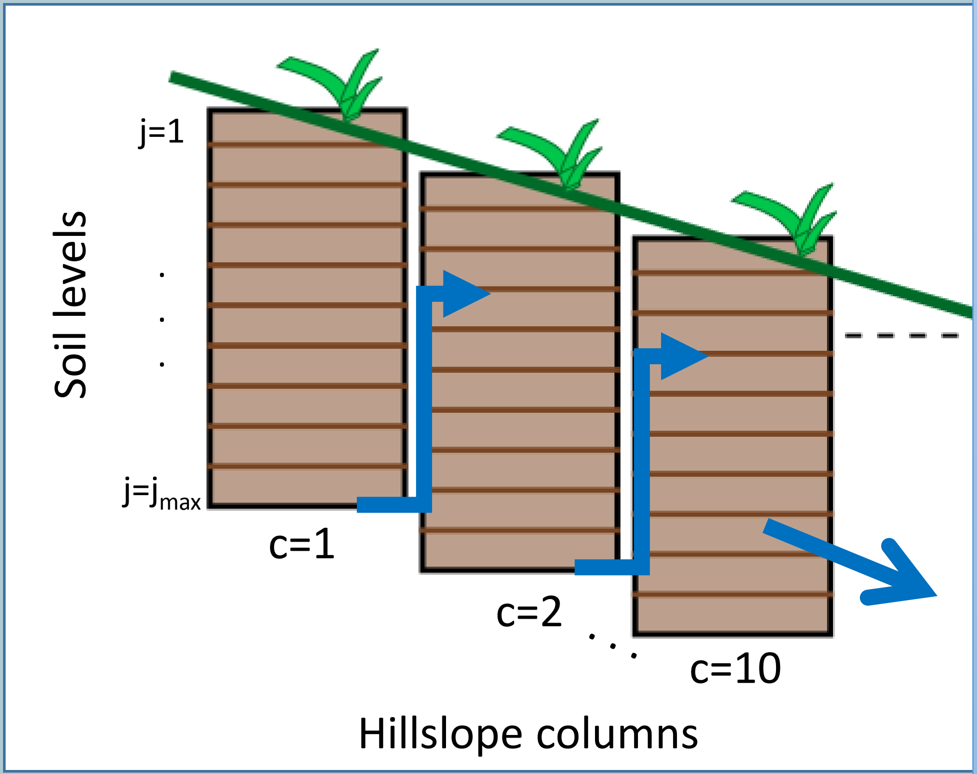
…

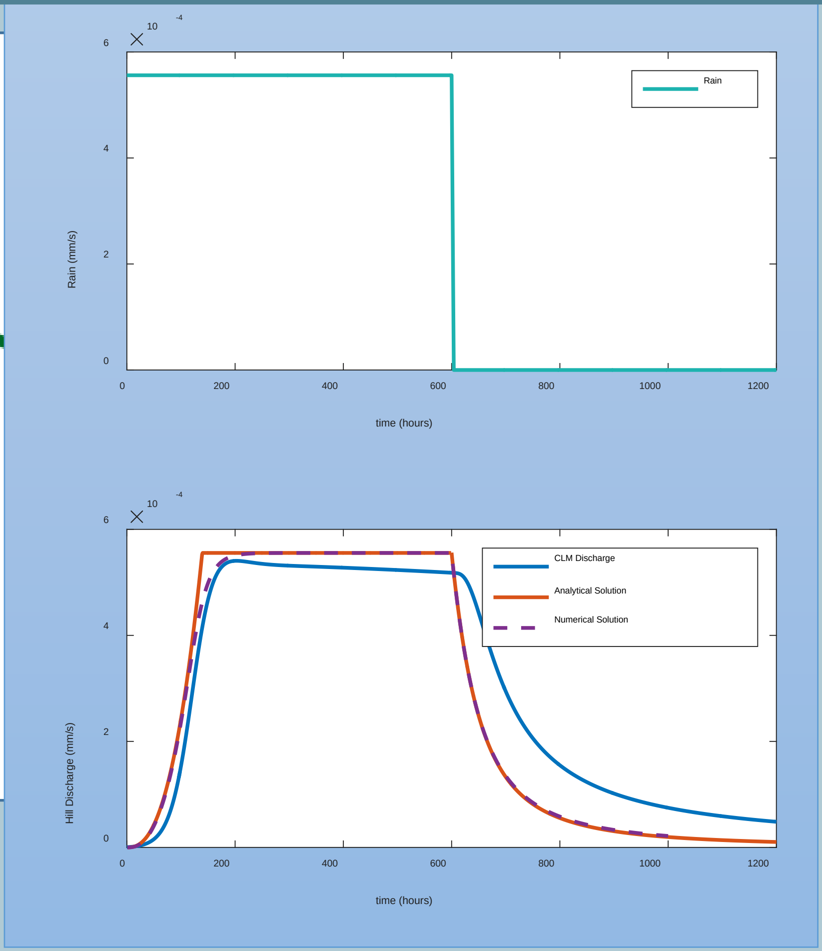
Hillslope Lateral Flow Test Case



- Toy drainage hillslope with single point CLM
- Constant slope: tan(slope)=0.3
- No ground/vegetation ET fluxes, constant air temp forcing
- Rain forcing square wave
- Moisture-based form of Richards eqn.

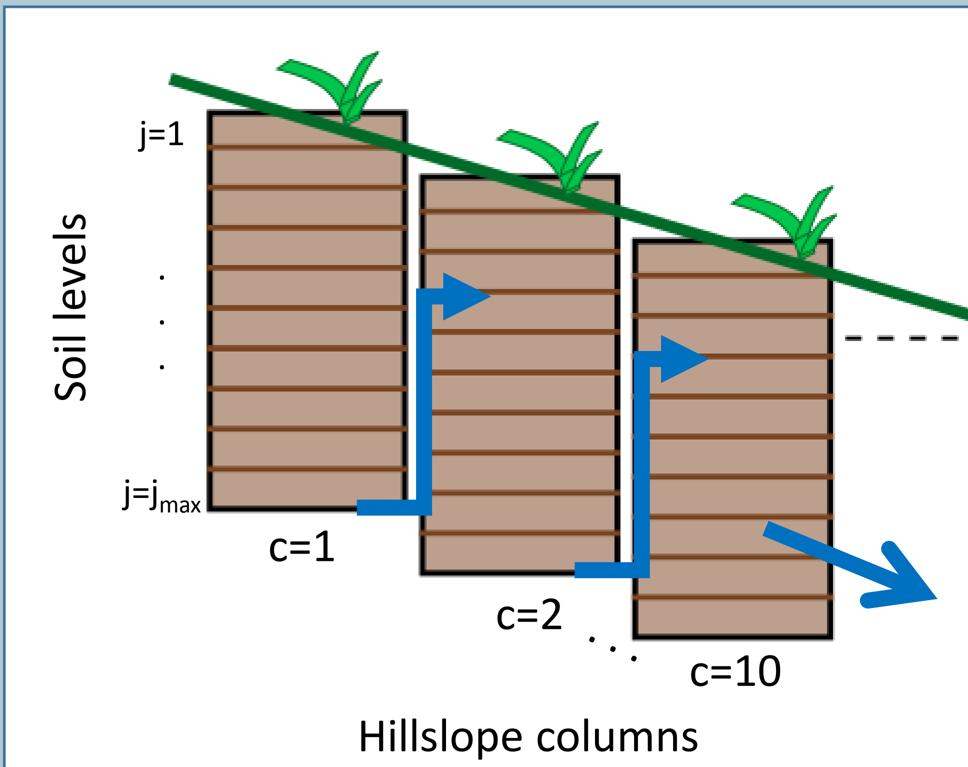
Hillslope Lateral Flow Test Case

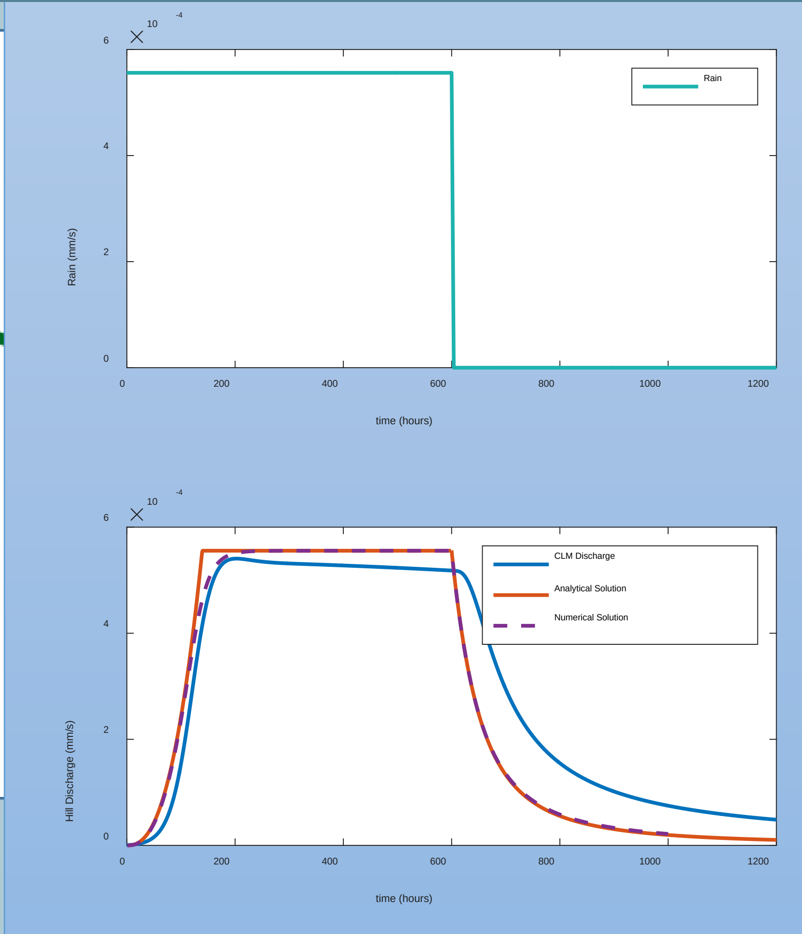




(Solns. described in *Wigmosta and Lettenmaier, 1999)*

Hillslope Lateral Flow Test Case





- 1-D gridcell numerical soln.:

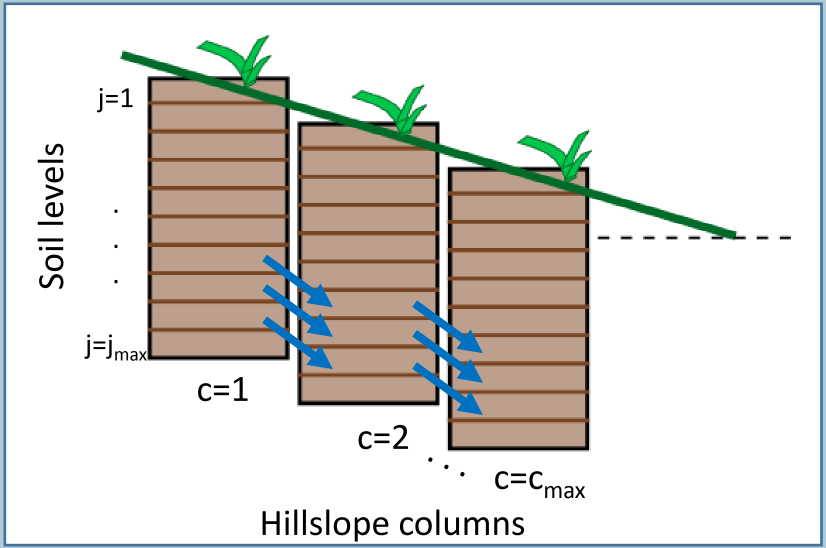
$$Q_{out,c} = \frac{-K_0 * Depth * \tan(slope)}{n}\left(1 - \frac{wt_c}{Depth}\right)^n$$

$$\Delta wt_c = \frac{\Delta t}{por.}\left(\frac{Q_{out,c} - Q_{out,c-1}}{A_c} - Rain\right)$$

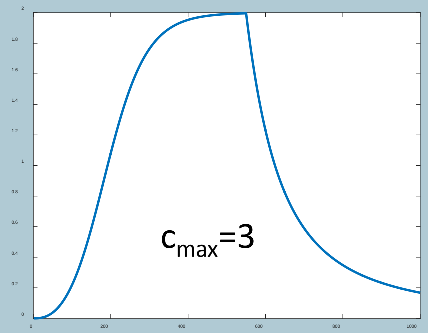
(Solns. described in *Wigmosta and Lettenmaier, 1999)*

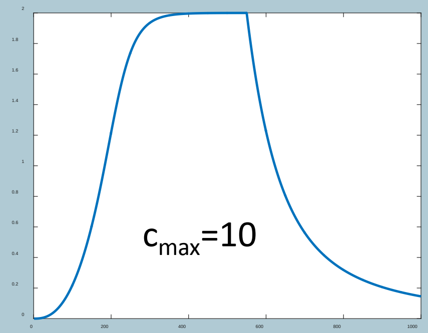
Immediate next steps

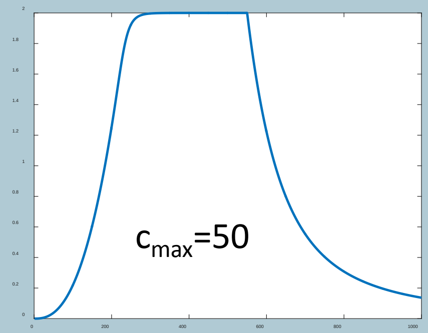
- Transfer to corresponding soil layers



- Optimize # of hillslope columns







Next steps – Where we are:

1) Divide a current CLM column into n columns, organized by lateral drainage relationships
2) Implement hydraulically connected columns with lateral groundwater flow driven by the water table gradient
3) At the column level, couple lateral and vertical flow, fully integrating the soil and groundwater stores
4) Explore the drainage relationships using high resolution DEM elevation data and field knowledge of catchment geomorphology
5) Assemble Fluxnet, research watersheds, and CZOs etc. for test cases and data that resolve sub-grid hydrologic variations and connectivity, selecting sites that represent a range of sub-grid hydrology
6) Assemble and standardize the test cases and data into benchmarking metrics to be contributed to ILAMB
7) Establish mechanism for meaningful dialogues and data/knowledge exchange between the CZO and ESM land model communities

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