Future Directions: Subgrid Hydrology in CLM

Justin Perket$^{1,2}$, Martyn Clark$^1$, Dave Lawrence$^1$, Ying Fan Reinfelder$^2$, Sean Swenson$^1$

$^1$ 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
Open Hydroclimatology Questions

• How can we improve climate predictions by advancing representation of the terrestrial water cycle?
Open Hydroclimatology Questions

• How can we improve climate predictions by advancing representation of the terrestrial water cycle?
• How does the hydrologic influence of land-atmosphere fluxes affect climate?
Open Hydroclimatology Questions

• How will natural and anthropogenic forcings affect:
  • Stores (e.g., canopy, snowpack, soil moisture, groundwater, rivers, lakes)?
  • Fluxes (e.g., evaporation, transpiration, snowmelt, infiltration, runoff, subsurface lateral flow, river discharge)?
Open Hydroclimatology Questions

• How can climate influence freshwater availability? Vegetation stress?
Motivation

• Need efficient representation of hillslope hydrology dynamics (with subgrid variability) for global water cycle interactions with climate

• Lateral subsurface flow critical to represent terrestrial water connectivity, but missing from most earth system models
CLM 5.0 Subgrid Hierarchy
CLM 5.0 Subgrid Hierarchy
CLM Subgrid Hierarchy with Hillslope Representation
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
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

\[ Q_{c}^{out} = \frac{-K_{0}D_{soil}\tan(slope)}{n} \left(1 - \frac{D_{table}}{D_{soil}}\right)^{n} \]

- Checks to prevent soil moisture < specific yield in any layer
- Withdraws from deeper layers if needed
- \( Q_{c}^{in} \) adds to water table layer
- \( Q_{c}^{net} = Q_{c}^{out} - \frac{Area_{(c-1)}}{Area_{c}} Q_{c-1}^{out} \)

\( Q_{c}^{in} \)
Implemented Hillslope Lateral Flow

• Now the vegetated land unit kinda looks like...
Synthetic Test Cases

• Constant slope with 700 hour constant rain

• Saturated flow downhill (kinematic wave)

• Compared to simple analytical & numerical solutions
Synthetic Test Cases

• Constant slope with 700 hour constant rain

• Saturated flow downhill (kinematic wave)

• Compared to simple analytical & numerical solutions
Synthetic Test Cases

Soil Moisture Across Hillslope Columns

Hill Top
Column 1

Column 10
Hill Bottom
Synthetic Test Cases

- Constant slope w/ 700 hour constant rain
- Increased water storage, higher water table going downhill
- Compares well with analytical solutions for matching hillslope geometry and soil properties
Reynolds Creek Watershed

• Compared Single Point CLM w/ site forcing to Critical Zone Observatory measurements
Topographic Sensitivity

- Control:
  - 1m soil depth
  - 10% slope

- 2 columns: upland & lowland

- Trial Series 1: converging basin

<table>
<thead>
<tr>
<th>Trial #</th>
<th>Parameter Varied</th>
<th>Column</th>
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<tbody>
<tr>
<td>1a</td>
<td>Area (relative to 1st col.)</td>
<td>Upslope 1, Downslope 1/2</td>
</tr>
<tr>
<td>1b</td>
<td>Area (relative to 1st col.)</td>
<td>Upslope 1, Downslope 1/4</td>
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<tr>
<td>1c</td>
<td>Area (relative to 1st col.)</td>
<td>Upslope 1, Downslope 1/8</td>
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</table>
Parameter Variation: Converging Area

- Representative Year 2004, cumulative fluxes

- Control:
  - 1m soil depth
  - 10% slope

- Converge to 1/2th, 1/4th, 1/8th area
Topographic Sensitivity

- **Control:**
  - 1m soil depth
  - 10% slope

- **2 columns:** upland & lowland

- **Trial Series 2:** Slowing slope downhill

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<tr>
<td>2d</td>
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**Diagram:**
- Control
- Smaller Downslope Lateral Flow
Parameter Variation: Subsurface Flow / Slope

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

- Control:
  - 1m soil depth
  - 10 % slope

- Trial Series 3: deepening soil downhill

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<tr>
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<tr>
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<td>Soil Depth (m)</td>
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Parameter Variation: Soil Depth

- Representative Year 2004, cumulative fluxes
- Control:
  - 1m soil depth
  - 10% slope
- Depth to bedrock: 2m, 4m, 8m
Reynolds Creek Mountain East

- Eddy flux towers, streamflow and SWE observations
Reynolds Creek Mountain East

- Single Column CLM gives low lowland evapotranspiration compared to obs.
Reynolds Creek Mountain East

- CLM w/ multi-column hillslope increases ET
Reynolds Creek Mountain East

Graph showing precipitation (mm/day) from Jan 2004 to Jan 2008 with data points for Snow and Rain.

Graph showing Snow Water Equivalent (SWE, mm) from Jan 2004 to Jan 2008 with data points for Observation and CLM.
Next Steps

- Columns having unique vegetation
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• Multi-slope basins (with different topographies and effective forcings)
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• Columns having unique vegetation
• Multi-slope basins (with different topographies and effective forcings)
• Global simulations with Digital Elevation Model-derived datasets