Understanding Impacts of Subsurface and Surface Heterogeneity on Evapotranspiration in Mountain Pine Beetle Infested Watersheds

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GSA 2013 Annual Meeting
Session T40. Applications and Developments of Coupled Hydrologic Models

October 28, 2013
What we know: Subsurface heterogeneity influences land surface processes

Influences of subsurface heterogeneity and vegetation cover on soil moisture, surface temperature and evapotranspiration at hillslope scales

Adam L. Atchley • Reed M. Maxwell

Quantifying the effects of three-dimensional subsurface heterogeneity on Hortonian runoff processes using a coupled numerical, stochastic approach

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Received 23 August 2007; received in revised form 18 January 2008; accepted 24 January 2008
Available online 19 February 2008

... plus many more!

as well as,

• infiltration
• vegetation
• atmospheric conditions
Something else to consider: Scaling

Scaling, soil moisture and evapotranspiration in runoff models

Eric F. Wood
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The role of scaling laws in upscaling

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Article

Proof of concept of regional scale hydrologic simulations at hydrologic resolution utilizing massively parallel computer resources

Stefan J. Kollet,1 Reed M. Maxwell,2 Carol S. Woodward,3 Steve Smith,4 Jan Vanderborght,5 Harry Vereecken,5 and Clemens Simmer1

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... plus more!

in terms of,

• hydrologic processes
• application in models
The unknowns: Questions to ponder…

- How can we take small scale heterogeneities like that of soil moisture or evapotranspiration which may vary significantly over one watershed and apply them at a regional scale?

- Do vegetation and climate dynamics influence the degree that scale matters?

- Do subsurface characteristics combined with landscape changes compound or counteract the importance of scale?

- What changes do we see in evapotranspiration as we move from the small to large scale with a heterogeneous subsurface?
Evapotranspiration and scale

Does ET from a tree or stand really represent the watershed?
ParFlow: A tool for hydrologic modeling

- Integrated surface water-groundwater model
- **Land surface**: Vegetation processes through Common Land Model (CLM), coupled water-energy balance
- **Overland flow/surface runoff**: Diffusive/kinematic wave and Manning’s equation
- **Groundwater flow**: variably-saturated, three-dimensional Richards equation
- Fully coupled, mass conservative, parallel implementation
Model setup for forest domain in Colorado

<table>
<thead>
<tr>
<th>Property</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Domain Size</td>
<td>1000m x 1000m x 3m</td>
</tr>
<tr>
<td>Resolution</td>
<td>2m (surface), 0.1 (subsurface)</td>
</tr>
<tr>
<td>Surface Cover</td>
<td>Evergreen needleleaf forest</td>
</tr>
<tr>
<td>Subsurface Soil</td>
<td>Sandy, clay loam</td>
</tr>
<tr>
<td>Atmospheric Forcing</td>
<td>Breckenridge, Colorado</td>
</tr>
<tr>
<td>Simulation Duration</td>
<td>1 year</td>
</tr>
</tbody>
</table>

Varied parameters:

- Subsurface anisotropy:
  \[ \lambda_x = \lambda_y = 10m \text{ and } \lambda_x = \lambda_y = 50m \ (\lambda_z = 1m) \]

- Subsurface heterogeneity:
  \[ \sigma^2 = 0.1 \ (\text{homogenous}) \text{ and } \sigma^2 = 1 \ (\text{heterogenous}) \]
Subsurface heterogeneity reflects spatial ET distribution
ET at different resolutions shows highly variable spatial patterns

Parameters:
Slope = 0%
$\lambda_x = \lambda_y = 50m$
$\sigma^2 = 1$

Evapotranspiration (mm/yr)

446
459
452
451
445
442
438
Histories reinforce spatial variations

- Resolution = 2m
  - \( \sigma = 3.566 \text{ mm/yr} \)

- Resolution = 10m
  - \( \sigma = 3.561 \text{ mm/yr} \)

- Resolution = 100m
  - \( \sigma = 3.3 \text{ mm/yr} \)

- Resolution = 500m
  - \( \sigma = 1.2 \text{ mm/yr} \)
Subsurface characteristics further influence ET

Decrease anisotropy: \( \lambda_x = \lambda_y = 10 \text{m} \)

Decrease variance: \( \sigma^2 = 0.1 \)

Slope = 0%, \( \lambda_x = \lambda_y = 50 \text{m}, \sigma^2 = 1 \)

Mean = 442 mm/yr
\( \sigma = 3.6 \text{ mm/yr} \)

Slope = 0%, \( \lambda_x = \lambda_y = 10 \text{m}, \sigma^2 = 1 \)

Mean = 445 mm/yr
\( \sigma = 7.1 \text{ mm/yr} \)

Slope = 0%, \( \lambda_x = \lambda_y = 10 \text{m}, \sigma^2 = 0.1 \)

Mean = 444 mm/yr
\( \sigma = 2.2 \text{ mm/yr} \)
Conclusions from modeling

- Modeling **scale** does change the **range of ET** values observed
  - Increase in variability at smaller scales
  - Average values remains the same

- The distribution of ET values is **influenced by subsurface** properties.

- So, what is next?!
Application to landscape changes from Mountain Pine Beetle

Pitch tubes.

Mountain pine beetle (*dendroctonus ponderosae*).

Edburg et al. (2012)
Future ET scaling work

Topography

Heterogeneity

Regrowth
Thank you!

For more on mountain pine beetles:
Session T43. Ecohydrological Impacts from Climate-Induced Changes in Land Cover and Vegetation in Mountain Environments

Wednesday, October 30, 2013 from 8:00am-12:00pm, Room 302
Mountain Pine Beetle in North America

Edburg et al. (2012)
Hydrologic Impacts

Modified from Mikkelson et al. (2013)

Phases of Infestation

<table>
<thead>
<tr>
<th>Green Phase (0-1 Years Post-Infestation)</th>
<th>Red Phase (1-4 Years Post-Infestation)</th>
<th>Grey Phase (4+ Years Post-Infestation)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SWE</td>
<td>SWE</td>
<td>SWE</td>
</tr>
<tr>
<td>T</td>
<td>T</td>
<td>T</td>
</tr>
<tr>
<td>N.S.C.</td>
<td>Q*</td>
<td>A</td>
</tr>
<tr>
<td>θ</td>
<td>E</td>
<td>E</td>
</tr>
<tr>
<td>Green Phase</td>
<td>Red Phase</td>
<td>Grey Phase</td>
</tr>
</tbody>
</table>

SWE: Snow Water Equivalent
T: Temperature
N.S.C.: Nontree Structure Component
Q*: Soil Water
A: Air
θ: Water Potential
E: Evapotranspiration

Modified from Mikkelson et al. (2013)
Why Now?

- Large uniform stands of mature lodgepole pine trees
- Stressed trees due to drought conditions
- Increased winter temperatures