Modeling Root Hydraulic Redistribution in CLM4.5: Pitfalls and Gains

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One Motivation for this Work: the “Likely ET Bias” from Vegetation Removal

- Removing vegetation increased ET in some places

CESM LMWG/BGCWG, NCAR, Boulder

Tang and Riley, 2013
Suspected Causes for the Likely ET Bias

- Soil resistance
- Boundary layer turbulent transport parameterization
- Time stepping
- Pedotransfer function for hydraulic properties
- Btran or root water uptake function
- Numerical solver of the Richards’ equation
- Rooting depth and profile
- Saturated and unsaturated zone coupling
- Driving data, e.g. precipitation, soil texture
- Surface albedo parameterization
- Missing processes, e.g. hydraulic redistribution
Investigated Two Possible Culprits (Tang and Riley 2013)

- Soil resistance
- Boundary layer turbulent transport parameterization
- Time stepping
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- Missing processes, e.g. hydraulic redistribution
Recap: Explored potential causes

(b) Amazon Basin gridcell

ET (mm day$^{-1}$)

Bare soil: CLM4 Default
Bare soil: CLM4 New
Bare soil: CLM4 Newlit
Bare soil: CLM4 New−10s
Veg: CLM4 Default
Veg: CLM4 New
Veg: CLM4 New−10s

Year

Tang and Riley, 2013
Effect of New Soil Resistance in CLM4.5 is Relatively Small

![Graph](image)

**Graph (a):**
- Blue line: QIAN: CLM45
- Green line: QIAN: CLM45_62

**Graph (b):**
- Blue line: QIAN: CLM45_62 – CLM45

**Figure Captions:**
- Latent heat (W m$^{-2}$) vs. Latitude (degree)
- Latent heat difference (W m$^{-2}$)
Next Set of Suspected Culprits

- Soil resistance
- Boundary layer turbulent transport parameterization
- Time stepping
- Pedotransfer function
- Btran or root water uptake function
- Numerical solver of the Richards’ equation
- Rooting depth and profile
- Saturated and unsaturated zone coupling
- Driving data, e.g., precipitation
- Missing processes, e.g., hydraulic redistribution
- Others, e.g., surface albedo parameterization
Objectives

• Implement root hydraulic redistribution using the Amenu-Kumar model (HESS, 2008)
  - Hypothesis: Root hydraulic redistribution will enhance ET over vegetated soil

• Discuss uncertainties on simulated global ET resulting from using three different pedotransfer functions (Cosby eq. 4, Cosby eq. 5, and Noilhan-Planton) and numerical implementations
  - Hypothesis: interpreting ET is clouded by many uncertainties
The Amenu-Kumar model

\[
\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial z} \left[ K_{sh} \left( \frac{\partial \psi_{sm}}{\partial z} - 1 \right) \right] - K_{rh,rad} (\psi_{sm} - \psi_{rp})
\]

\[
0 = \frac{\partial}{\partial z} \left[ K_{rh,ax} \left( \frac{\partial \psi_{rp}}{\partial z} - 1 \right) \right] + K_{rh,rad} (\psi_{sm} - \psi_{rp})
\]

Fig. 2. Conceptual view of the hydraulic redistribution model as used in this study.
Sequential Coupling vs. Tight Coupling

Sequential model
• Process-splitting method

Step 1: solve Richards’ equation

\[
\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial z} \left[ K_{sh} \left( \frac{\partial \psi_{sm}}{\partial z} - 1 \right) \right] - K_{rh,rad} (\psi_{sm} - \psi_{rp})
\]

Step 2: solve root model

\[
0 = \frac{\partial}{\partial z} \left[ K_{rh,ax} \left( \frac{\partial \psi_{rp}}{\partial z} - 1 \right) \right] + K_{rh,rad} (\psi_{sm} - \psi_{rp})
\]

Coupled model
• Form and solve coupled system

CESM LMWG/BGCWG, NCAR, Boulder
Sequential model (SM) showed a large sensitivity to time stepping while the coupled model (CM) did not.
• We explored several uncertainty sources using the coupled model:
  – Root conductivity
  – Pedotransfer function
  – Drainage parameterization
  – Root depth
  – Btran
  – Convection velocity in Monin-Obukhov parameterization
Sierra site latent heat evaluation

[Graph showing the comparison of latent heat (W m$^{-2}$) across different models and configurations over the months from 0 to 12.]
Sierra site latent heat evaluation

Sequential solution closer to observations, but improper numerical implementation
Sierra site latent heat heat evaluation

Gain from more reasonable mechanisms

Latent heat (W m\(^{-2}\))

Month

HD
HD-Kx10
CLM45
Cosby-Eq4
Noilhan
CLM45-bare
Cosby-Eq4 bare
Noilhan-bare
HD-Seq
FluxNet
HD-no drainage
HD-root 3.9m
HD-btranx1.5
HD-Kx60
HD-WC half
Small hydraulic redistribution at high precipitation sites

- HD
- HD–Kx10
- CLM45
- Cosby–Eq4
- Noilhan
- CLM45–bare
- Cosby–Eq4 bare
- Noilhan–bare
- HD–Seq
- FluxNet

Amazon Tapajos

HD effect
Sequential coupling vs. tight coupling: Nonphysical change in global ET

Sequential coupling minus tight coupling
Example: hydraulic redistribution affects seasonal root water uptake
Example: hydraulic redistribution affects seasonal soil moisture

CLM4.5 – CLM4.5-HD

Wetter

Drier

Month

Depth (m)
Change in latitudinal ET for vegetation removal experiments

Hydraulic redistribution impacts vegetation removal effect outside of high-precipitation regions.
Summary and further work

• Robust numerical solution fit observation at Blodgett Forest worse than sequential solution
  – CLM is rife with these types of numerical solution problems

• Hydraulic redistribution reduces the possible ET bias in vegetation removal experiments by enhancing dry period ET

• The three pedotransfer functions did not result in very large differences in the ET anomaly from vegetation removal, but they likely underestimated the impacts (e.g. LBA experiment indicates very different soil texture compared to what CLM45 uses)

• For a full evaluation of the ET problem, CLM needs restructuring to account for flexible formulations of many processes, e.g., pedotransfer function, root depth profile, soil resistance, root water uptake, etc.
Acknowledgements

• This work was supported by DOE
LH evaluation against FLUXNET-MTE

(a) Latent heat (W m$^{-2}$) vs. Latitude (degree)

(b) Latent heat difference (W m$^{-2}$) compared to FLUXNET-MTE

Legend:
- FLUXNET–MTE
- QIAN: CLM45
- QIAN: CLM45–HD
- CRU: CLM45
- CRU: CLM45HD

2−σ uncertainty
Extra slides
Change in latitudinal ET for vegetation removal experiments

(a) Bare soil ET minus Vegetated ET (mm day$^{-1}$) vs. Latitude

(b) Mean precipitation (mm year$^{-1}$) vs. Latitude

CLM45–Cosby Eq.4

CLM45

CLM45–Noilhan Eq.

CLM45–HD
Uncertain hydraulic parameter estimation by pedotransfer function for soils in Iran