Implementing Plant Hydraulics for CLM5

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Motivation:
Land is the critical interface through which humanity affects, adapts to, and mitigates global environmental change.

Comprehensive representations of land biogeophysics, hydrology, plant physiology, biogeochemistry, anthropogenic land use, and ecosystem dynamics.
Motivation:
Land is the critical interface through which humanity affects, adapts to, and mitigates global change.

Can we represent vegetation water potential in CLM?

Comprehensive representations of land biogeophysics, hydrology, plant physiology, biogeochemistry, anthropogenic land use, and ecosystem dynamics.
Model Vegetation
Water Potential

Introduction - 2
Plant Hydraulic Stress: “PHS”

- Solve for vegetation water potential values that:
  - satisfy flow continuity
  - match supply & demand
- Water supply
  - Darcy’s Law
  - \( q = k(\psi) A \Delta \psi \)
- Water demand
  - \( E = E_{\text{max}} f(\psi_{\text{leaf}}) \)
  - \( E_{\text{max}} \) via Medlyn

Model Description - 1
Each timestep PHS solves for
- root,
- stem,
- shade, and
- sun leaf water potential

Find the set of water potentials that balances
- water supply
  - $q = kA\Delta \psi$
- water demand
  - $E = E_{\text{max}}f(\psi)$
Medlyn Stomatal Conductance Model
Medlyn Stomatal Conductance Model

PHS
- Attenuation based on leaf water potential

SMS
- Attenuation based on soil water potential

CLM5 default

All previous versions

Model Description - 3
Medlyn Stomatal Conductance Model

PHS
- Attenuation based on leaf water potential
- Distributed among soil layers based on hydraulic gradient

SMS
- Attenuation based on soil water potential
- Distributed among soil layers based on BTRAN heuristic

CLM5 default

All previous versions

STRESS

SINK

Model Description - 3
Caxiuãna, Brazil

Experiment Description

PHS
- Throughfall Ambient
- Throughfall Excluded

SMS
- Throughfall Ambient
- Throughfall Excluded
Root Water Extraction
Root Water Extraction
Hydraulic Gradient
Root Water Extraction

\[ q = k \ A \ \Delta \psi \]
Hydraulic Gradient
Root Water Extraction

PHS:
prognostic water potential

\[ q = k \ A \left( \psi_{\text{soil},i} - \psi_{\text{root}} \right) \]
Hydraulic Gradient
Root Water Extraction

PHS:
prognostic water potential

$q = k \ A \ (\psi_{\text{soil},i} - \psi_{\text{root}})$

SMS:
constant, parameter
Hydraulic Gradient
Root Water Extraction

\[ q = k \ A \ (\psi_{\text{soil},i} - \psi_{\text{root}}) \]

PHS

SMS
Hydraulic Gradient
Root Water Extraction

\[ q = k \cdot A \left( \psi_{\text{soil},i} - \psi_{\text{root}} \right) \]
- Caxiuana 2003
- Bars show median conductance: $k \, [s^{-1}]$
- Lines span interquartile range
Hydraulic Redistribution

cartoon credit: https://nature.berkeley.edu/dawsonlab
PHS on Ambient throughfall
- total HR = 1.12m
- total ET = 4.34m
PHS on Ambient throughfall
- total HR = 1.12m
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Hydraulic Redistribution - 1

PHS on Ambient throughfall
- total HR = 1.12m
- total ET = 4.34m
Hydraulic Stress

cartoon credit: Fields et al., Acta horticulturae
- Dry season (SON-2003) mean diurnal cycle
- PHS based on leaf matric potential
- SMS based on soil water potential
Hydraulic Constraint vs. Soil Moisture Stress

Hydraulic Stress - 2

Constrained to points with FSDS >400 W/m², <425 W/m².

(a) PHS

(b) SMS

(c) TFE

(d) AMB

Wettest

Driest
Monthly mean
- Stress
- Photosynthesis
- Transpiration
Modeling vegetation water potential in CLM ...

- Yields a more physical model
Modeling vegetation water potential in CLM ... 

- Yields a more physical model
- Expands interface with
  - hydraulic community
  - remote sensing

Conclusion - 1
Thanks!

- Entire NCAR land model working group
- Columbia Water Center
- Slides online: goo.gl/Mqoozb
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extra slide