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Some Progress in Land Atmosphere Interaction Studies

Xubin Zeng, Mark Decker, and Xiaodong Zeng

Department of Atmospheric Sciences
University of Arizona, Tucson, AZ 85721, USA
xubin@atmo.arizona.edu

- Revised soil moisture Richards equation
- Shrub submodel for dynamic vegetation modeling
- Global monsoon onset/retreat

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1. Soil moisture Richards equation

Solution: revised form of the Richards equation

In the atmosphere: Vertical velocity equation:

$$\frac{dw}{dt} = \frac{1}{\rho}\frac{\partial p}{\partial z} - g \quad + \text{other terms}$$

hydrostatic approximation:

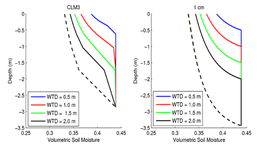
$$\frac{1}{\rho}\frac{\partial P}{\partial z} - g = 0$$

In the soil: soil moisture-based Richards equation:

$$\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial z}\left[K\frac{\partial(\psi + z)}{\partial z}\right] - S$$

with a steady-state solution:

$$\psi(\theta) + z = \psi_{sat} + z_w$$



Deficiency: Numerical solution in CLM3.5 and other land models cannot maintain this steady state solution of the differential equation even for zero flux (top and bottom) boundary conditions

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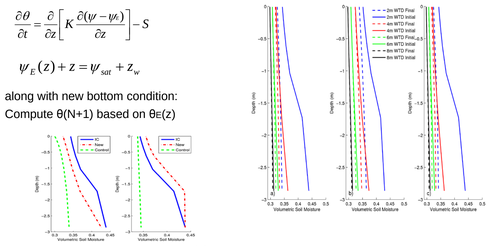
Why was this not recognized in the past? Because free-drainage bottom boundary condition is dominant.

Solution:

$$\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial z}\left[K\frac{\partial(\psi - \psi_E)}{\partial z}\right] - S$$

$$\psi_E(z) + z = \psi_{sat} + z_w$$

along with new bottom condition:
Compute θ(N+1) based on θE(z)



q_S = -1, 1 mm/day

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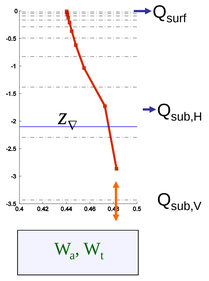
Changes to CLM3.5



- CLM3.5: Couple to groundwater after solution for vertical water movement
  - z_∇, W_a, W_t
- New: Direct coupling within solution for water movement
  - z_∇

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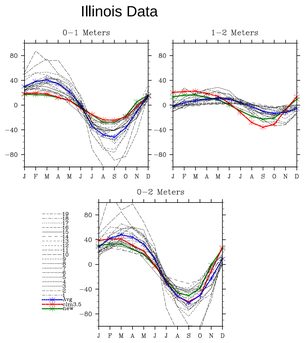
Our WTD computation:

$$\psi_{sat}\left[\frac{\theta_E(z)}{\theta_{sat}}\right]^{-B} + z = \psi_{sat} + z_w$$

with mass conservation constraint: the sum of soil moisture deficit from all layers equals the integral of $\theta_E(z)$ deficit.

Illinois Data



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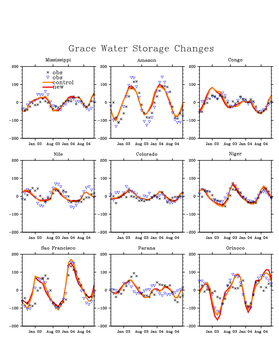

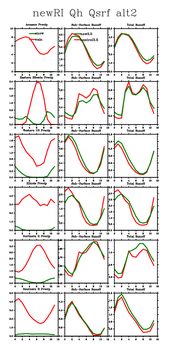

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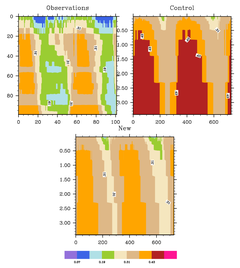
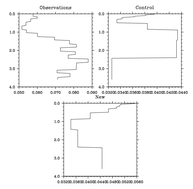
Amazon





Obs and New have a clear minimum at 1 m

Control has a min at 0.5 m

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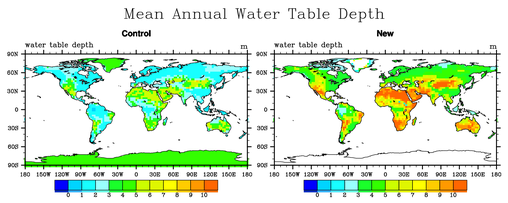

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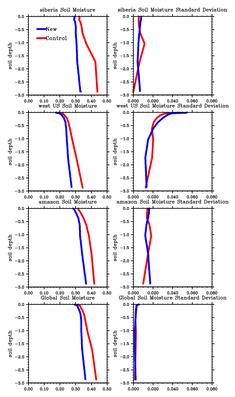

Siberia

Western U.S.

Amazon

Global land

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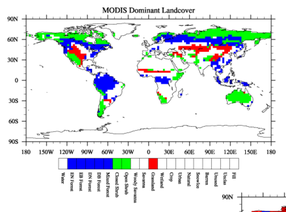
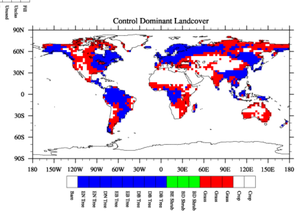


2. Shrub submodel



Without shrub components, the NCAR CLM-DGVM is deficient in simulating the global distribution of tree-grass-shrub distributions compared with the MODIS data

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Shrub submodel key features

- drought-tolerance in the photosynthesis computation – use of different soil moisture stress function for shrubs
- appropriate phenology type – raingreen for shrubs; no air temperature limitation for establishment
- appropriate morphology parameters
- consistent treatment of fractional vegetation coverage [in default DGVM, photosynthesis over plant crown area (PCA) while plant maintenance respiration over foliar projective cover (FPC) are used; FPC < PCA]
- tree/grass/shrub hierarchy for light competition

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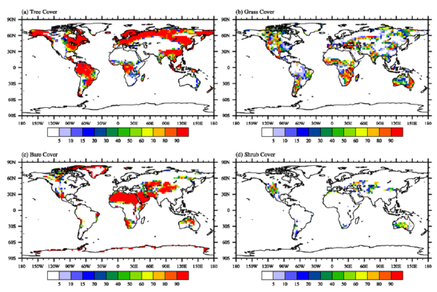
400-Yr Simulation using DGVM with shrub submodel



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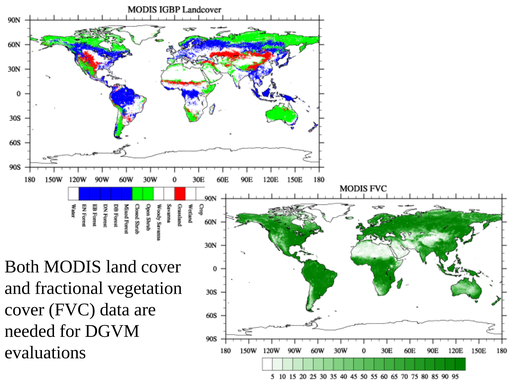

Both MODIS land cover and fractional vegetation cover (FVC) data are needed for DGVM evaluations

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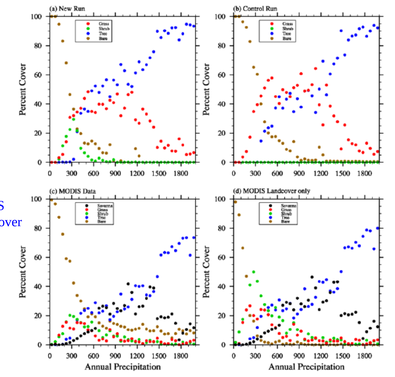
NEW

OLD



MODIS Land cover + FVC

MODIS Land cover only

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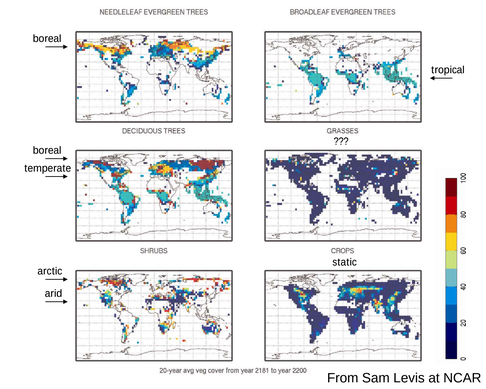

From Sam Levis at NCAR

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3. Global monsoon onset/retreat

Normalized precipitable water (PW) index:

NPWI = (PW – PWmin)/(PWmax – PWmin)

where PWmax and PWmin are the ten-year averages of the annual max and min daily PW at each grid cell.

Proposed objective criterion:

The monsoon onset (or retreat) date for grid cell G is defined as the first day (d) when NPWI is greater (or less) than the Golden Ratio (0.618) for 3 consecutive days in 7 of the 9 cells centered at cell G in day d or d 1.

Explanations: `3 consecutive days', `9 cells', `Golden Ratio'

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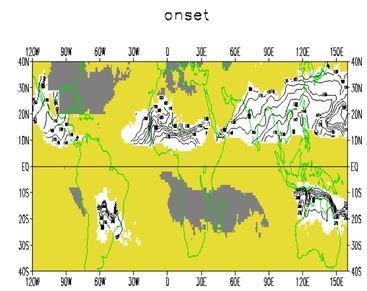

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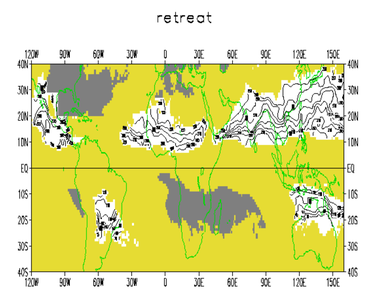

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Summary

- The numerical solution in CLM (and probably most other land models) cannot maintain the hydrostatic steady state solution of the differential Richards equation. This problem can be solved by using the revised form of the Richards equation. This would improve the soil moisture modeling in CLM as well [Zeng and Decker, 2008, J. Hydrometeor.; Decker and Zeng, 2008, JAMES]
- Developed a shrub submodel for the DGVM for the global competition of trees, grass, and shrubs. Use of MODIS land cover data alone is not sufficient for the DGVM model evaluation (particularly for shrubs) [X.D. Zeng et al., 2008, Global Biogeochemical Cycles]
- Developed a global unifed monsoon onset/retreat index [Zeng and Lu, 2004, J. Climate]