Impact of the Modified Richards Equation on CLM3.5

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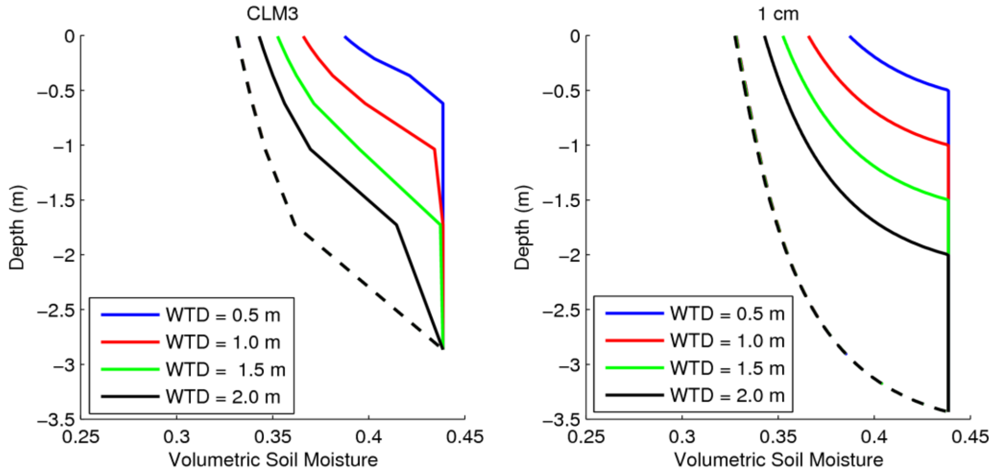
Motivation



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

Current Solution in CLM3.5: Supersaturated water in soil layers is removed and then added back to the soil column.

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

Our solution: Revise the equation so that the numerical solution can maintain the properties of the original partial differential equation

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

General Remarks

i) CLM3.5 is much better than CLM3.0

ii) CLM3.5 is too wet

iii) Soil Moisture variability is deficient in CLM3.5

Question: Can we improve these two deficiencies while maintaining the drastic improvements of CLM3.5 over CLM3.0?

Key Differences

- CLM3.5

1. Mathematically incorrect numerical solution

2. Physically unrealistic solution by solving the tridiagonal solution of soil moisture using zero flux bottom BC followed by surface-groundwater interaction

3. Many more parameters and new prognostic variables

- New Formulations

1. Mathematically correct solution using revised Richards equation

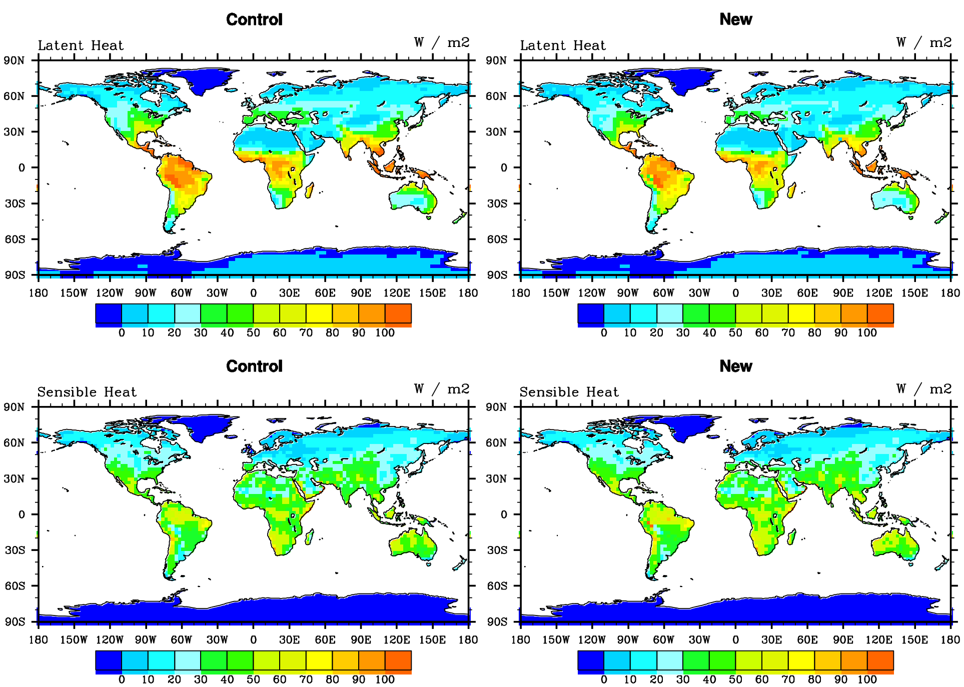
2. Direct surface-groundwater coupling in the tridiagonal solution

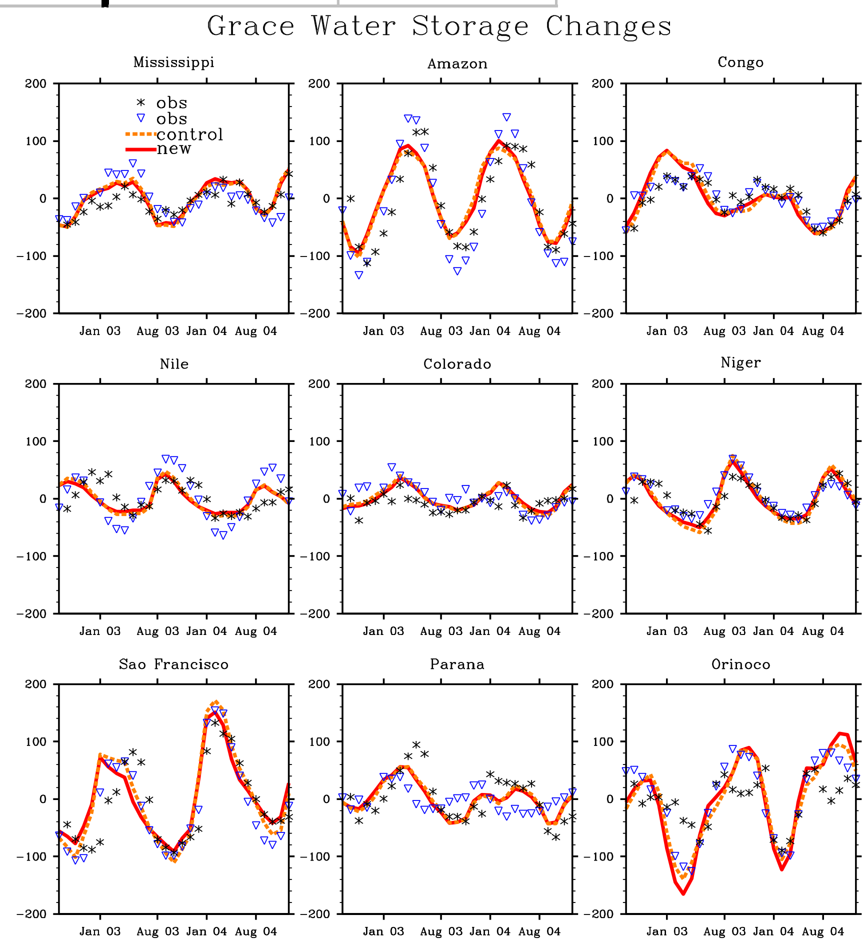
3. Only three parameters and single diagnostic variable (z_{∇})

   $F_{sat,Max}$, $Q_{h,max}$, $K_{sat,bot}$

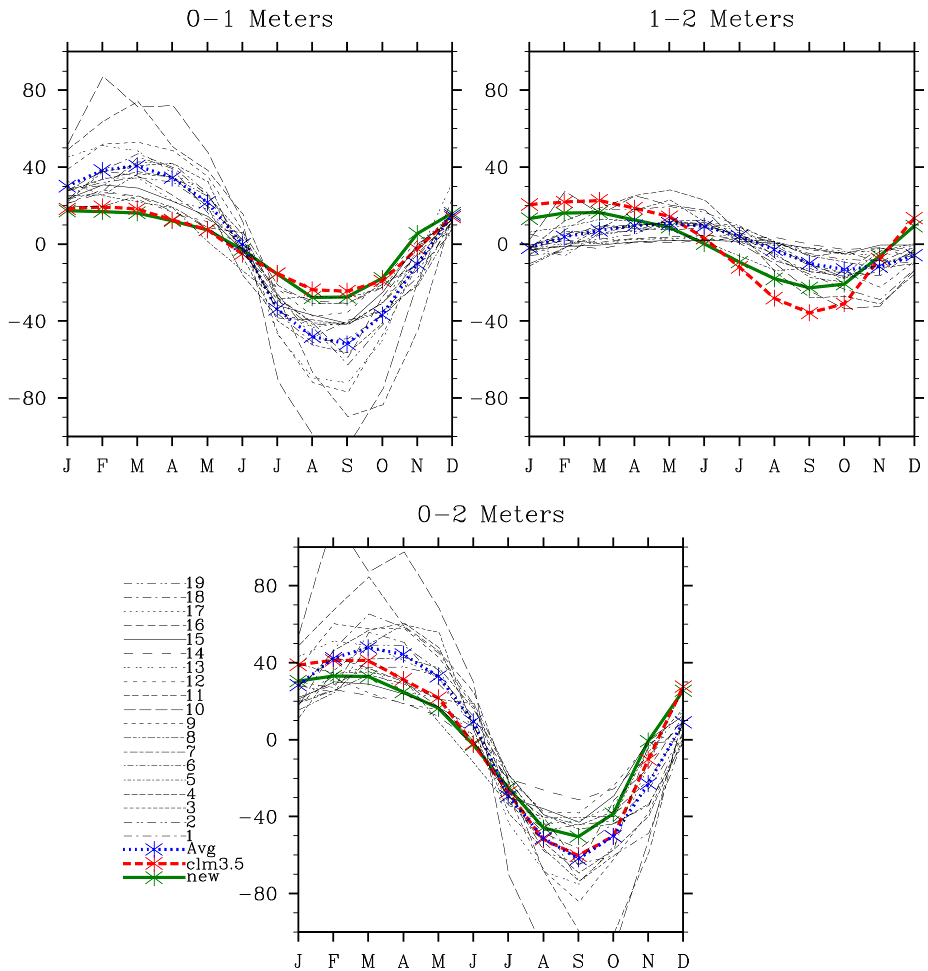
Ground Evaporation (mm/day)		Transpiration (mm/day)		Latent Heat (mm/day)	
Control	New	Control	New	Control	New
0.566	0.507	0.578	0.563	1.441	1.368
Surface Runoff (mm/day)		**Total Runoff (mm/day)**		**Surface/Subsurface**	
Control	New	Control	New	Control	New
0.158	0.248	0.717	0.696	0.22	0.356

GSWP2: 0.5

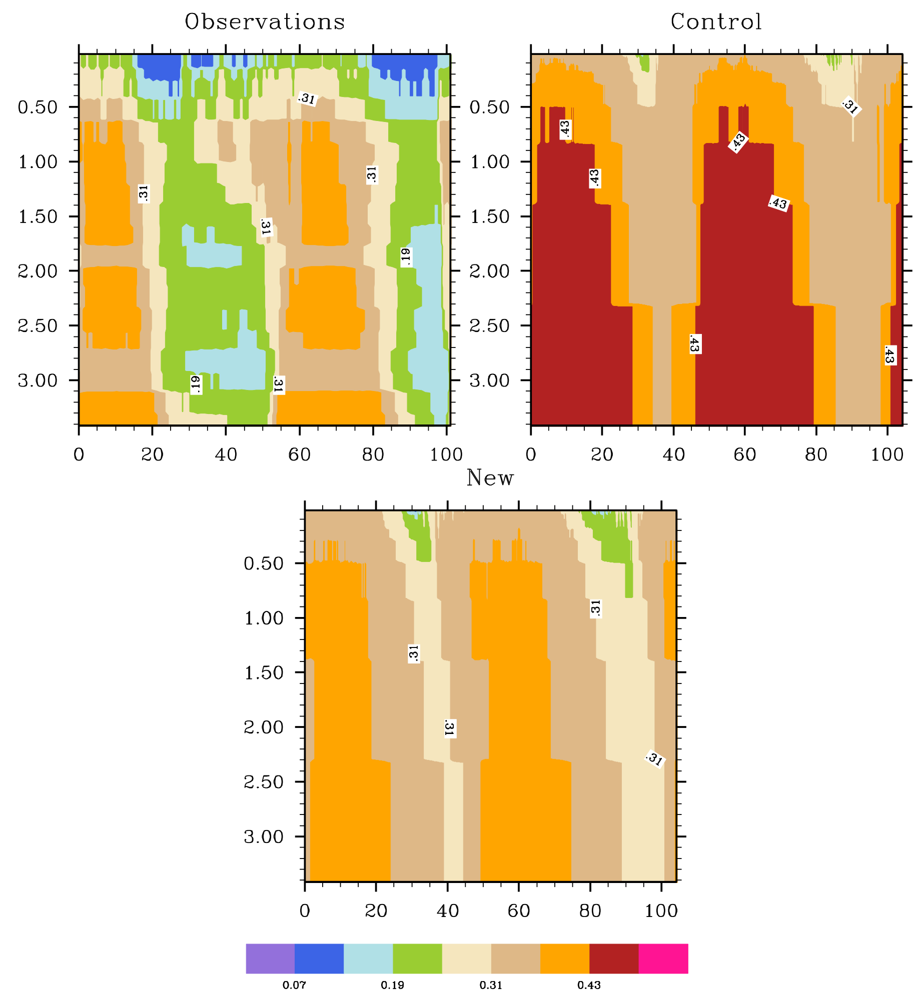




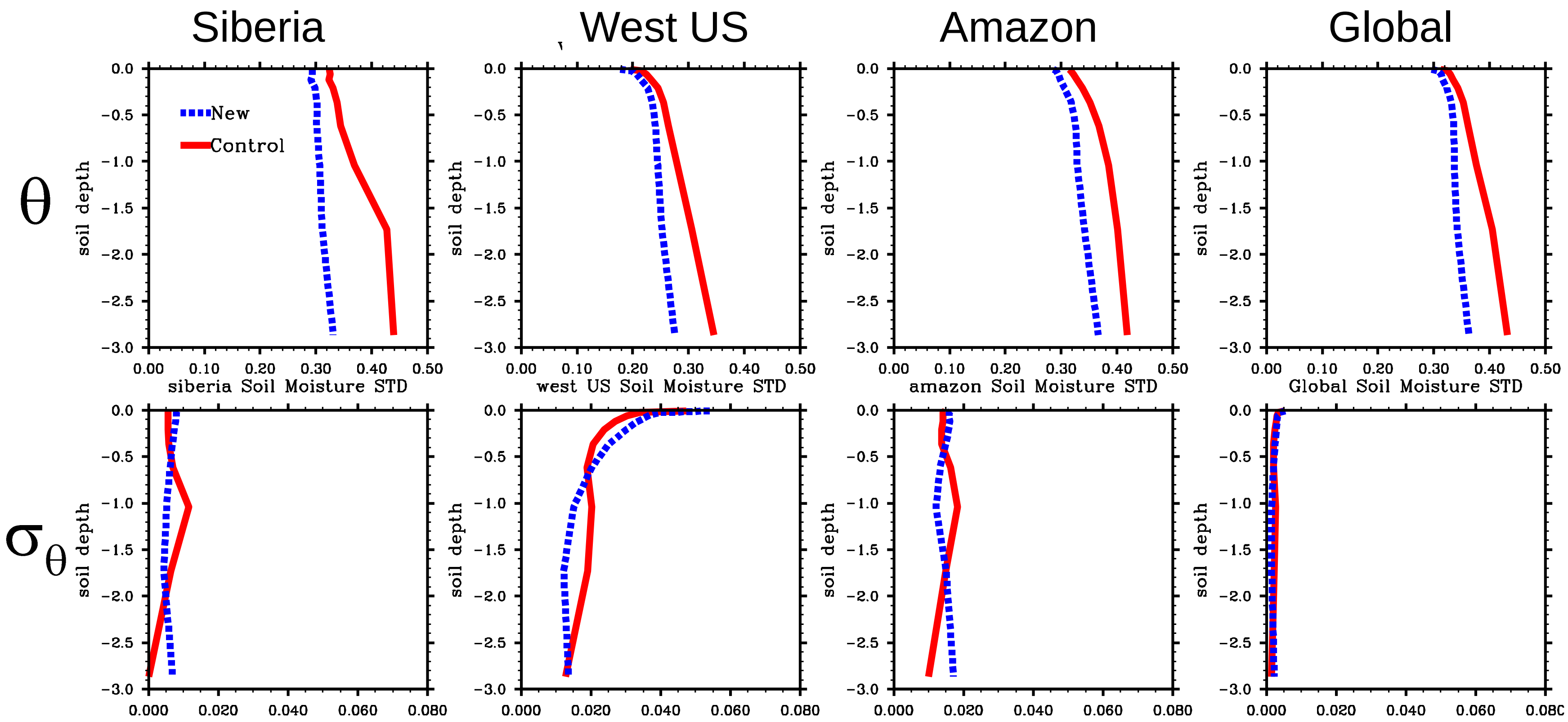
Illinois



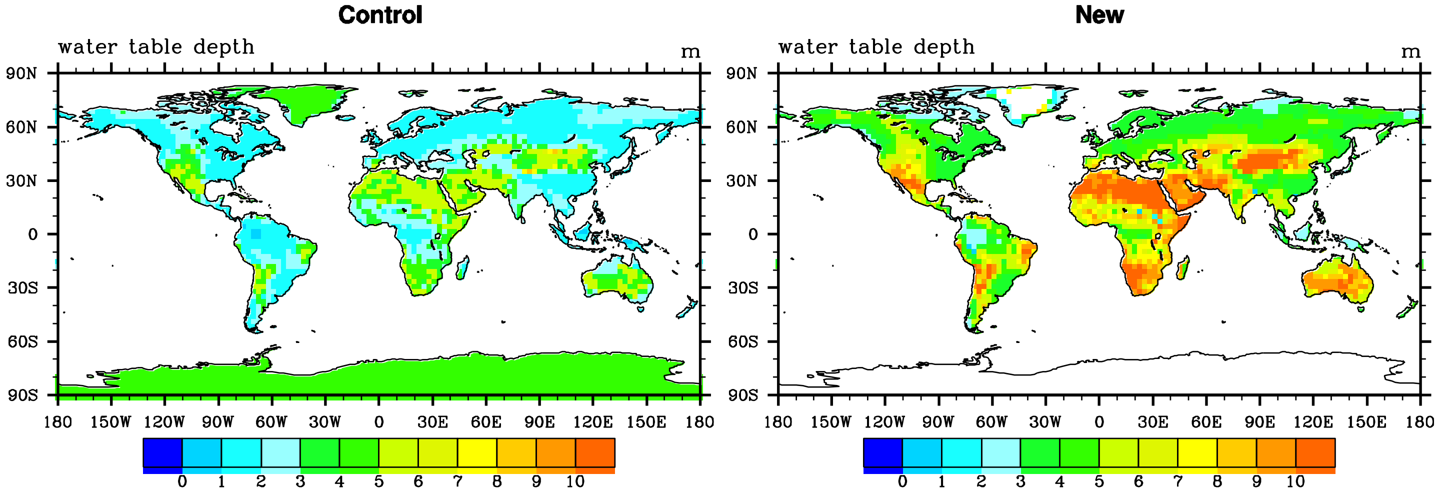
Amazon



Soil Moisture: Amount and Variation



Mean Annual Water Table Depth



Conclusions

- CLM3.5

1. Mathematically incorrect numerical solution
2. Physically unrealistic solution by solving the tridiagonal solution of soil moisture using zero flux bottom BC followed by surface-groundwater interaction
3. Many more parameters and new prognostic variables
4. Wetter soil column

- New Formulations

1. Mathematically correct solution using revised Richards equation
2. Direct surface-groundwater coupling in the tridiagonal solution
3. Only three parameters and single diagnostic variable (z_{∇})
4. Drier soil column, improved variability

All model simulations done using NCAR computers using CLM3.5 coding standards

Additional thought: Do we need a separate groundwater model?

- Pro: groundwater is physically coupled to unsaturated zone; provide a new dimension

  Remark: we all agree (including our own work)
- Question: what is groundwater?

  Answer: physically, just saturated soil, and Richards Equation can handle both unsaturated and saturated soil
- CLM3.5: 10 soil layers + GW layer with rockbed (zero vertical flux) at bottom

  A more physical way: have 11 soil layers in CLM3.5 directly along with zero vertical flux at bottom
- Our approach is even more general by allowing GW depth below 10 m