Progress towards development of a variably saturated subsurface model for CLM

Gautam Bisht[α] (gbisht@lbl.gov) **and William J. Riley**[α]

[α]Earth Sciences Division, Lawrence Berkeley National Laboratory.

ABSTRACT

- Groundwater, which accounts for 30% of freshwater reserves globally, is a vital source for human water supply.
- Climate change is expected to impact the quality and quantity of groundwater in the future.
- Numerous numerical studies have shown impacts of near-surface soil moisture dynamics on several key Earth system processes.
- Despite the obvious need to accurately represent soil moisture dynamics, the current version of the Community Land Model (CLM) employs a non-unified treatment of hydrologic processes in the subsurface.
- To overcome above-mentioned shortcoming, we implemented a **variably saturated Richards equation** (RE).

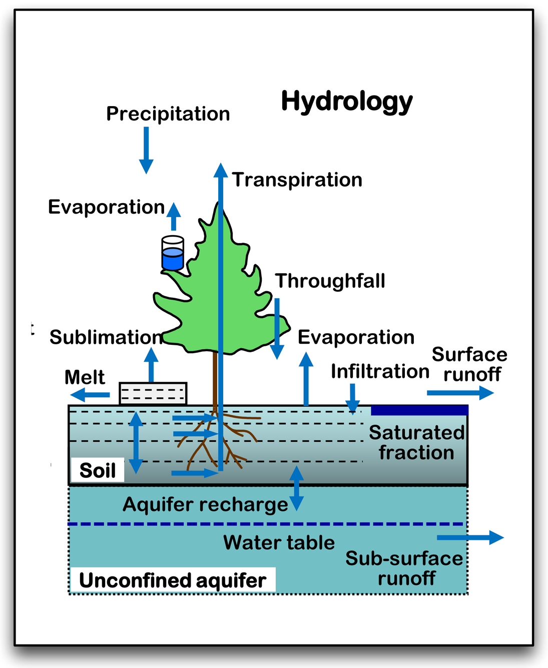

Figure 1 : Schematic representation of hydrologic processes in CLM

VARIABLY SATURATED FLOW MODEL

The governing equation for flow through porous media is given by

$$\frac{\partial(\phi s_w \rho)}{\partial t} = -\nabla \cdot (\rho \boldsymbol{q}) + Q \qquad (1)$$

and

$$\boldsymbol{q} = -\frac{k k_r}{\mu} \nabla (P + \rho g z) \qquad (2)$$

where ϕ is the soil porosity [-], s_w is saturation [-], ρ is water density [kg m^{-3}], $\boldsymbol{q}$ is Darcy flux [m s^{-1}], Q is the general source/sink term of water [kg m^{-3} s^{-1}], k is intrinsic permeability [m ^{2}], k_r is relative permeability [-], μ is viscosity of water [Pa s], P is pressure [Pa], g is the acceleration due to gravity [m s^{-2}], and z is the elevation [m]. In order to close the system, we choose van Genuchten [1980] and Mualem [1976] constitutive relationships.

The PDE of groundwater flow (Eq 1) can be rewritten as a system of two Differential Algebraic Equations (DAEs):

$$f_P \equiv \frac{\partial m}{\partial t} + \nabla \cdot (\rho \mathbf{q}) - Q = 0 \quad \text{in } \Omega \times [0, T] \qquad (3a)$$

$$f_m \equiv m - (\phi s_w \rho) = 0 \qquad (3b)$$

NUMERICAL SOLUTION

- Method of lines (MOL) is employed for spatial discretized of the DAE system.
- Variable-order, variable coefficient Backward Differential Formula is used to integrate the system in time.
- The DAE system is assembled using multi-physics capabilities in PETSc, while temporal integration is performed using SUNDIALS.
- Advantage of using PETSc and SUDIALS is that only six new subroutines are required:
  - Two subroutines for residual calculations, and
  - Four subroutines for jacobian computation.

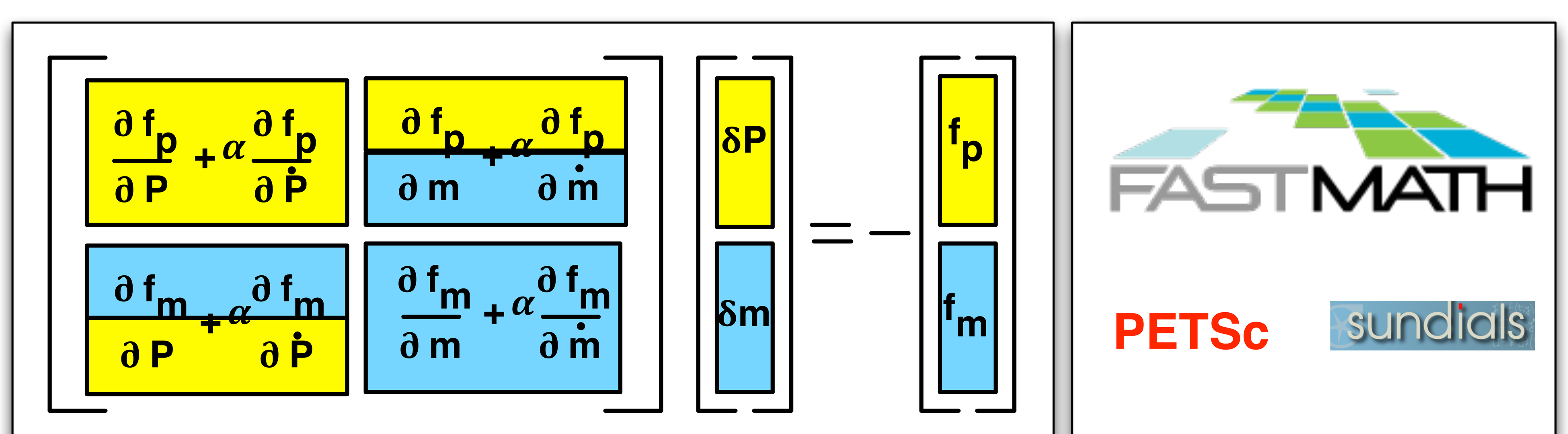

Figure 2 : Schematic representing numerical solution of DAE

RESULTS: INFILTRATION IN A VERY DRY SOIL

- Evolution of a wetting front within a dry 1 [m] deep soil column as reported in Celia et al. (1990) is simulated.
- Soils: $K_{sat} = 0.00922$ [cm s^{-1}]; $\theta_r = 0.102$ $\theta_s = 0.368$ $\alpha = 0.0335$ [cm^{-1}]
- Conditions
  - IC : $P(z, t = 0) = -10$[m]
  - BC: $P(z = 0, t) = -0.75$[m]
- VSFM captures the sharp wetting profile at $t = 24$ [hr] and agrees with results reported in Celia et al. (1990).

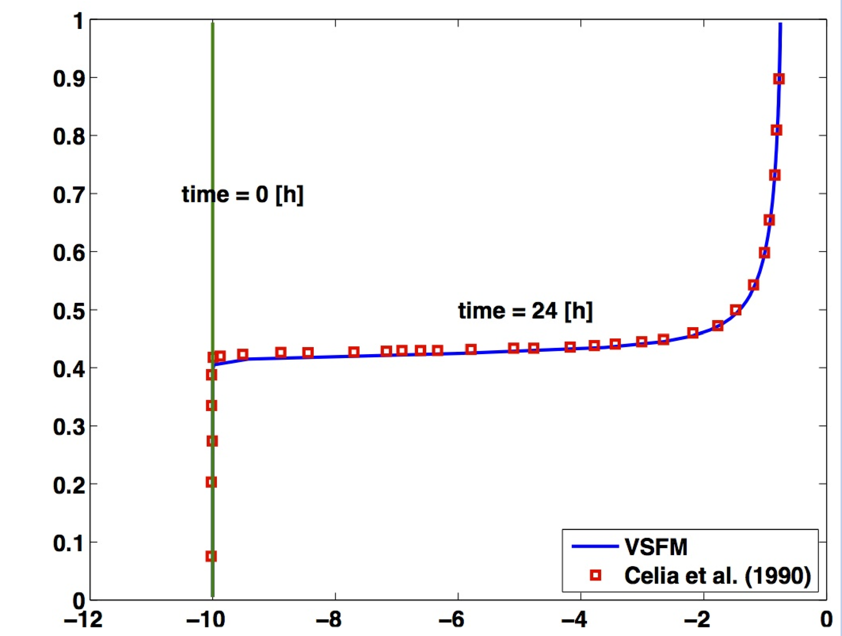

Figure 3 : Evolution of wetting front

RESULTS: TRANSIENT FLOW IN LAYERED SOILS

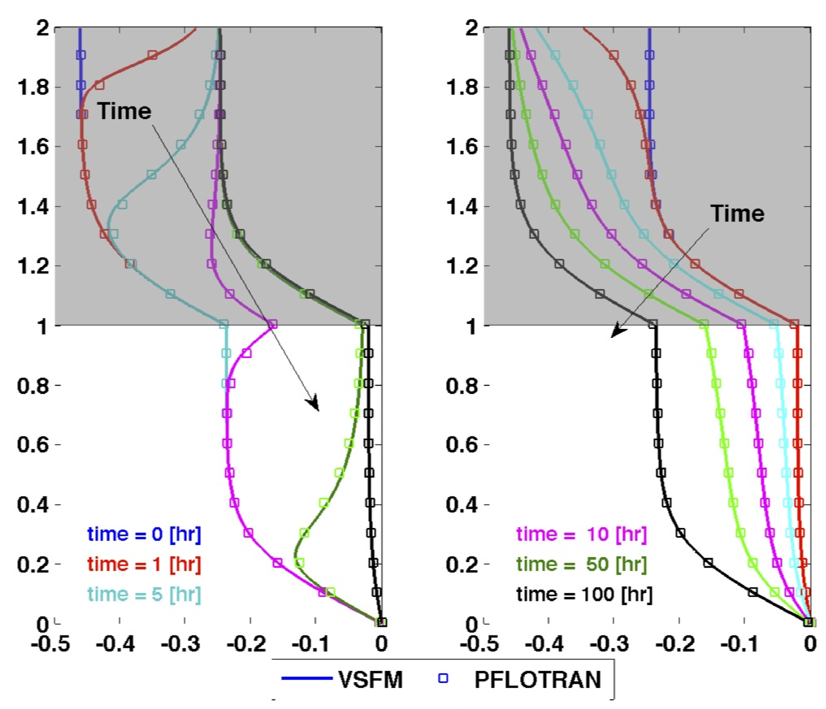

Figure 4 : (a) Wetting and (b) Drying in layered soils

- Evolution of pressure profile between two steady state conditions for layered soils is studied.
- $K_{s,top-soil}/K_{s,bot-soi} = 10$
- Top boundary conditions
  - Wetting: Top flux 2.5×10^{-6} [m s^{-1}]
  - Drying: Top flux 2.8×10^{-8} [m s^{-1}]
- The top soil layer, with higher hydraulic conductivity, responds quickly to change in top boundary condition as compared to bottom soil layer.
- VSFM results agrees with PFLOTRAN simulations.

RESULTS: WATER TABLE DYNAMICS

- This numerical experiment demonstrates the unified treatment of saturated and unsaturated in VSFM.
- Soils are same as in Celia et al. (1990).
- Conditions
  - IC : Hydrostatic condition with water table at 0.5 [m]
  - BC: Top flux $= 2.5 \times 10^{-5}$ [m s^{-1}]
- The simulated steady state water table depth at $t = 1$[d] is 0.7 [m], which agrees with PFLOTRAN results.

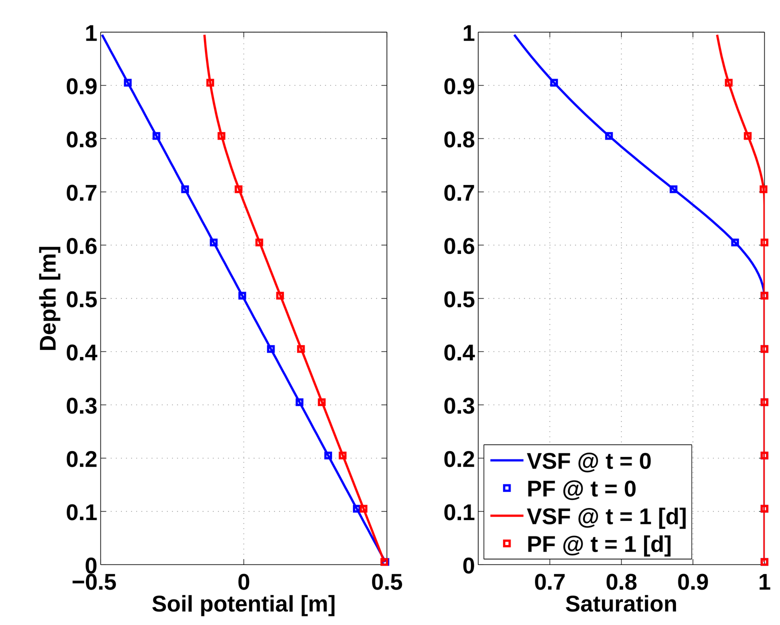

Figure 5 : Transient water table dynamics

FUTURE WORK

- Global offline CLM simulations are planned with default subsurface model and newly implemented variably saturated Richards equation to investigate the impact on surface–subsurface processes with a unified treatment of vadose and pheratic zone.

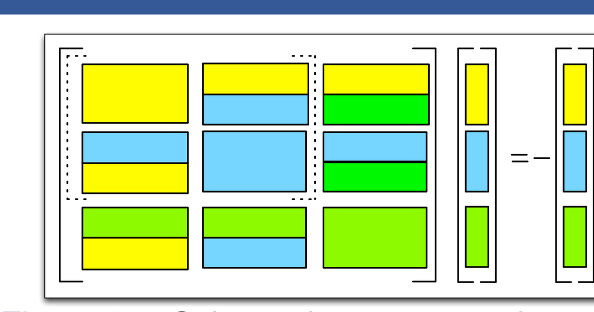

Figure 6 : Schematic representation of VSFM's extension.

- We plan to extend the current VSFM by coupling it with a hydraulic root distribution model to investigate plant water uptake for deep rooted forrest systems.
- Lastly, we plan to extend 1D subsurface flow model to be quasi-3D by implementing lateral fluxes as source/sink terms within 1D solution of the variably saturated Richards equation.

REFERENCES

Celia, M. A., Bouloutas, E. T., and Zarba, R. L.: A general mass-conservative numerical solution for the unsaturated ßow equation, Water Resour. Res., 26, 1483–1496, 1990

Mualem, Y. (1976). A new model for predicting the hydraulic conductivity of unsaturated porous media, Water Resources Research 12 513-522.

van Genuchten, M.Th. (1980), A closed-form equation for predicting the hydraulic conductivity of unsaturated soils, Soil Science Society of America Journal 44 (5): 892-898.

2014 Climate Modeling PI Meeting, May 12 - 14, 2014

Funding for this study was provided by the US Department of Energy, BER Program. Contract # DE-AC02-05CH11231.