Unified treatment of hydrologic processes in the unsaturated-saturated zone within ALM

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**Objective**

- Numerous modeling and observation studies have shown a positive soil moisture-rainfall feedback.
- Groundwater, which accounts for 30% of freshwater reserves globally, is expected to be impacted in quantity and quality by climate change.
- The current version of the ACME Land Model (ALM) employs a non-unified treatment of hydrologic processes in the subsurface.
- To overcome above-mentioned issue a variably saturated flow model (VSFM) is developed that uses Portable, Extensible Toolkit for Scientific Computation (PETSc) library.

**Approach**

- The governing equations for flow in porous media are given by:
  \[
  \frac{\partial (\phi s_w \rho)}{\partial t} = \nabla \cdot \left( \rho \mathbf{q} \right) + Q \\
  \mathbf{q} = -\frac{k_k}{\mu} \nabla (P + \rho g z)
  \]

  where \( \phi \) is the soil porosity [-], \( s_w \) is water saturation [-], \( \rho \) is water density [kg m\(^{-3}\)], \( \mathbf{q} \) is Darcy flux [m s\(^{-1}\)], \( Q \) is a source of water [kg m\(^{-2}\)s\(^{-1}\)], \( k \) is intrinsic permeability [m\(^2\)], \( \phi \) is relative permeability [-], \( \mu \) is viscosity of water [Pa s], \( k_k \) is liquid pressure [Pa], \( g \) is the acceleration due to gravity [m s\(^{-2}\)], and \( z \) is the elevation [m].

- In order to close the system of equation, we choose van Genuchten [1980] and Maulem [1976] constitutive relationship.
- Finite volume spatial discretization and backward euler temporal integration is used in the VSFM.
- The set of resulting non-linear equations are solved using PETSc.

**Results**

- Evolution of a wetting front within a dry 1[m] deep soil column as reported in Celia et al. (1980).
- VSFM captures the sharp wetting profile at \( t = 24 \) [hr] and agrees well with reported data.
- Evolution of pressure profile between two stead conditions for layered soils.
- The top soil layer, with higher hydraulic conductivity responds quickly to change in top boundary condition as compared to bottom soil layer.
- The numerical experiment demonstrates the unified treatment of saturated and unsaturated zone in the VSFM for a constant infiltration flux.
- The water table rises by 0.2 [m] at the end of simulation.

  
  - Macropore flow simulation performed using a Dual Continuum Connected Matrix approach.
  - A constant infiltration flux is applied only to the macropore, which accounts for 5% of the total volume and has \( K_{sat} \) 2000 times larger than bulk soil.
  - VSFM results agree with PFLOTRAN.