F: Vertically resolved biophysics in ALM for the soil-plant-atmosphere continuum

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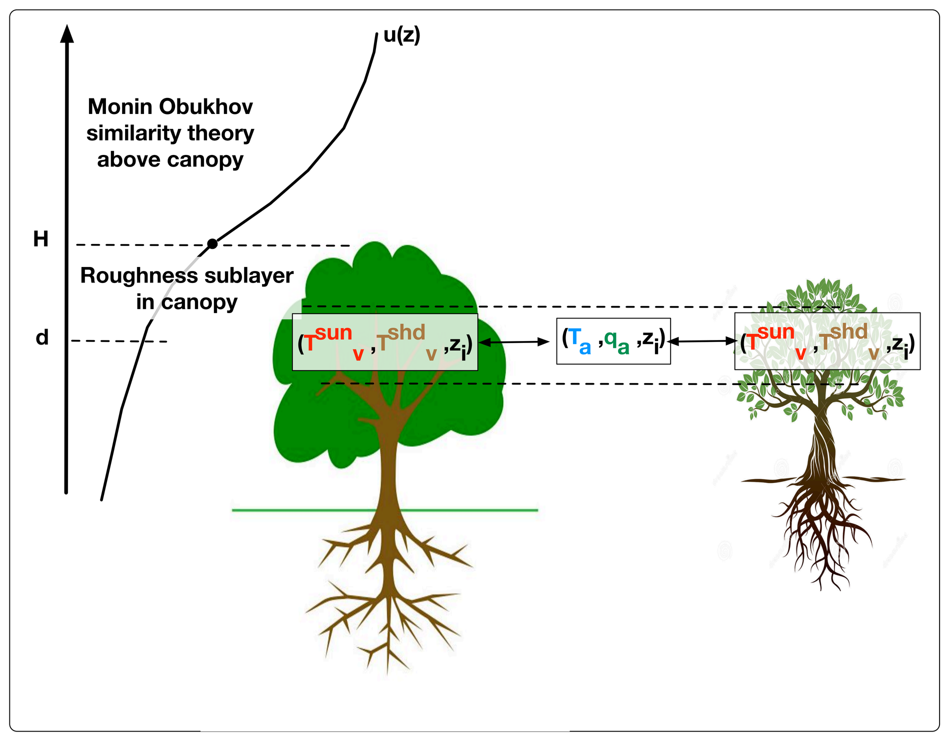
Objective

- Several recent studies have demonstrated the need for explicitly resolving the vertical regimes of light and thermal within the vegetation canopies and the surrounding air space to accurately capture vegetation response to future climate perturbations
- Develop a rigorously verified, vertically-resolved, soil-plant-atmosphere continuum (SPAC) model to simulate transport of water, energy, and carbon using the multi physics problems (MPP) framework.



Approach

The governing equations for multi-layer SPAC model is given by:

Conservation of energy in vegetation:

$$C_v \frac{\partial T_v^{sun}(z)}{\partial t} = R_{net}^L(T_v^{sun}, z) + R_{net}^S - H_v^{sun}(T_v^{sun}, T_a, z) - \lambda E_v^{sun}(T_v^{sun}, q_a, z)$$

$$C_v \frac{\partial T_v^{shd}(z)}{\partial t} = R_{net}^L(T_v^{shd}, z) + R_{net}^S - H_v^{shd}(T_v^{shd}, T_a, z) - \lambda E_v^{shd}(T_v^{shd}, q_a, z)$$

Conservation of energy in canopy air space:

$$C_a^p \rho_a \frac{\partial T_a(z)}{\partial t} = -\frac{\partial}{\partial z}\left(-k C_a^p \rho_a \frac{\partial T_a(z)}{\partial z}\right) + H_v^{sun}(T_v^{sun}, T_a, z) + H_v^{shd}(T_v^{shd}, T_a, z)$$

Conservation of mass in canopy air space:

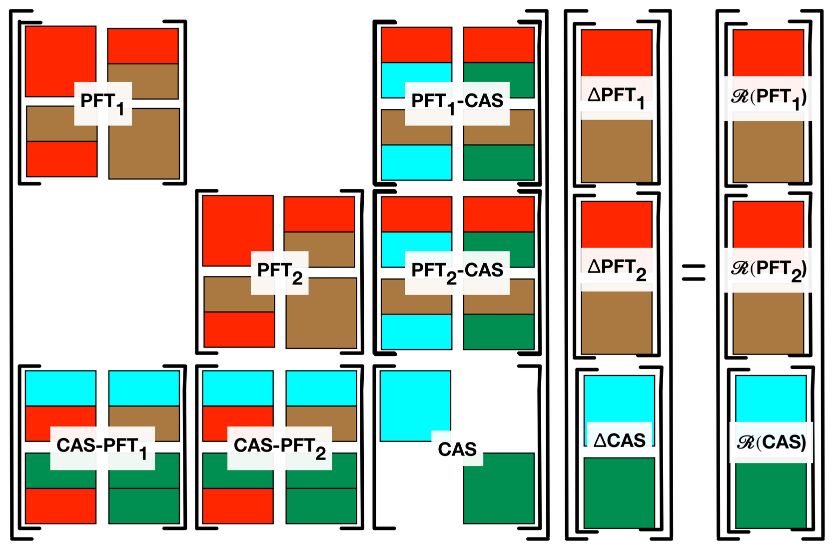
$$\rho_a \frac{\partial q_a(z)}{\partial t} = -\frac{\partial}{\partial z}\left(-k\rho_a \frac{\partial q_a(z)}{\partial z}\right) + E_v^{sun}(T_v^{sun}, q_a, z) + E_v^{shd}(T_v^{shd}, q_a, z)$$

The multi-layer SPAC model additionally needs the following quantities:

- Multi-layer shortwave radiation model that considers beam and direct radiation in photosynthetically active and near-infrared bands separately.
- The wind profile within and above canopy; and vertical eddy diffusivity.

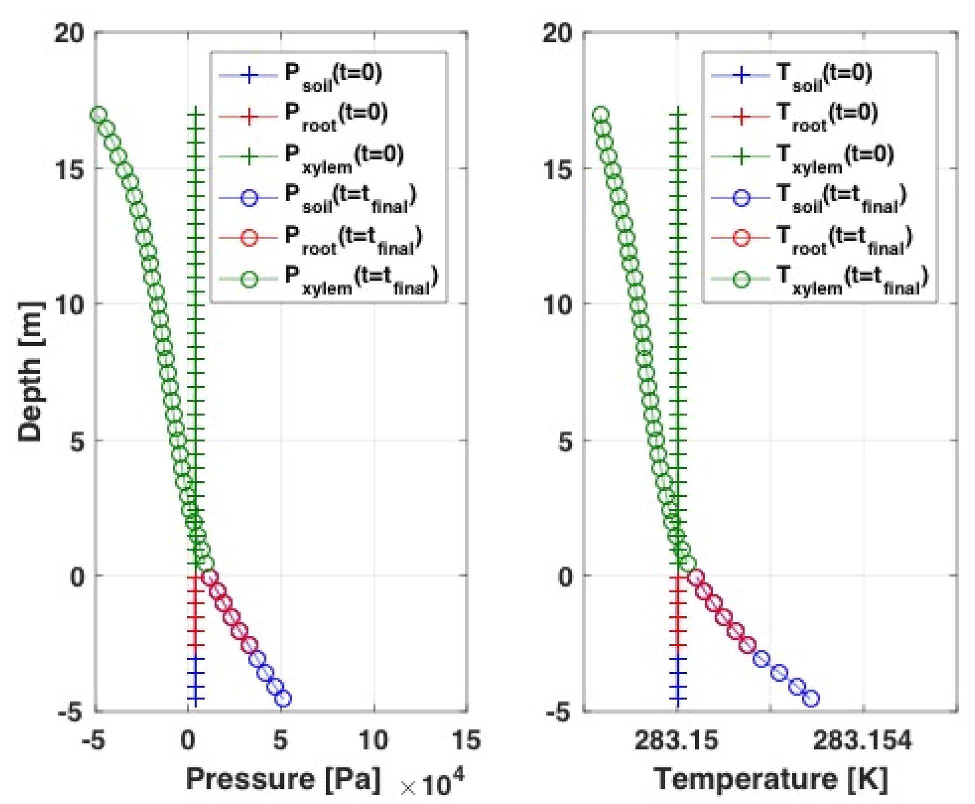
Methodology

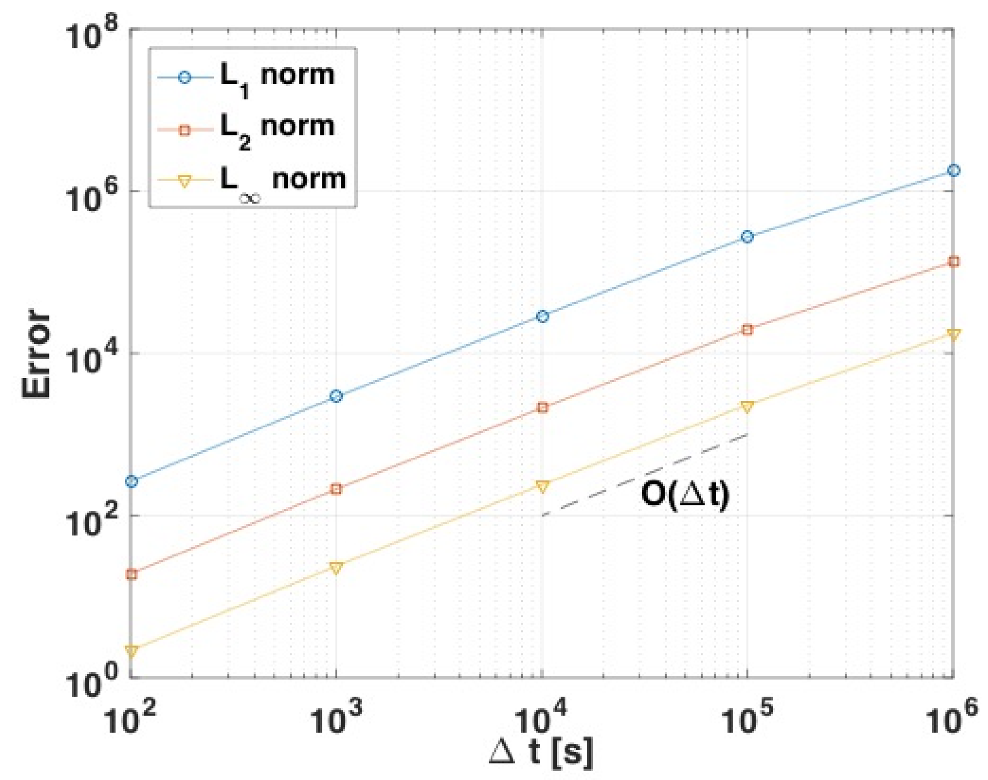
- R_{net}^S profile will be computed first.
- Vertical velocity profile will be computed using CAS state variables from previous time step.
- Lower soil boundary condition will be used from previous time step.
- Longwave radiative transfer matrix approach of Gu (1998) to compute absorbed net longwave radiation at each vertical level in the canopy will be extended to account for sunlit and shaded leaves.
- PETSc library will be used to provide numerical solution.



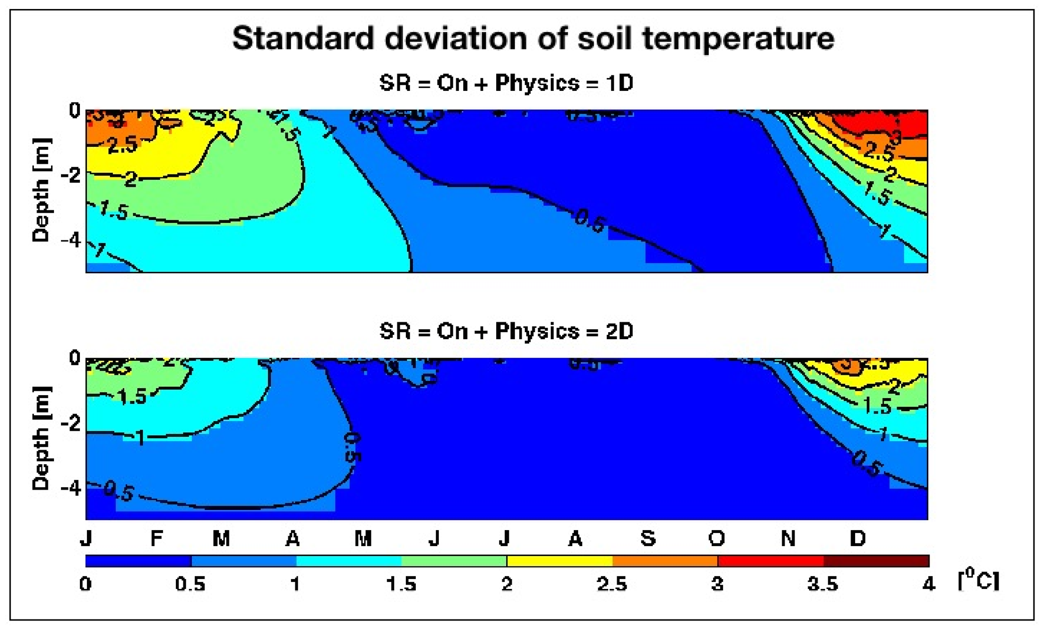
Examples of MPP framework

- Evolution of pressure and temperature for an idealized soil–root–xylem problem.
- Linear convergence of L_1, L_2, and L_∞ error of numerical solution.





- Snow–soil–standing water thermal model with microtopographic features in Arctic.
- Snow redistribution results in surface Tsoil heterogeneity that propagates deeper in the soil column.
- 1D subsurface model overestimates σ_{Tsoil} as compared to 2D model.



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