The Noah Multi-Physics Land Surface Model: Description and Comparison of Options

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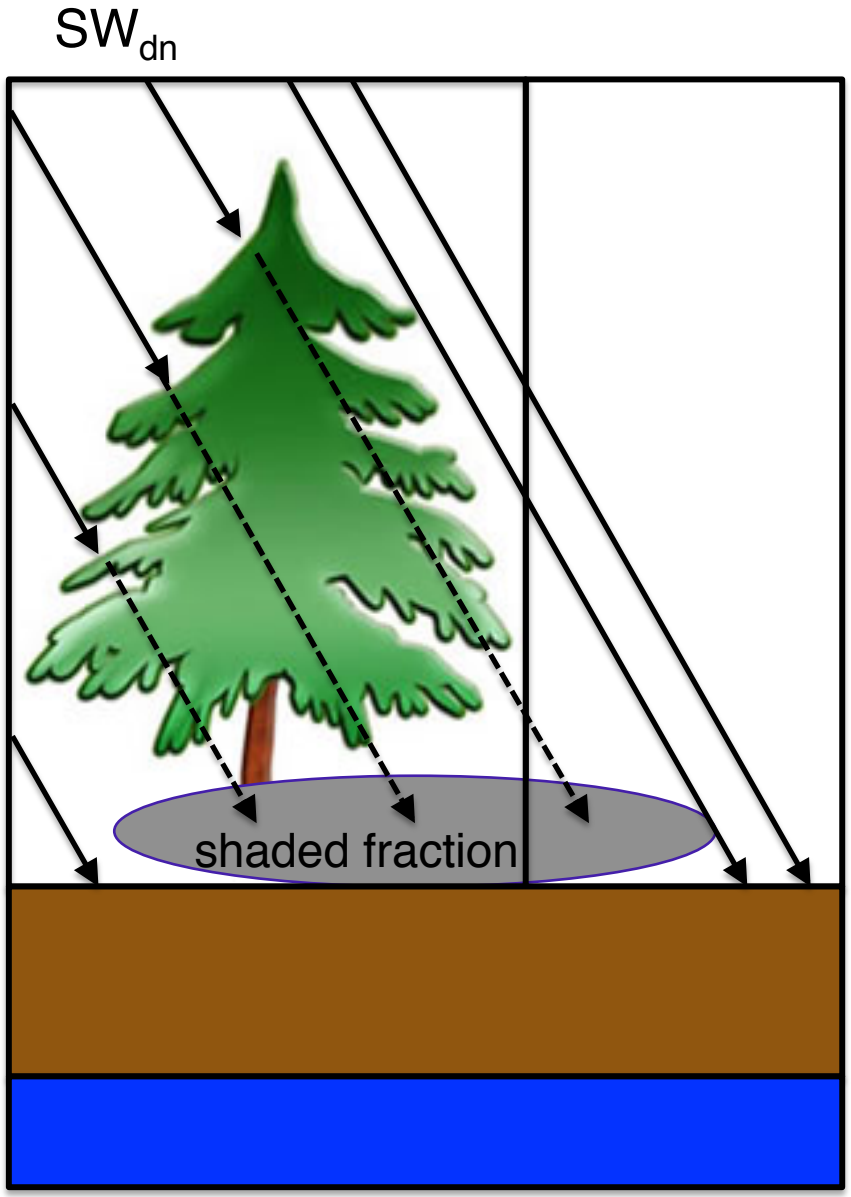
What is Noah-MP?

Noah-MP is an extended version of the Noah LSM with enhanced Multi-Physics options to address critical shortcomings in Noah

- Canopy radiative transfer with shading geometry
- Separate vegetation canopy
- Dynamic vegetation
- Ball-Berry canopy resistance
- Multi-layer snowpack
- Snowpack liquid water retention
- Interaction with aquifer
- Snow albedo treatment
- New frozen soil scheme
- New snow cover



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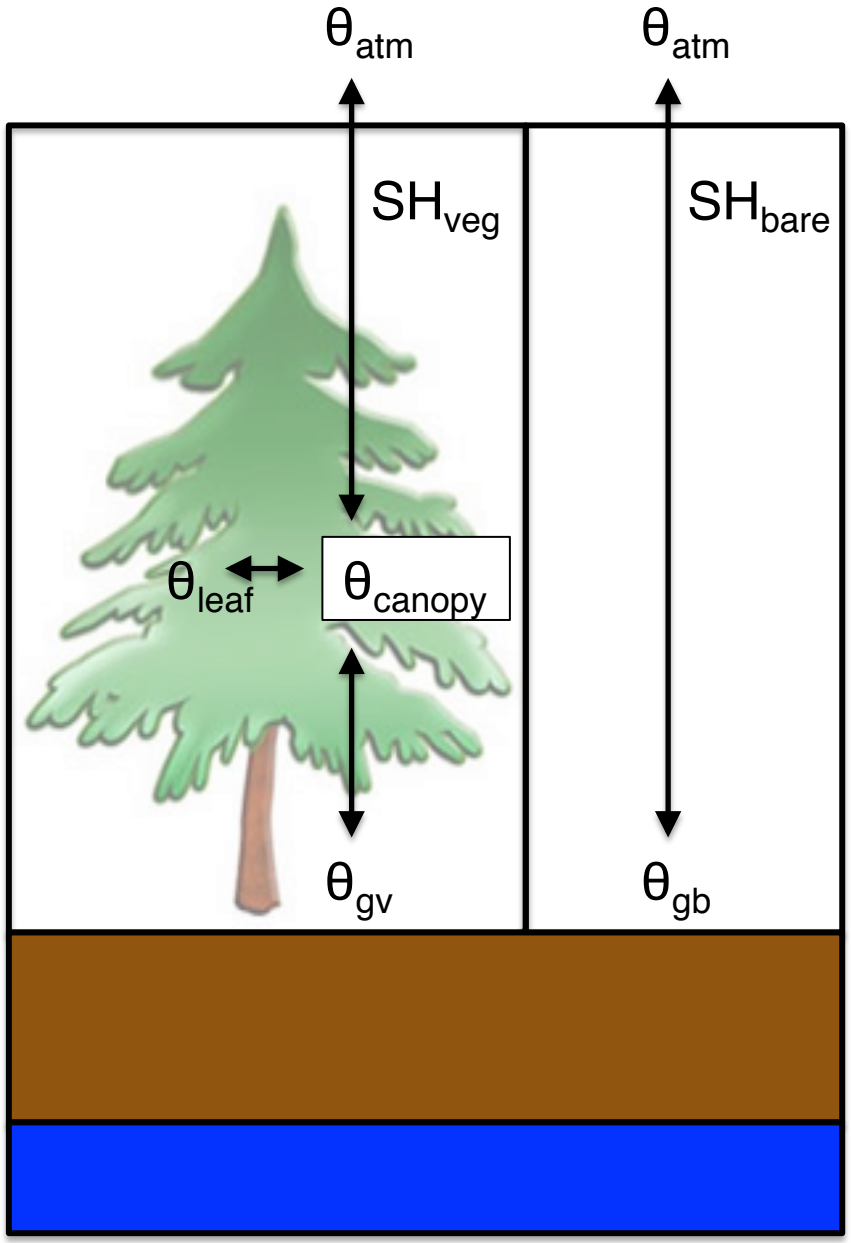

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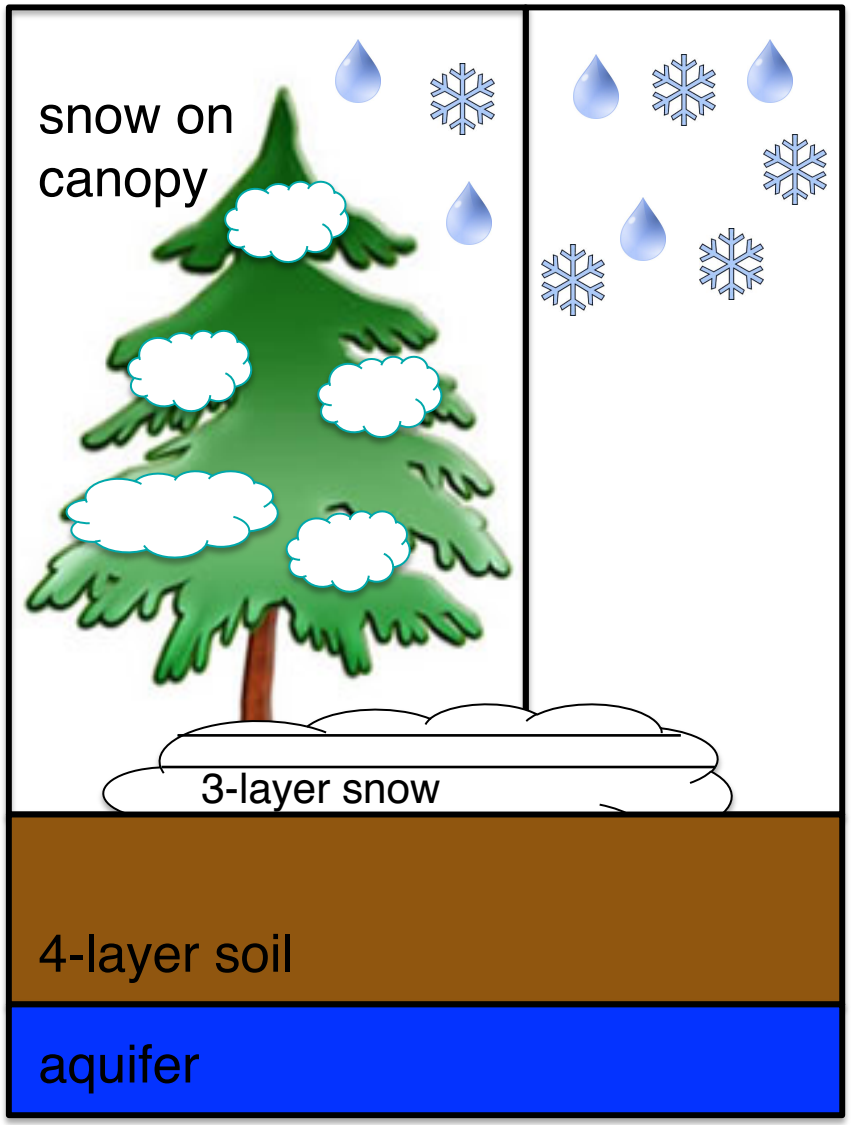

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What is Noah-MP?

Noah-MP contains several options for land surface processes:

1. Dynamic vegetation/vegetation coverage (4 options – default: off)
2. Canopy stomatal resistance (2 options – default: Ball-Berry)
3. Canopy radiation geometry (3 options – default: shadows – f(sun))
4. Soil moisture factor for stomatal resistance (3 options – default: Noah)
5. Runoff and groundwater (4 options – default: TOPMODEL)
6. Surface layer exchange coefficients (4 options – default: MP M-O)
7. Supercooled soil liquid water/ice fraction (2 options – default: no iter)
8. Frozen soil permeability options (2 options – default: linear effects)
9. Snow surface albedo (2 options – default: CLASS)
10. Rain/snow partitioning (3 options – default: Jordan f(T))
11. Lower soil boundary condition (2 options – default: fixed bottom T)
12. Snow/soil diffusion solution (2 options – default: flux boundary)

Total of ~50,000 permutations can be used as multi-physics ensemble members

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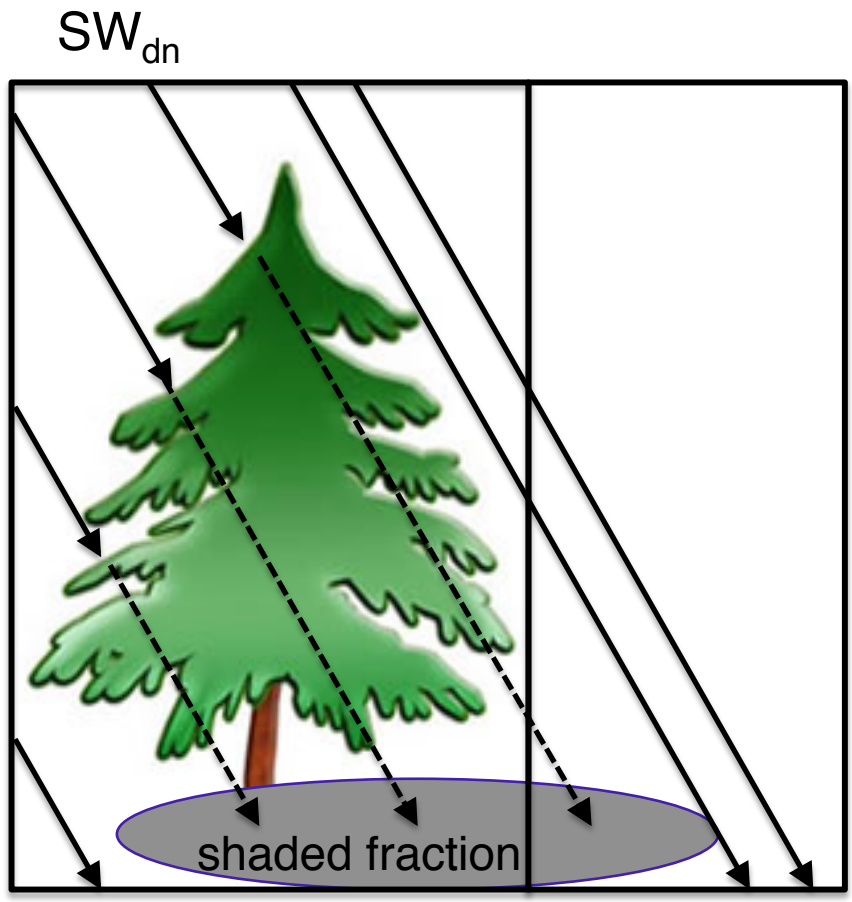
Canopy Radiative Transfer

Noah-MP uses a two-stream radiative transfer treatment through the canopy based on Dickinson (1983) and Sellers (1985)

- Canopy morphology parameters:
  - Canopy top and bottom
  - Crown radius, vertical and horizontal
  - Vegetation element density, i.e., trees/grass leaves per unit area
  - Leaf and stem area per unit area
  - Leaf orientation
  - Leaf reflectance and transmittance for direct/diffuse and visible/NIR radiation
- Multiple options for spatial distribution
  - Full grid coverage
  - Vegetation cover equals prescribed fractional vegetation
  - Random distribution with slant shading



Canopy Radiative Transfer

- Over a Noah-MP grid, individual tree elements are randomly distributed and have overlapping shadows
- Noah-MP albedo is calculated based on canopy parameters
- Noah prescribes snow-free and snow-covered albedo from satellite climatology

SE Minnesota in Google Maps

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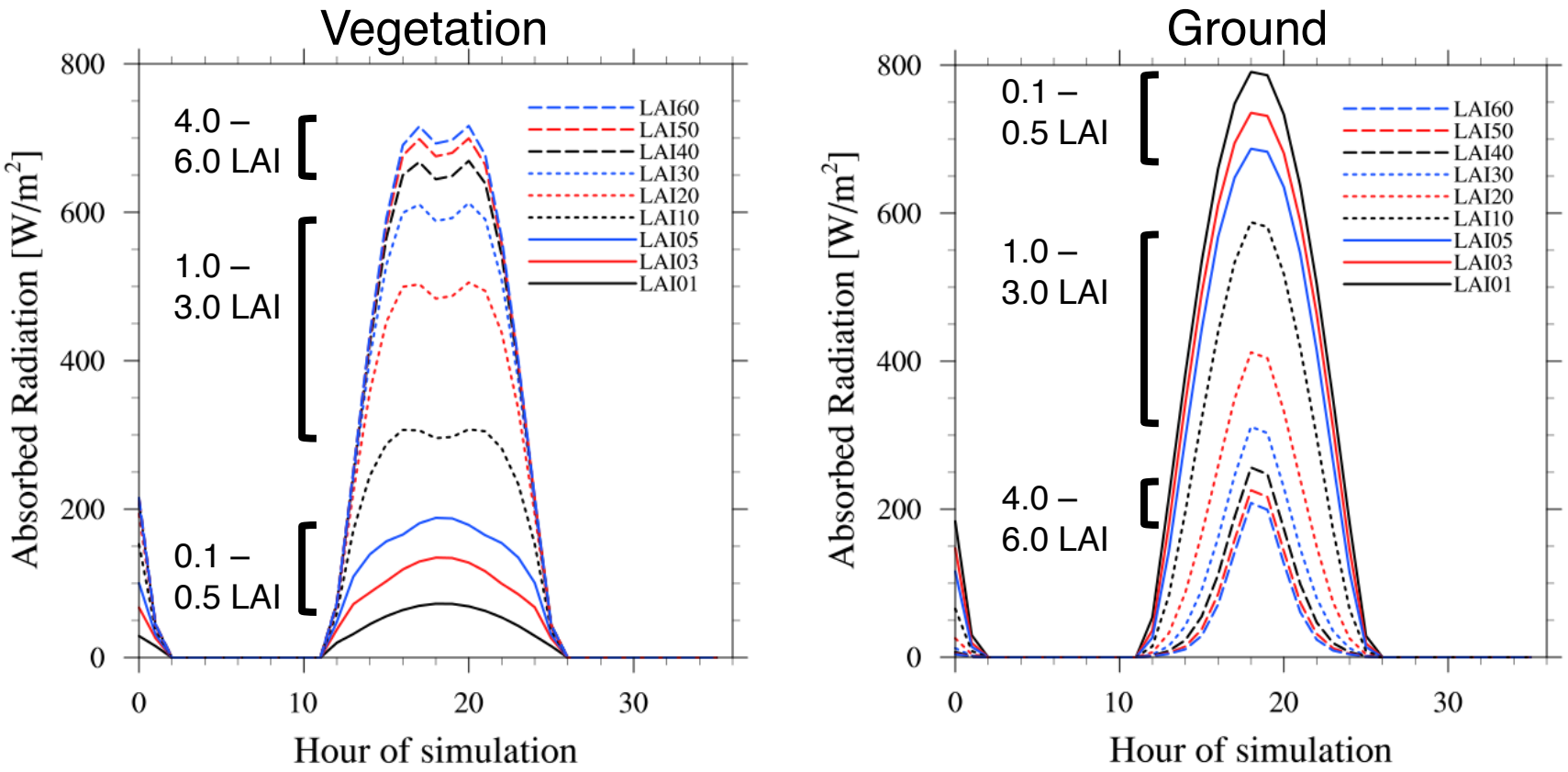
Canopy Radiative Transfer



- Idealized 36-hr simulation with 50% vegetation cover, evergreen needleleaf forest, July 13, 2010
- Canopy and ground absorbed radiation as a function of LAI from 0.1 to 6.0

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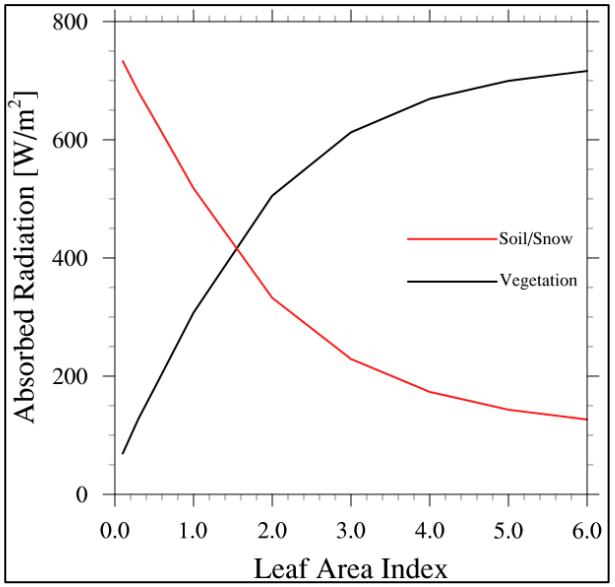
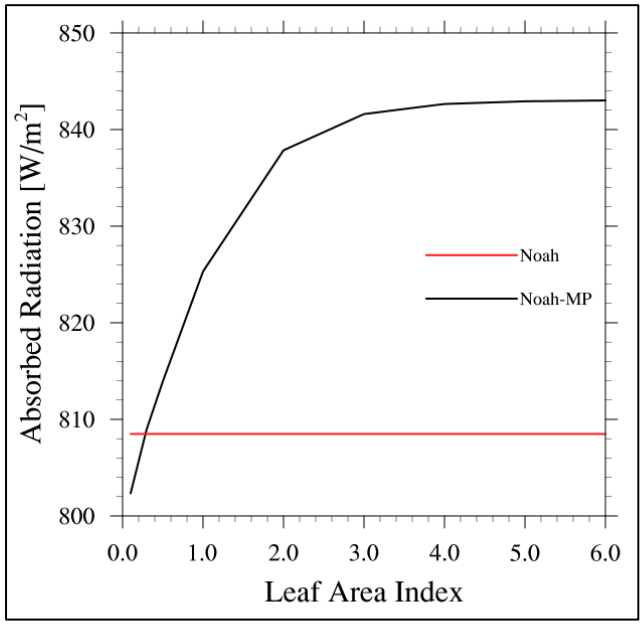
Canopy Radiative Transfer

- Canopy and ground absorbed radiation at hour 20 (near peak) as a function of LAI from 0.1 to 6.0
- Strong sensitivity to LAI for low (<3) vegetation densities
- SW_{dn} ~ 1000 W/m^2





- Total absorbed radiation in Noah-MP and Noah at hour 20 (near peak) as a function of LAI from 0.1 to 6.0
- A key point here is that all of the absorbed energy in Noah goes into the "surface" while Noah-MP maintains a separate canopy and ground energy partitioning

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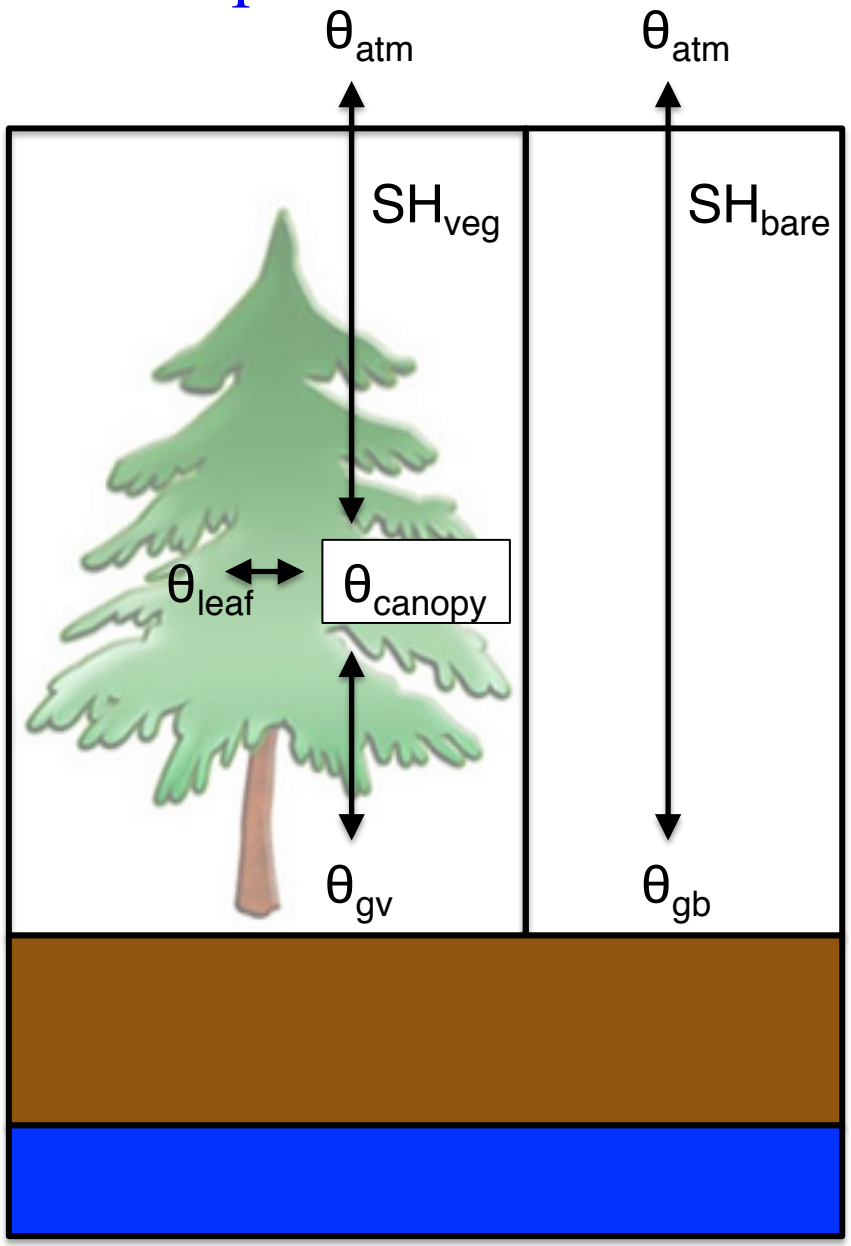
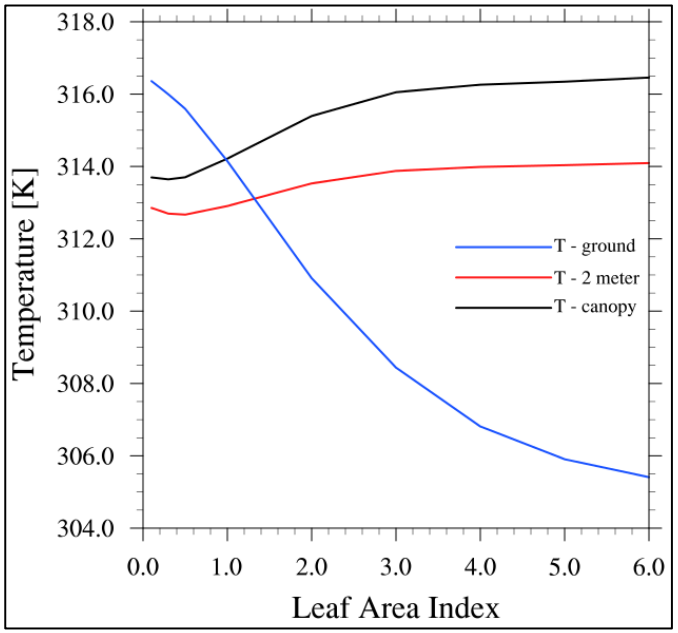
Multiple Land Surface Temperatures

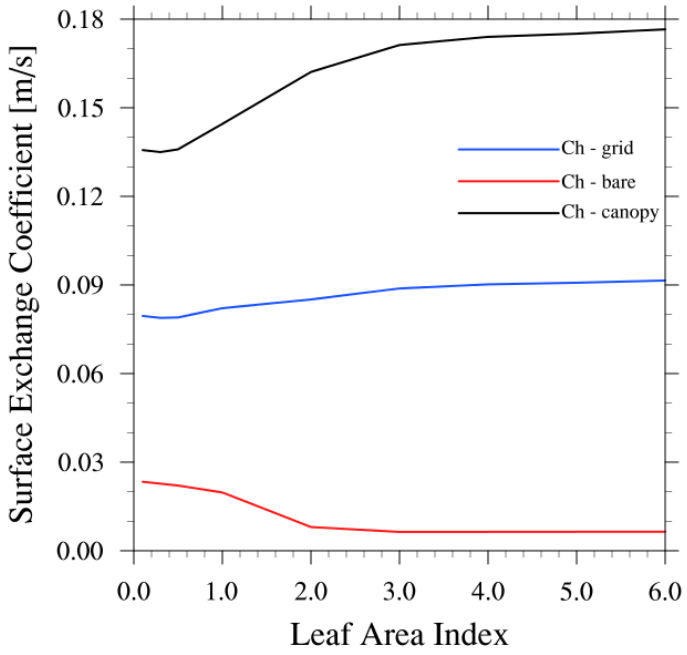
- Noah-MP contains
  - Canopy air temperature
  - Leaf surface temperature
  - Soil/snow surface temperature both below and between canopy
- Noah considers only one bulk surface skin temperature
- Implications for snow and near-surface air temperature
  - Noah surface temperatures are limited to near freezing when snow present; can lead to low temperature bias in winter
  - Noah-MP canopy temperature distinct from snow temperature can be above freezing
  - More surface energy is removed as sensible heat instead of high albedo required in Noah to maintain snow



Multiple Land Surface Temperatures

- Canopy air, ground surface, and 2-meter temperature at hour 20 (near peak radiation) as a function of LAI from 0.1 to 6.0
- Canopy air and 2-meter temperature are relatively insensitive to LAI compared to ground temperature





- Surface exchange between vegetation and atmosphere is about an order of magnitude greater than exchange between ground and atmosphere
- Ground surface becomes decoupled from atmosphere with increasing LAI due to increased shading

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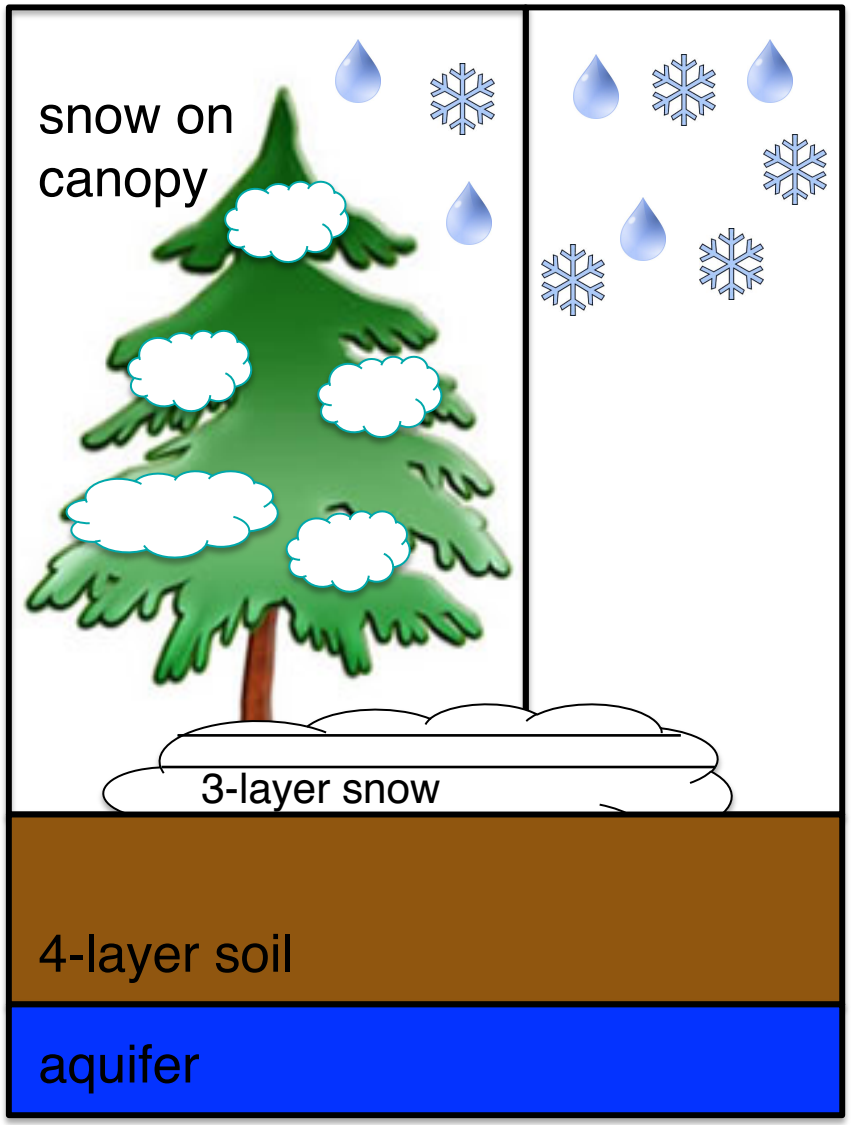
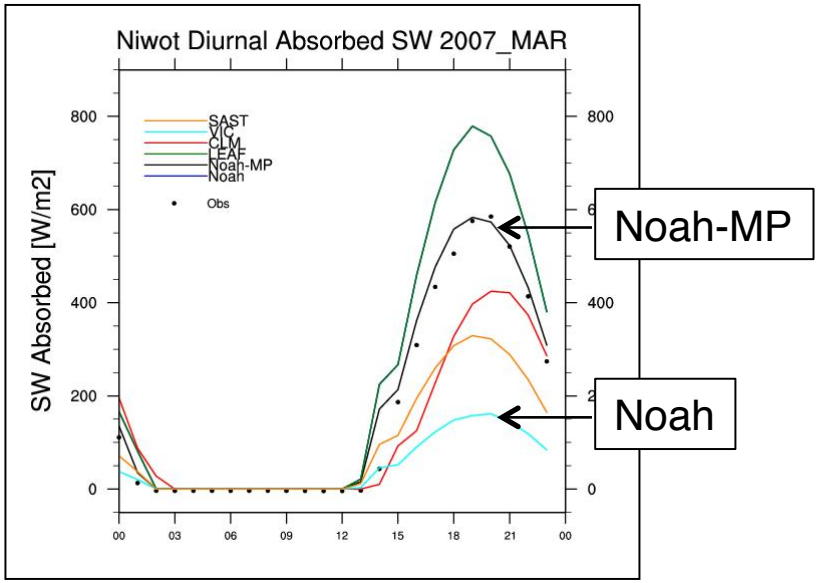
Surface Hydrology: Snow Treatment and Aquifer

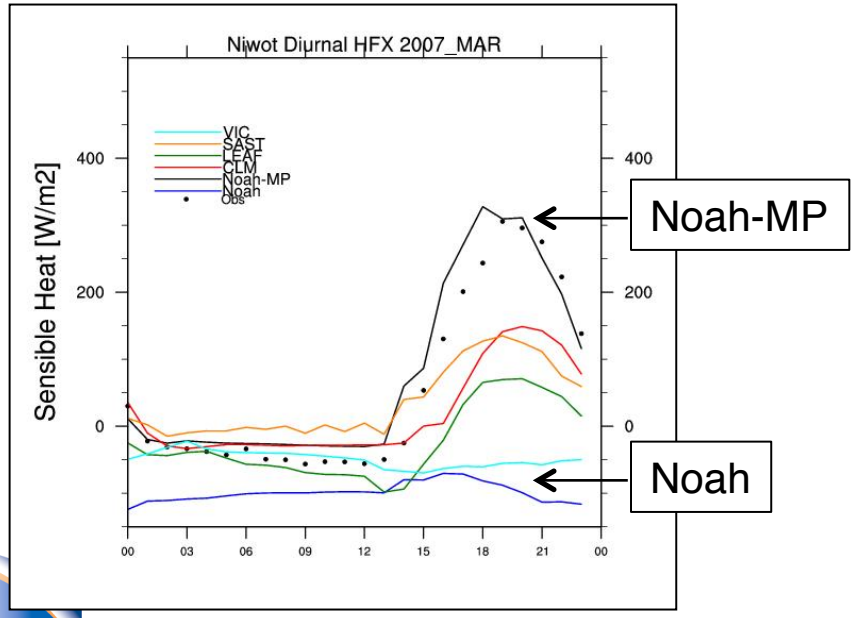
- Noah-MP contains
  - Three-layer snow model with liquid water retention
  - Canopy snow interception
  - Option with water table depth
- Noah considers only one snow/ soil layer and free water drainage
- Implications for snow and soil hydrology
  - Better treatment of heat flux through snow pack
  - Allows for sublimation from canopy intercepted snow
  - Liquid water retention (not present in Noah) maintains snow during melt periods
  - Soil layers can recharge via aquifer water in dry periods (important for regional climate simulations)



Surface Hydrology: Snow Treatment

- When compared to other LSMs in offline tests, Noah-MP does very well compared to observed tower fluxes at Niwot Ridge forest site
- Noah albedo is too high

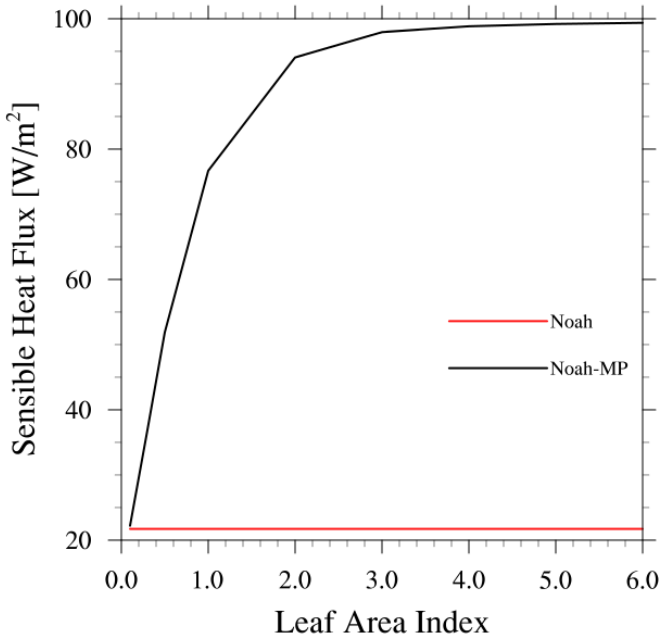


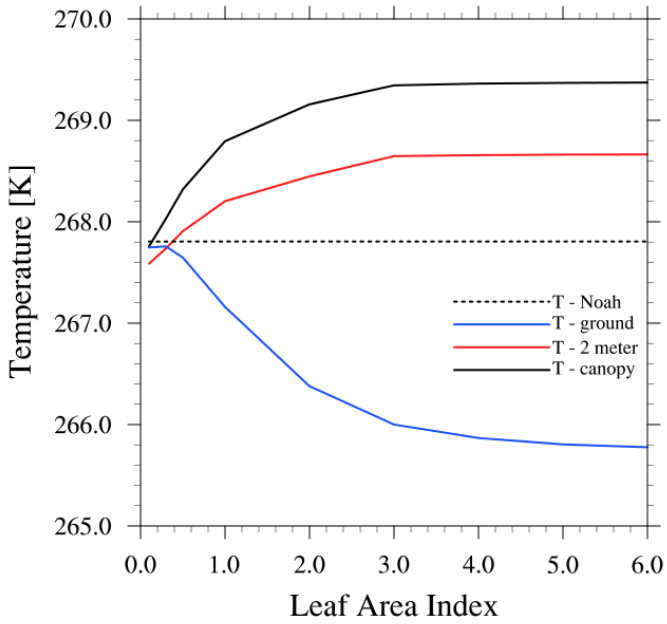


- Noah-MP is also properly partitioning absorbed radiation into sensible heat flux at Niwot Ridge in spring
- Noah incoming energy is reflected resulting in less energy to the atmosphere

Surface Hydrology: Snow Treatment

- In idealized coupled WRF runs for January 2, 2010 with 10mm SWE on ground, Noah and Noah-MP produce similar fluxes for very low LAI
- As LAI increases, Noah-MP sensible heat flux to the atmosphere increases (SW_{dn} ~ 250 W/m^2)





- Temperature results show Noah and Noah-MP have similar 2-meter temperatures for low vegetation amount
- Differ by ~1C with increased LAI

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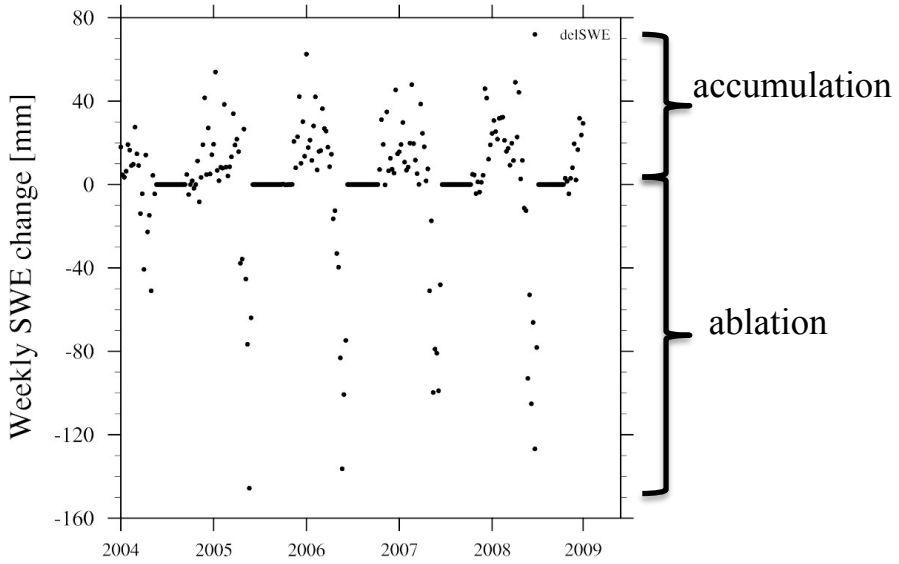
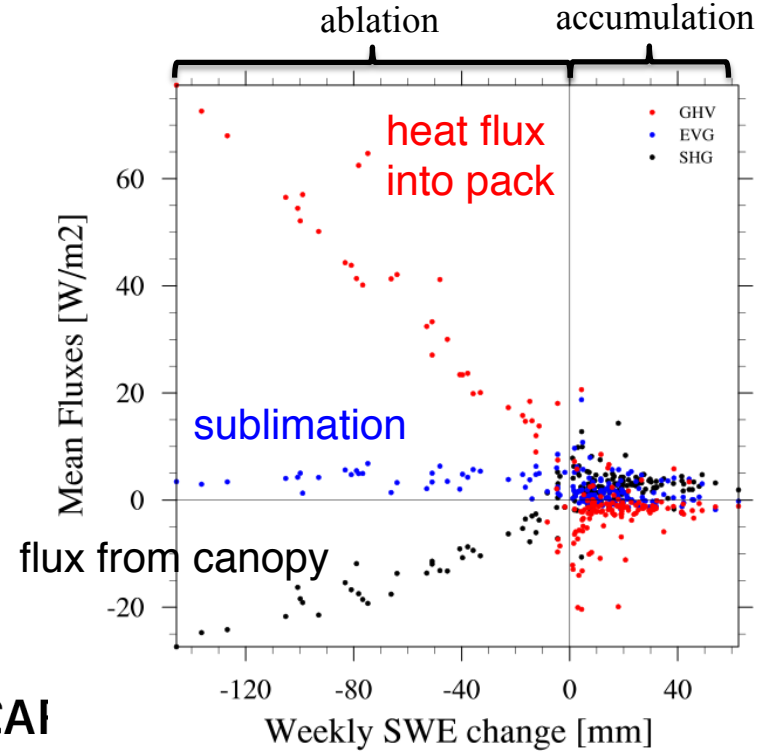
Surface Hydrology: Snow Treatment

- Continuous offline runs for five years at Niwot Ridge, CO
- Separate periods into weekly changes in snow water equivalent





- For ablation phase, there is a strong relationship between heat flux into pack and sensible heat from canopy with amount of snow ablated
- Sublimation is almost constant and unrelated during ablation period

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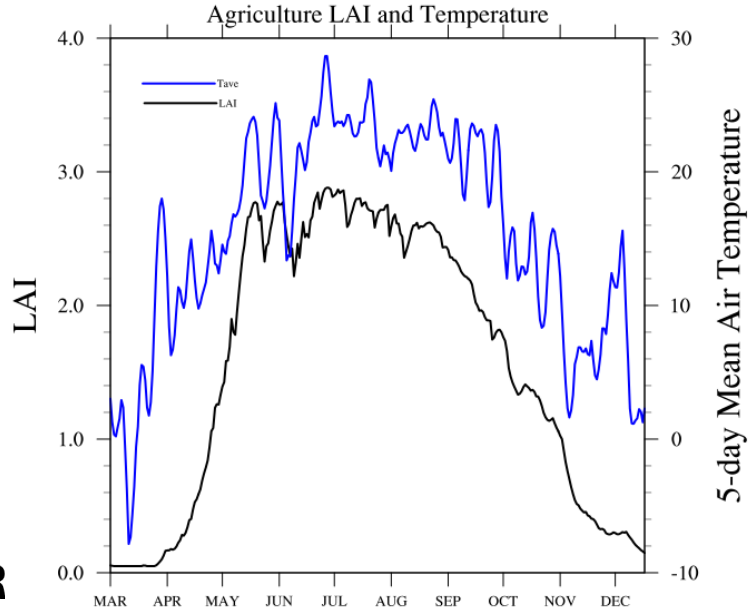
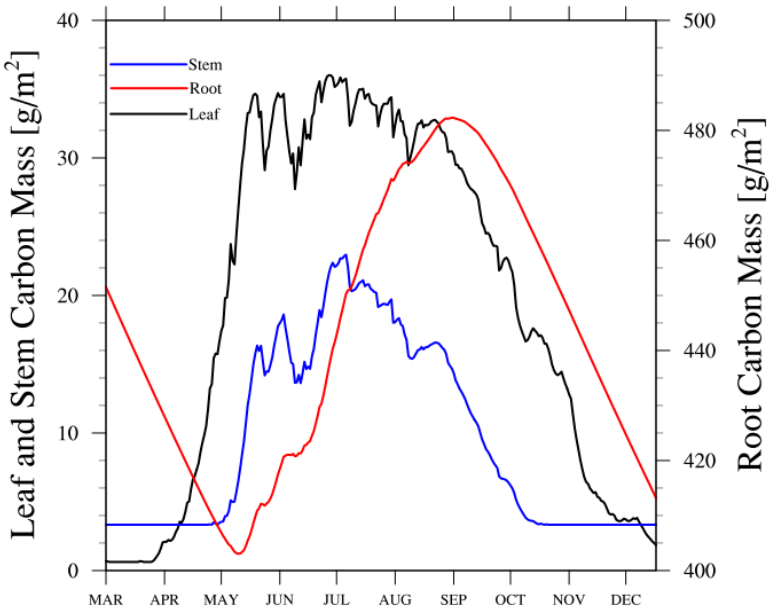
Stomatal Resistance Options and Dynamic Vegetation

- Noah-MP contains
  - Photosynthesis model with Ball-Berry stomatal resistance
  - Jarvis resistance option
  - Dynamic vegetation model that allocates photosynthesis carbon to vegetation (leaves, stems, root, wood) and soil (fast/slow pools)
- Noah uses Jarvis scheme and prescribed horizontal and vertical vegetation (f_{veg} and LAI)
- Implications for regional climate simulations
  - Two distinct vegetation treatments for multi-physics ensembles
  - Interaction between climate and vegetation condition





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Why Noah-MP?

- Multi-physics options for multi-physics ensembles
- Potential for expansion, e.g., adding crop capability to carbon allocation model – currently no crop species
- Interactive vegetation and aquifer for regional climate simulations
  - Another step forward will be coupling with WRF-Hydro for 2D routing
- Separate canopy with radiative transfer allows for
  - more detailed analysis of surface processes
  - better partitioning of surface energy
  - improve biases especially in winter/snow cases

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