The Noah-MP Land Surface Model

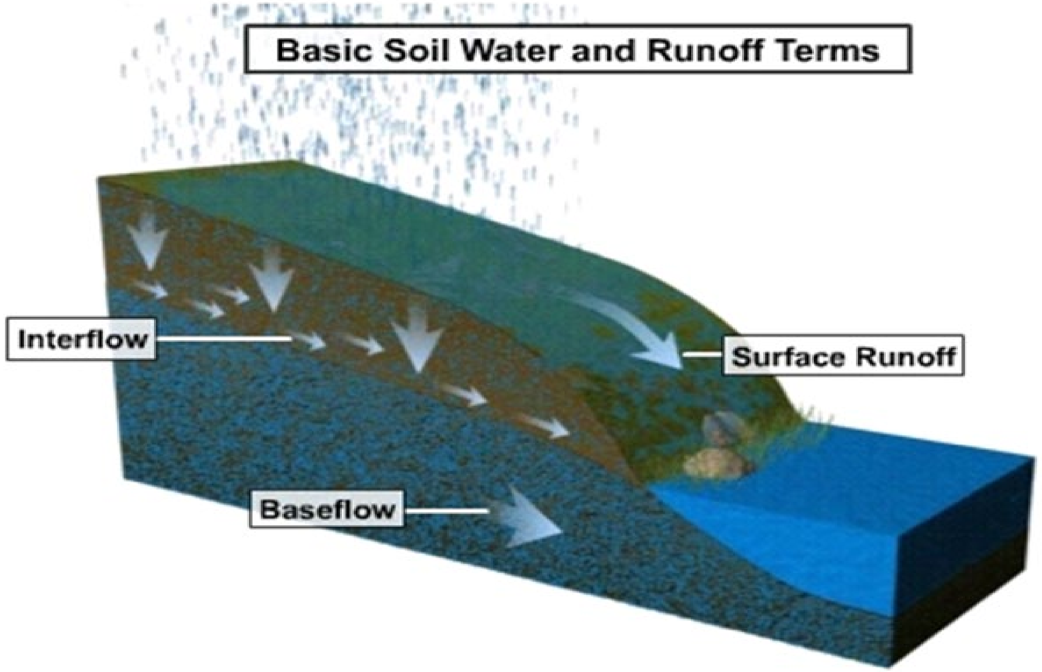
Research Applications Laboratory
National Center for Atmospheric Research

Land Surface Models: Summary

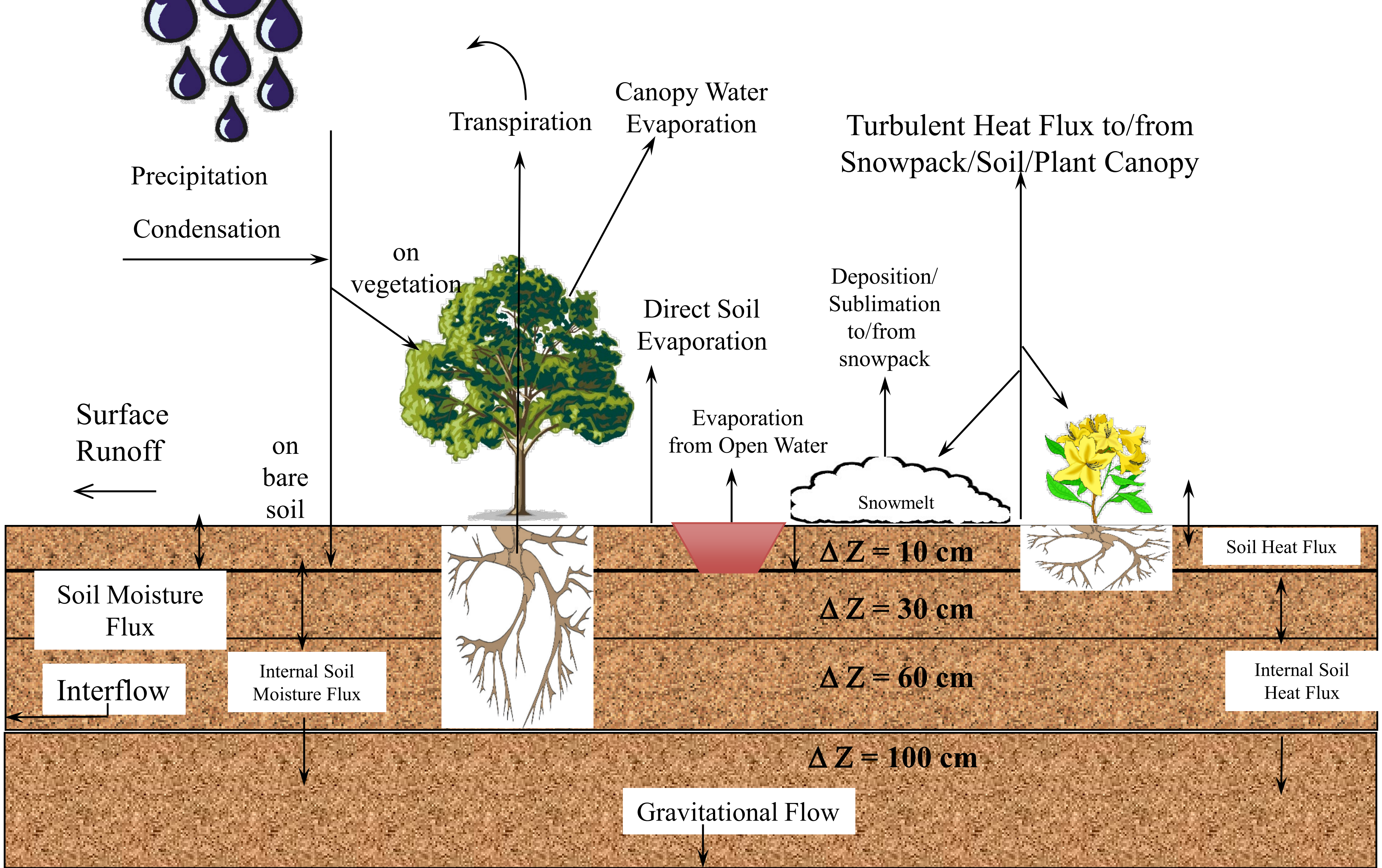
- Land surface models have long been used as stand-alone eco-hydrology models or as boundary conditions for atmospheric and hydrology models
- Land surface models exist within a wide spectrum of complexity but all generally attempt to accomplish the same thing: partitioning of energy and water stores/fluxes (at many timescales)
- Land surface models can be broken down into two parts:
  - Physics: approximating the complex real world by a set of physically-based (hopefully) equations
  - Parameters: adapts the approximated physics to work for heterogeneous surfaces (vegetation/soil/etc.)
- More complex physics tends to produce more parameters
- Current generation LSMs aim to
  - improve surface representation especially when significant heterogeneities exist
  - provide land process-level information to an expanding user base
  - test multiple process representations in one model

Land Surface Models: One Piece of a Larger Modeling System

- Land surface models, as an upper boundary of a soil hydrology model, take:
  - Precipitation and partition into fluxes (evapotranspiration, surface/underground runoff) and storage (soil moisture and snowpack)
  - Solar and atmospheric energy and partition in fluxes (ET, sensible heat, ground/snow heat) and storage (snow/soil heat content)
- Models are generally 1D.



Conceptual Land Surface Processes



Noah-MP: A Community Land Model

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 116, D12109, doi:10.1029/2010JD015139, 2011

The community Noah land surface model with multiparameterization options (Noah-MP): 1. Model description and evaluation with local-scale measurements

Guo-Yue Niu,[1,2] Zong-Liang Yang,[1] Kenneth E. Mitchell,[3] Fei Chen,[4] Michael B. Ek,[3] Michael Barlage,[4] Anil Kumar,[5] Kevin Manning,[4] Dev Niyogi,[6] Enrique Rosero,[1,7] Mukul Tewari,[4] and Youlong Xia[3]

Received 4 October 2010; revised 3 February 2011; accepted 27 March 2011; published 24 June 2011.

The community Noah land surface model with multiparameterization options (Noah-MP): 2. Evaluation over global river basins

Zong-Liang Yang,[1] Guo-Yue Niu,[1,2] Kenneth E. Mitchell,[3] Fei Chen,[4] Michael B. Ek,[3] Michael Barlage,[4] Laurent Longuevergne,[5] Kevin Manning,[4] Dev Niyogi,[6] Mukul Tewari,[4] and Youlong Xia[3]

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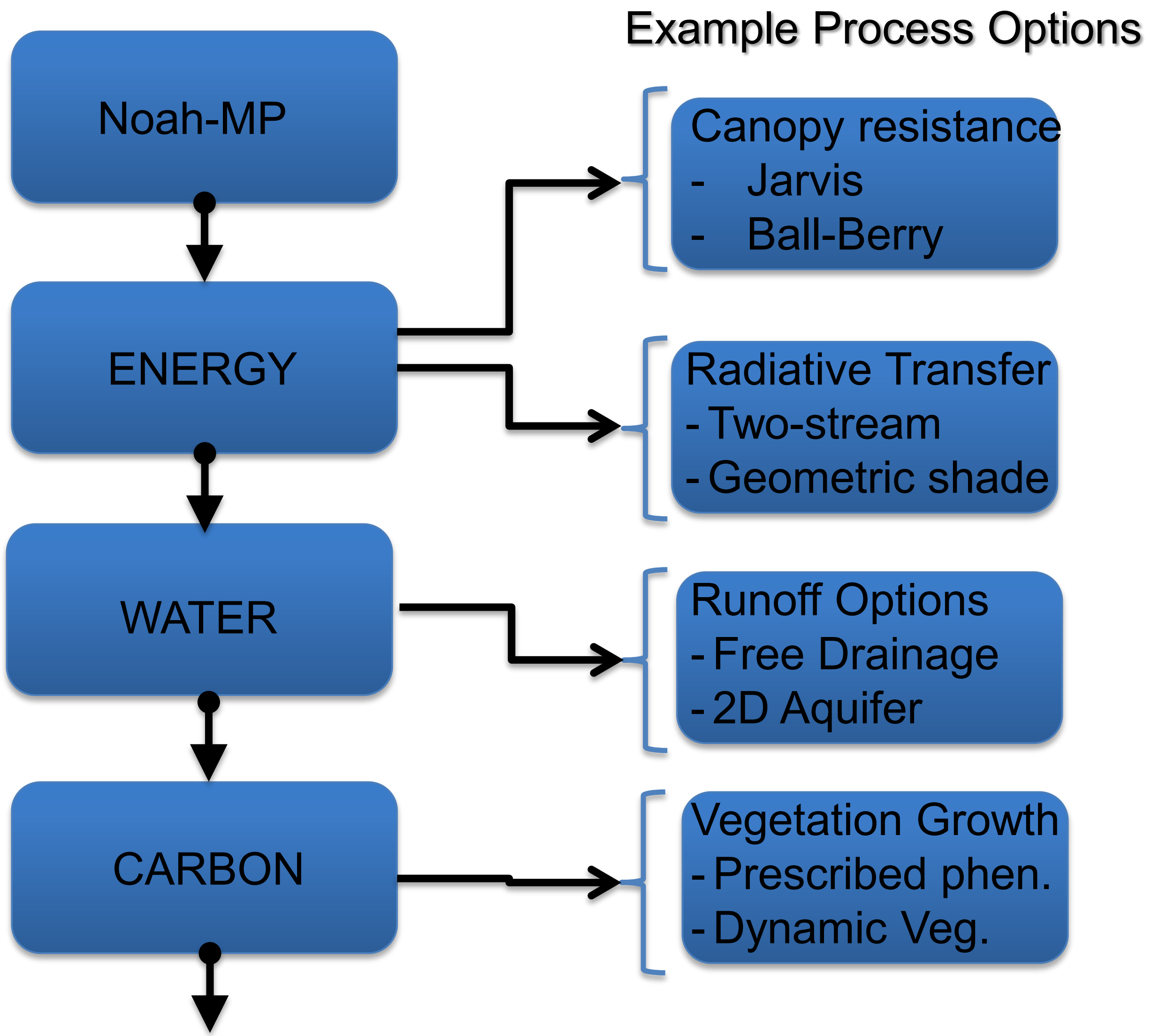
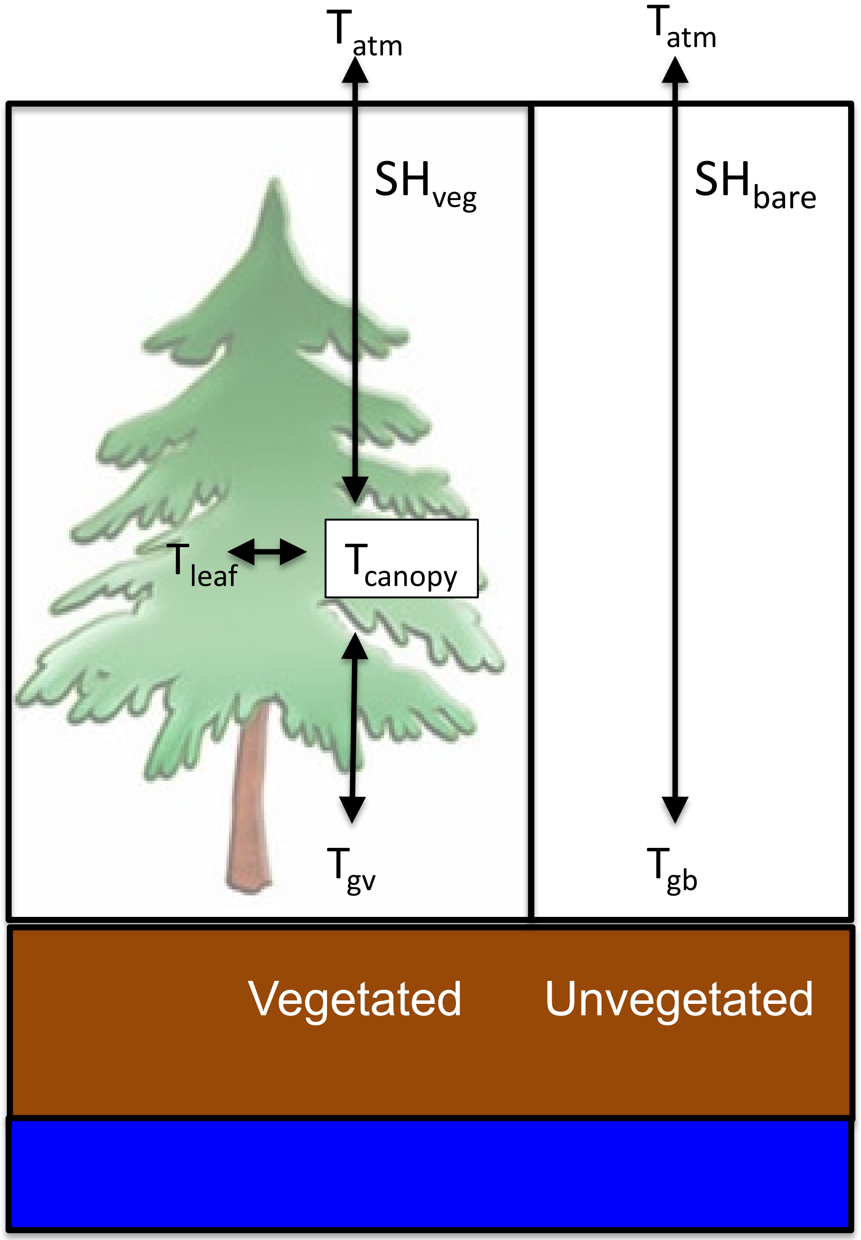
Noah-MP Calling Structure: Modularity at the Process Level



Noah-MP Physical Processes

Noah-MP is a land surface model that allows a user to choose multiple options for several physical processes

- Canopy radiative transfer with shading geometry
- Separate vegetation canopy
- Dynamic vegetation
- Vegetation canopy resistance
- Multi-layer snowpack
- Snowpack liquid water retention
- Simple groundwater options
- Snow albedo treatment
- New frozen soil scheme
- New snow cover



Noah-MP Surface Energy Budget

$$SW_{dn} - SW_{up} + LW_{dn} - LW_{up}(T_{sfc}) = SH(T_{sfc}) + LH(T_{sfc}) + G(T_{sfc})$$

SW_{dn},LW_{dn}: input shortwave and longwave radiation (external to LSM)

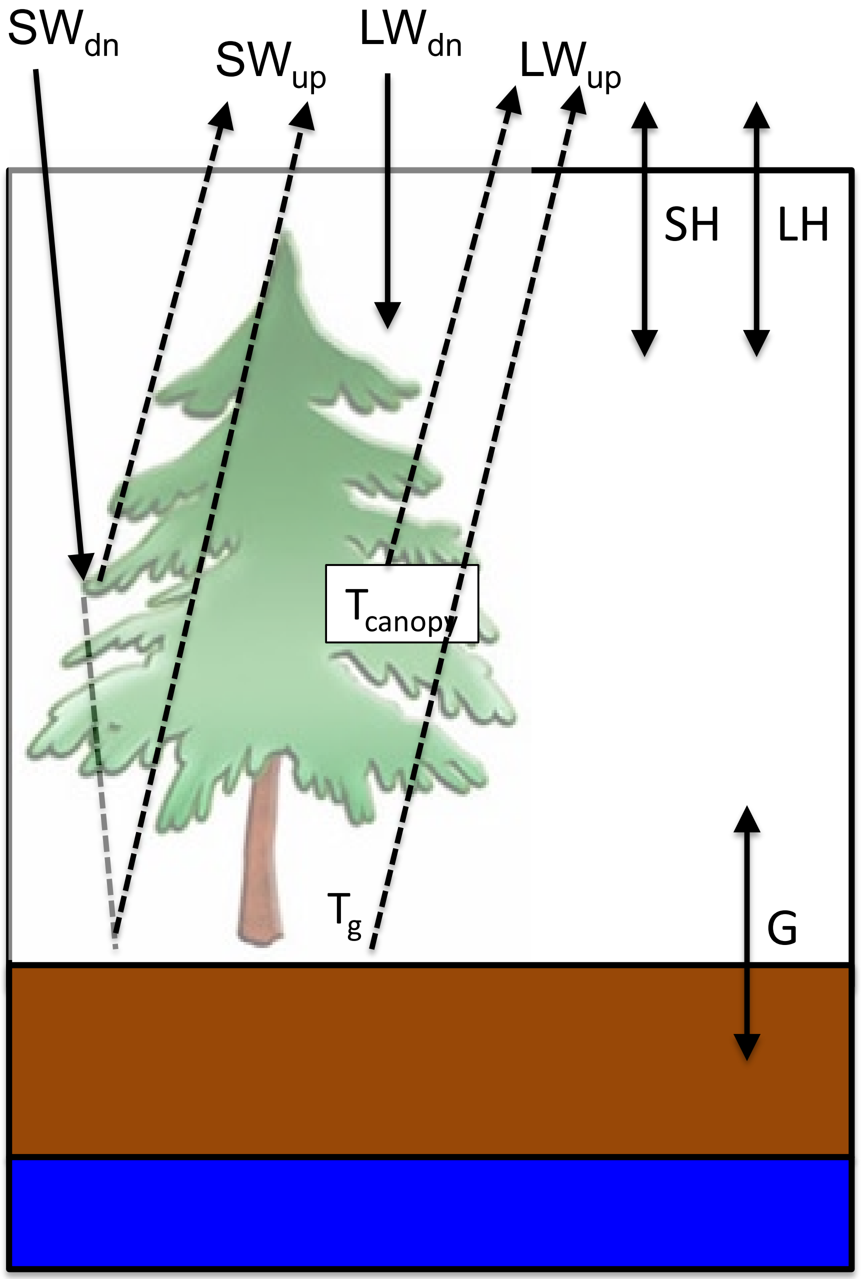
SW_{up} : reflected shortwave (albedo)

LW_{up} : upward thermal radiation

SH : sensible heat flux

LH : latent heat flux (soil/canopy evaporation, transpiration)

G : heat flux into the soil



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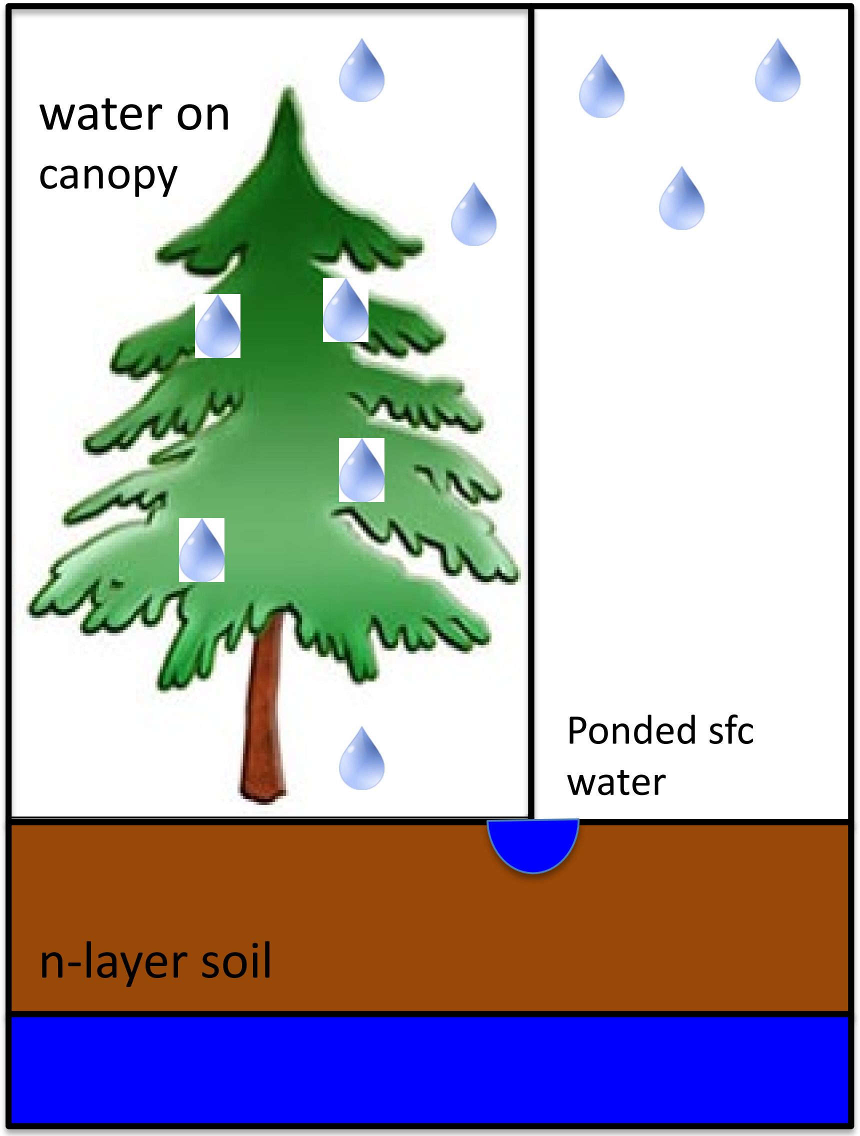

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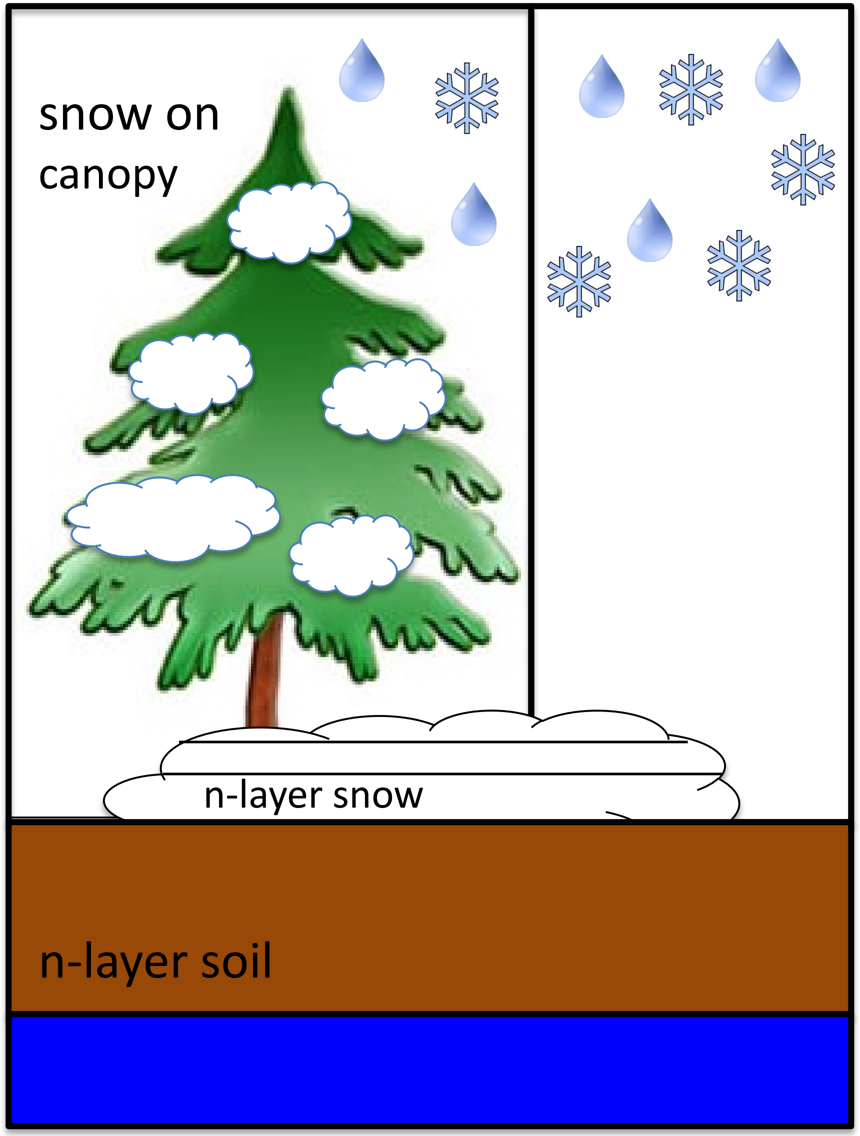


Noah-MP: Soil Water/Energy Transfer

Soil Moisture

$$\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial z}\left(D \frac{\partial \theta}{\partial z} \right) + \frac{\partial K}{\partial z} + F_\theta$$

- Richards Equation for soil water movement
- D, K are functions of soil texture and soil moisture)
- F_θ represents sources (rainfall) and sinks (evaporation)

Soil/Snow Temperature

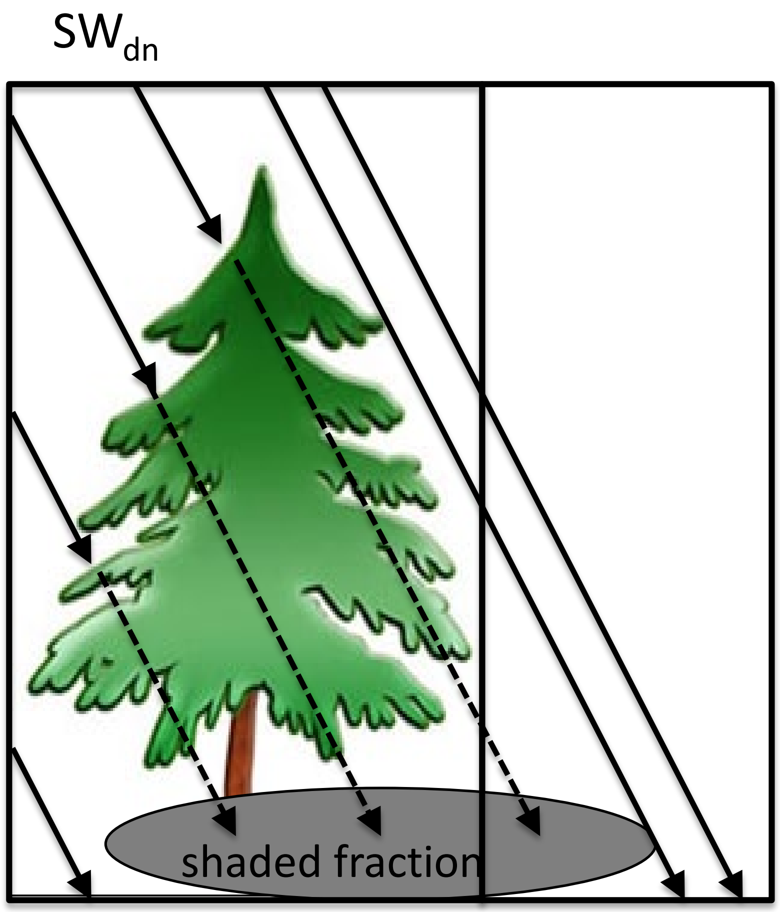
$$C(\theta)\frac{\partial T}{\partial t} = \frac{\partial}{\partial z}\left(K_t(\theta) \frac{\partial T}{\partial z} \right)$$

- C, K_t are functions of soil texture and soil moisture
- Soil temperature information used to compute ground heat flux

Noah-MP: More Physics, More Parameters

Noah-MP has a separate canopy and uses a two-stream radiative transfer treatment through the canopy

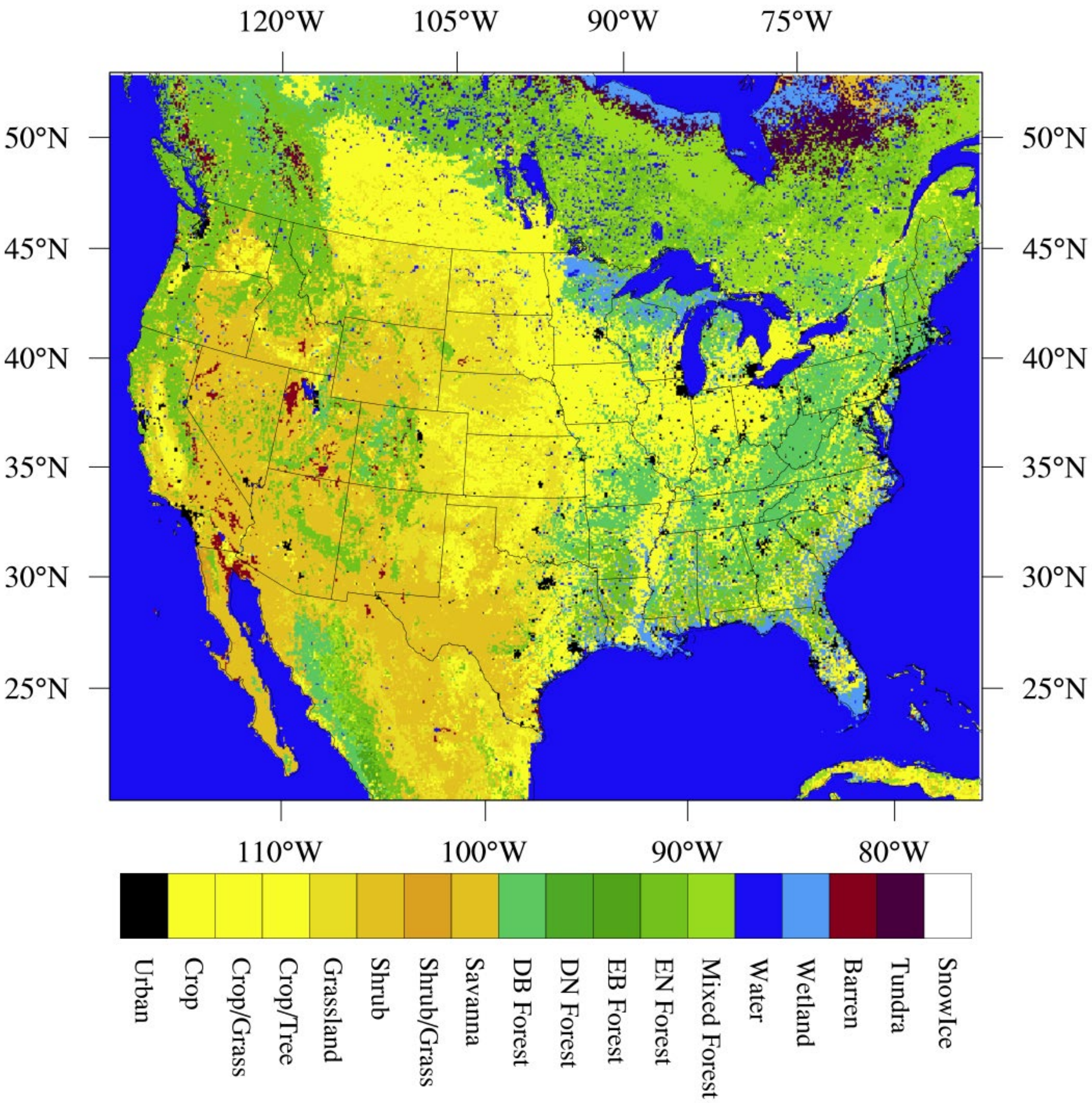
- Canopy parameters:
  - Canopy top and bottom
  - Crown radius, vertical and horizontal
  - Vegetation element density, i.e., trees/grass leaves per unit area
  - Leaf and stem area per unit area
  - Leaf orientation
  - Leaf reflectance and transmittance for direct/diffuse and visible/NIR radiation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



Key Input into the Noah-MP LSM

- Land-cover/vegetation classification
  - Many sources, generally satellite-based and categorically broad
- Soil texture class
  - Also general with large consolidations
- Many secondary parameters that can be specified as function of the above

Datasets: NLCD Land Cover



Parameters: Land Cover

MPTABLE.TBL contains a look-up table for vegetation classes

Limitations:

All pixels with the same vegetation have the same parameters

Modifying parameters affects all vegetation of the same type

```
!-----------------------------------------------------------------------------------------------------------------------
!          1       2       3       4       5       6       7       8       9      10      11      12      13      14      15      16      17
!-----------------------------------------------------------------------------------------------------------------------
CH2OP =   0.1,    0.1,    0.1,    0.1,    0.1,    0.1,    0.1,    0.1,    0.1,    0.1,    0.1,    0.1,    0.1,    0.1,    0.1,    0.1,    0.1,
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Z0MVT =  1.00,   0.15,   0.15,   0.15,   0.14,   0.50,   0.12,   0.06,   0.09,   0.50,   0.80,   0.85,   1.10,   1.09,   0.80,   0.00,   0.12,   0
HVT   =  15.0,   2.00,   2.00,   2.00,   1.50,   8.00,   1.00,   1.10,   1.10,   10.0,   16.0,   18.0,   20.0,   20.0,   16.0,   0.00,   0.50,   1
HVB   =  1.00,   0.10,   0.10,   0.10,   0.10,   0.15,   0.05,   0.10,   0.10,   0.10,   11.5,   7.00,   8.00,   8.50,   10.0,   0.00,   0.05,   0
DEN   =  0.01,   25.0,   25.0,   25.0,   25.0,   25.0,   100.,   10.0,   10.0,   0.02,   0.10,   0.28,   0.02,   0.28,   0.10,   0.01,   10.0,   0
RC    =  1.00,   0.08,   0.08,   0.08,   0.08,   0.08,   0.03,   0.12,   0.12,   3.00,   1.40,   1.20,   3.60,   1.20,   1.40,   0.01,   0.10,   1
MFSNO =  2.50,   2.50,   2.50,   2.50,   2.50,   2.50,   2.50,   2.50,   2.50,   2.50,   2.50,   2.50,   2.50,   2.50,   2.50,   2.50,   2.50,   2

! Row 1:  Vis
! Row 2:  Near IR
RHOL_VIS=0.00,   0.11,   0.11,   0.11,   0.11,   0.11,   0.11,   0.07,   0.10,   0.10,   0.10,   0.07,   0.10,   0.07,   0.10,   0.00,   0.11,   0
RHOL_NIR=0.00,   0.58,   0.58,   0.58,   0.58,   0.58,   0.58,   0.35,   0.45,   0.45,   0.45,   0.35,   0.45,   0.35,   0.45,   0.00,   0.58,   0

! Row 1:  Vis
! Row 2:  Near IR
RHOS_VIS=0.00,   0.36,   0.36,   0.36,   0.36,   0.36,   0.36,   0.16,   0.16,   0.16,   0.16,   0.16,   0.16,   0.16,   0.16,   0.00,   0.36,   0
RHOS_NIR=0.00,   0.58,   0.58,   0.58,   0.58,   0.58,   0.58,   0.39,   0.39,   0.39,   0.39,   0.39,   0.39,   0.39,   0.39,   0.00,   0.58,   0

! Row 1:  Vis
! Row 2:  Near IR
TAUL_VIS=0.00,   0.07,   0.07,   0.07,   0.07,   0.07,   0.07,   0.05,   0.05,   0.05,   0.05,   0.05,   0.05,   0.05,   0.05,   0.00,   0.07,   0
TAUL_NIR=0.00,   0.25,   0.25,   0.25,   0.25,   0.25,   0.25,   0.10,   0.10,   0.25,   0.25,   0.10,   0.25,   0.10,   0.25,   0.00,   0.25,   0

! Row 1:  Vis
! Row 2:  Near IR
TAUS_VIS=0.00,  0.220,  0.220,  0.220,  0.220,  0.220,  0.220,  0.001,  0.001,  0.001,  0.001,  0.001,  0.001,  0.001,  0.001,  0.000,  0.220,  0.
TAUS_NIR=0.00,  0.380,  0.380,  0.380,  0.380,  0.380,  0.380,  0.001,  0.001,  0.001,  0.001,  0.001,  0.001,  0.001,  0.001,  0.000,  0.380,  0.

XL    = 0.000,  -0.30,  -0.30,  -0.30,  -0.30,  -0.30,  -0.30,  0.010,  0.250,  0.010,  0.250,  0.010,  0.010,  0.010,  0.250,  0.000,  -0.30,  0.
! CWPVT =   3.0,    3.0,    3.0,    3.0,    3.0,    3.0,    3.0,    3.0,    3.0,    3.0,    3.0,    3.0,    3.0,    3.0,    3.0,    3.0,    3.0,
CWPVT =  0.18,   0.18,   0.18,   0.18,   0.18,   0.18,   0.18,   0.18,   0.18,   0.18,   0.18,   0.18,   0.18,   0.18,   0.18,   0.18,   0.18,
C3PSN =   1.0,    1.0,    1.0,    1.0,    1.0,    1.0,    1.0,    1.0,    1.0,    1.0,    1.0,    1.0,    1.0,    1.0,    1.0,    1.0,    1.0,
KC25  =  30.0,   30.0,   30.0,   30.0,   30.0,   30.0,   30.0,   30.0,   30.0,   30.0,   30.0,   30.0,   30.0,   30.0,   30.0,   30.0,   30.0,   3
AKC   =   2.1,    2.1,    2.1,    2.1,    2.1,    2.1,    2.1,    2.1,    2.1,    2.1,    2.1,    2.1,    2.1,    2.1,    2.1,    2.1,    2.1,
KO25  =  3.E4,   3.E4,   3.E4,   3.E4,   3.E4,   3.E4,   3.E4,   3.E4,   3.E4,   3.E4,   3.E4,   3.E4,   3.E4,   3.E4,   3.E4,   3.E4,   3.E4,   3
AKO   =   1.2,    1.2,    1.2,    1.2,    1.2,    1.2,    1.2,    1.2,    1.2,    1.2,    1.2,    1.2,    1.2,    1.2,    1.2,    1.2,    1.2,
AVCMX =   2.4,    2.4,    2.4,    2.4,    2.4,    2.4,    2.4,    2.4,    2.4,    2.4,    2.4,    2.4,    2.4,    2.4,    2.4,    2.4,    2.4,
AQE   =   1.0,    1.0,    1.0,    1.0,    1.0,    1.0,    1.0,    1.0,    1.0,    1.0,    1.0,    1.0,    1.0,    1.0,    1.0,    1.0,    1.0,

LTOVRC=   0.0,    1.2,    1.2,    1.2,    1.2,   1.30,   0.50,   0.65,   0.70,   0.65,   0.55,    0.2,   0.55,    0.5,    0.5,    0.0,    1.4,
DILEFC=  0.00,   0.50,   0.50,   0.50,   0.35,   0.20,   0.20,   0.20,   0.50,   0.50,   0.60,   1.80,   0.50,   1.20,   0.80,   0.00,   0.40,   0
DILEFW=  0.00,   0.20,   0.20,   0.20,   0.20,   0.20,   0.10,   0.20,   0.20,   0.50,   0.20,   0.20,   4.00,   0.20,   0.20,   0.00,   0.20,   0
RMF25 =  0.00,   1.00,   1.40,   1.45,   1.45,   1.45,   1.80,   0.26,   0.26,   0.80,   3.00,   4.00,   0.65,   3.00,   3.00,   0.00,   3.20,   3
SLA   =    60,     80,     80,     80,     80,     80,     60,     60,     60,     50,     80,     80,     80,     80,     80,      0,     80,
FRAGR =  0.00,   0.20,   0.20,   0.20,   0.20,   0.20,   0.20,   0.20,   0.20,   0.20,   0.20,   0.10,   0.20,   0.10,   0.10,   0.00,   0.10,   0
TMIN  =     0,    273,    273,    273,    273,    273,    273,    273,    273,    273,    273,    268,    273,    265,    268,      0,    268,
VCMX25=  0.00,   80.0,   80.0,   80.0,   60.0,   70.0,   40.0,   40.0,   40.0,   40.0,   60.0,   60.0,   60.0,   50.0,   55.0,   0.00,   50.0,   5
TDLEF =   278,    278,    278,    278,    278,    278,    278,    278,    278,    278,    278,    268,    278,    278,    268,      0,    268,
BP    = 1.E15,   2.E3,   2.E3,   2.E3,   2.E3,   2.E3,   2.E3,   2.E3,   2.E3,   2.E3,   2.E3,   2.E3,   2.E3,   2.E3,   2.E3,  1.E15,   2.E3,   2
MP    =    9.,     9.,     9.,     9.,     9.,     9.,     9.,     9.,     9.,     9.,     9.,     6.,     9.,     6.,     9.,     9.,     9.,
QE25  =    0.,   0.06,   0.06,   0.06,   0.06,   0.06,   0.06,   0.06,   0.06,   0.06,   0.06,   0.06,   0.06,   0.06,   0.06,   0.00,   0.06,   0
RMS25 =  0.00,   0.10,   0.10,   0.10,   0.10,   0.10,   0.10,   0.10,   0.10,   0.32,   0.10,   0.64,   0.30,   0.90,   0.80,   0.00,   0.10,   0
RMR25 =  0.00,   0.00,   0.00,   0.00,   0.00,   0.00,   1.20,   0.00,   0.00,   0.01,   0.01,   0.05,   0.05,   0.36,   0.03,   0.00,   0.00,   0
ARM   =   2.0,    2.0,    2.0,    2.0,    2.0,    2.0,    2.0,    2.0,    2.0,    2.0,    2.0,    2.0,    2.0,    2.0,    2.0,    2.0,    2.0,
FOLNMX=  0.00,    1.5,    1.5,    1.5,    1.5,    1.5,    1.5,    1.5,    1.5,    1.5,    1.5,    1.5,    1.5,    1.5,    1.5,   0.00,    1.5,
WDPOOL=  0.00,   0.00,   0.00,   0.00,   0.00,   0.00,   0.00,   1.00,   1.00,   1.00,   1.00,   1.00,   1.00,   1.00,   1.00,   0.00,   0.00,   1
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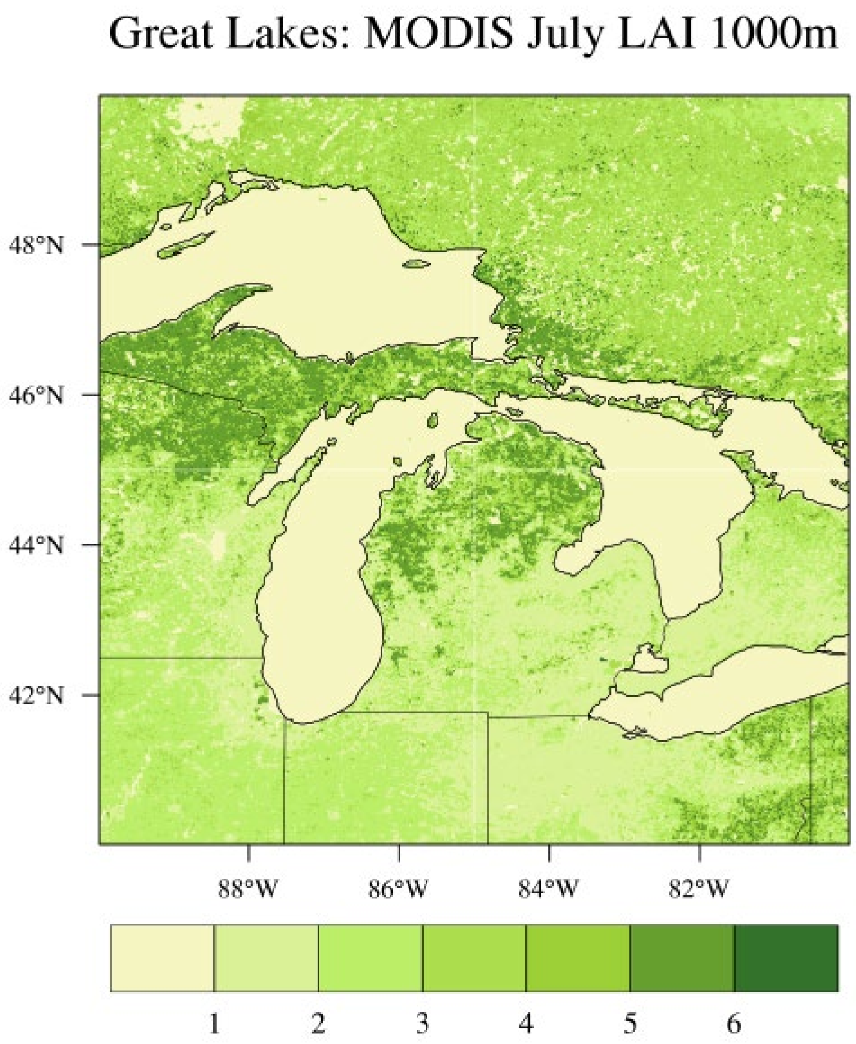
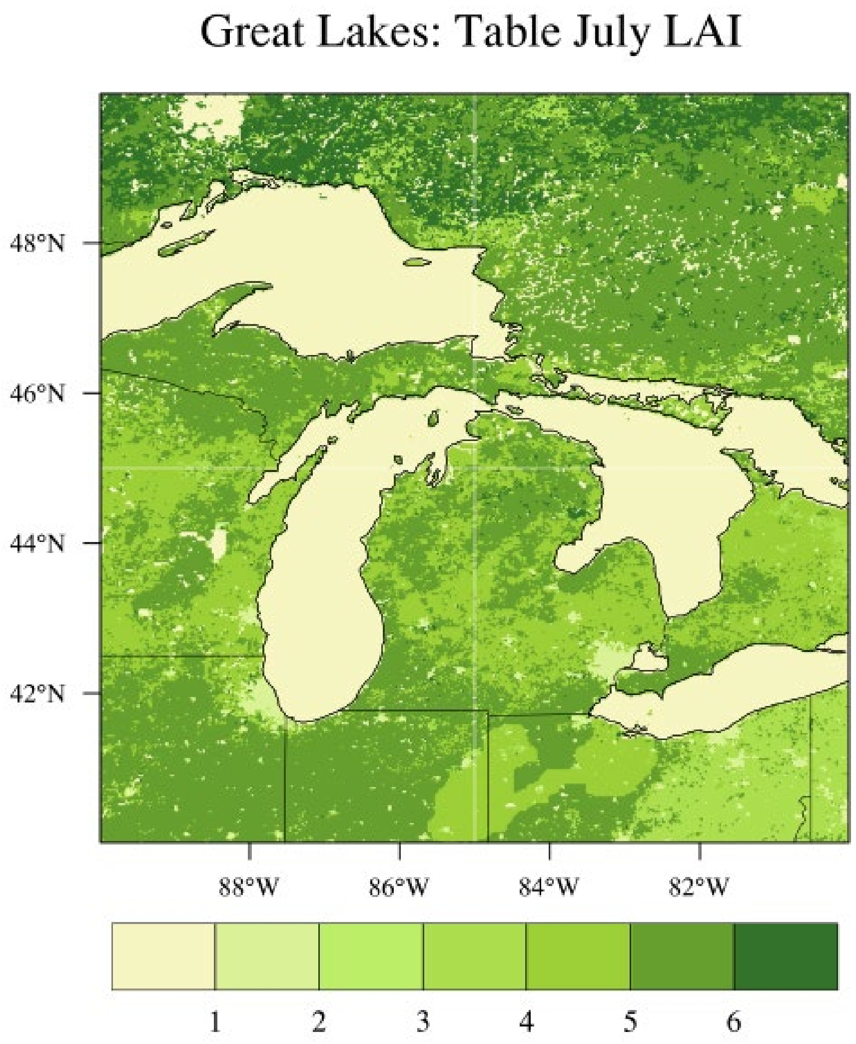
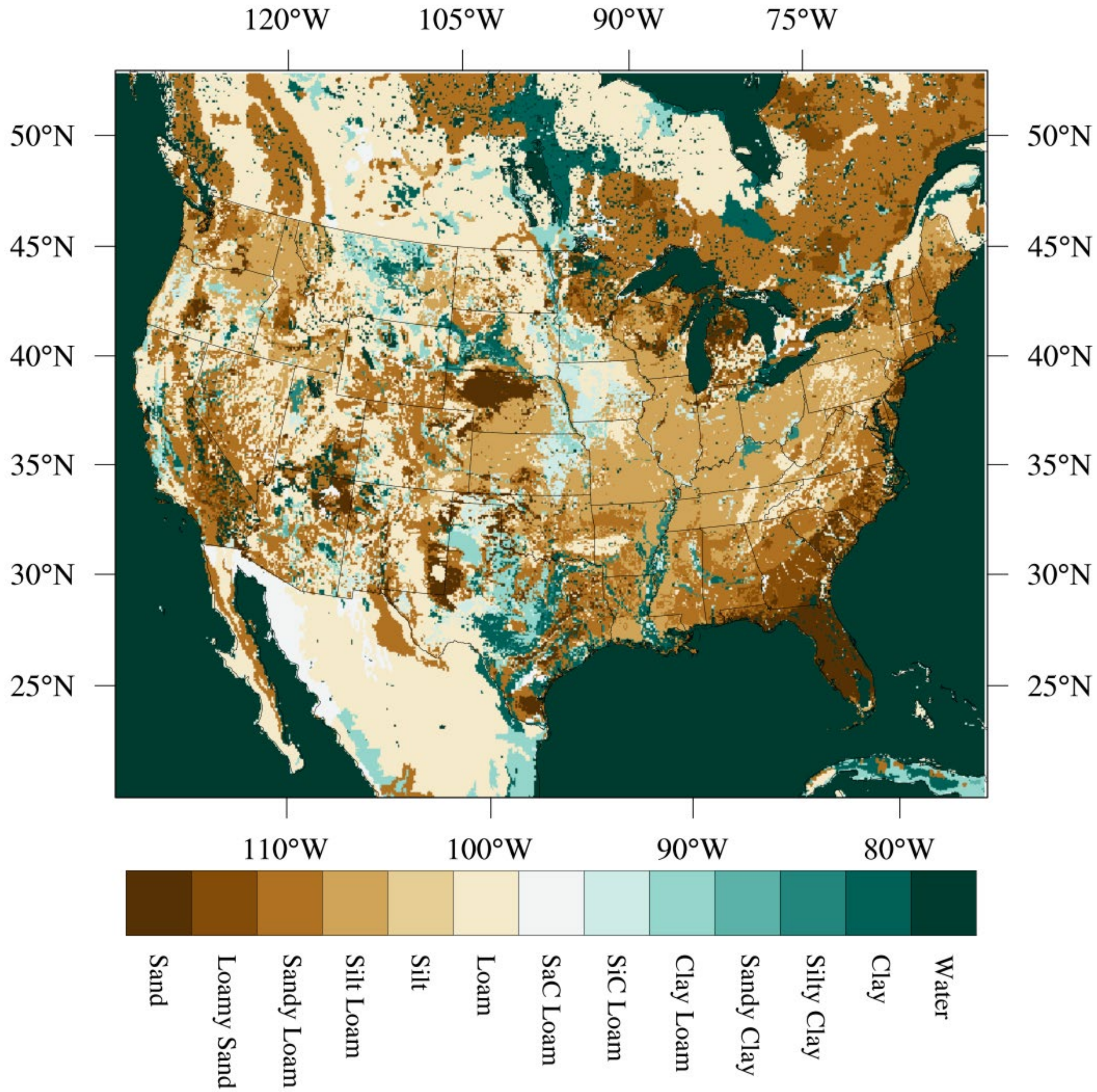
MODIS 1km Leaf Area Index Climatology

- Vegetation varying in time and space
- Comparison of MODIS LAI to default table-based LAI





Datasets: Soil Texture



Parameters: Soil Texture

Soil Parameters
STAS

19,1	'BB	DRYSMC	F11	MAXSMC	REFSMC	SATPSI	SATDK	SATDW	WLTSMC	QTZ	'
1,	2.79,	0.010,	-0.472,	0.339,	0.236,	0.069,	4.66E-5,	0.608E-6,	0.010,	0.92,	'SAND'
2,	4.26,	0.028,	-1.044,	0.421,	0.383,	0.036,	1.41E-5,	0.514E-5,	0.028,	0.82,	'LOAMY SAND'
3,	4.74,	0.047,	-0.569,	0.434,	0.383,	0.141,	5.23E-6,	0.805E-5,	0.047,	0.60,	'SANDY LOAM'
4,	5.33,	0.084,	0.162,	0.476,	0.360,	0.759,	2.81E-6,	0.239E-4,	0.084,	0.25,	'SILT LOAM'
5,	5.33,	0.084,	0.162,	0.476,	0.383,	0.759,	2.81E-6,	0.239E-4,	0.084,	0.10,	'SILT'
6,	5.25,	0.066,	-0.327,	0.439,	0.329,	0.355,	3.38E-6,	0.143E-4,	0.066,	0.40,	'LOAM'
7,	6.77,	0.067,	-1.491,	0.404,	0.314,	0.135,	4.45E-6,	0.990E-5,	0.067,	0.60,	'SANDY CLAY LOAM'
8,	8.72,	0.120,	-1.118,	0.464,	0.387,	0.617,	2.03E-6,	0.237E-4,	0.120,	0.10,	'SILTY CLAY LOAM'
9,	8.17,	0.103,	-1.297,	0.465,	0.382,	0.263,	2.45E-6,	0.113E-4,	0.103,	0.35,	'CLAY LOAM'
10,	10.73,	0.100,	-3.209,	0.406,	0.338,	0.098,	7.22E-6,	0.187E-4,	0.100,	0.52,	'SANDY CLAY'
11,	10.39,	0.126,	-1.916,	0.468,	0.404,	0.324,	1.34E-6,	0.964E-5,	0.126,	0.10,	'SILTY CLAY'
12,	11.55,	0.138,	-2.138,	0.468,	0.412,	0.468,	9.74E-7,	0.112E-4,	0.138,	0.25,	'CLAY'
13,	5.25,	0.066,	-0.327,	0.439,	0.329,	0.355,	3.38E-6,	0.143E-4,	0.066,	0.05,	'ORGANIC MATERIAL'
14,	0.0,	0.0,	0.0,	1.0,	0.0,	0.0,	0.0,	0.0,	0.0,	0.60,	'WATER'

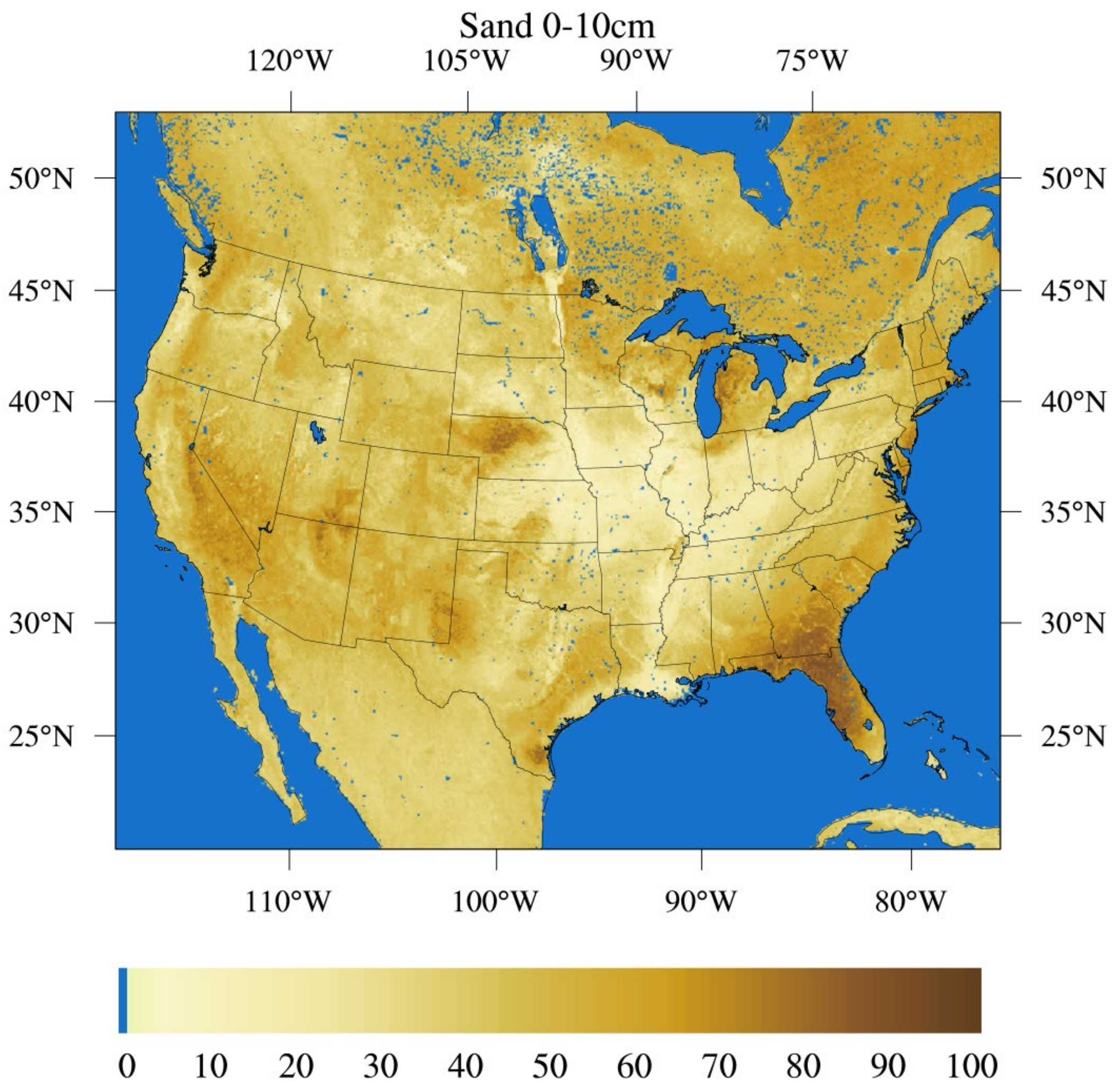
SOILPARM.TBL contains a look-up table for soil texture classes

Limitations:

All pixels with the same soil type have the same parameters

Modifying parameters affects all soil of the same type

Datasets: Soil Composition



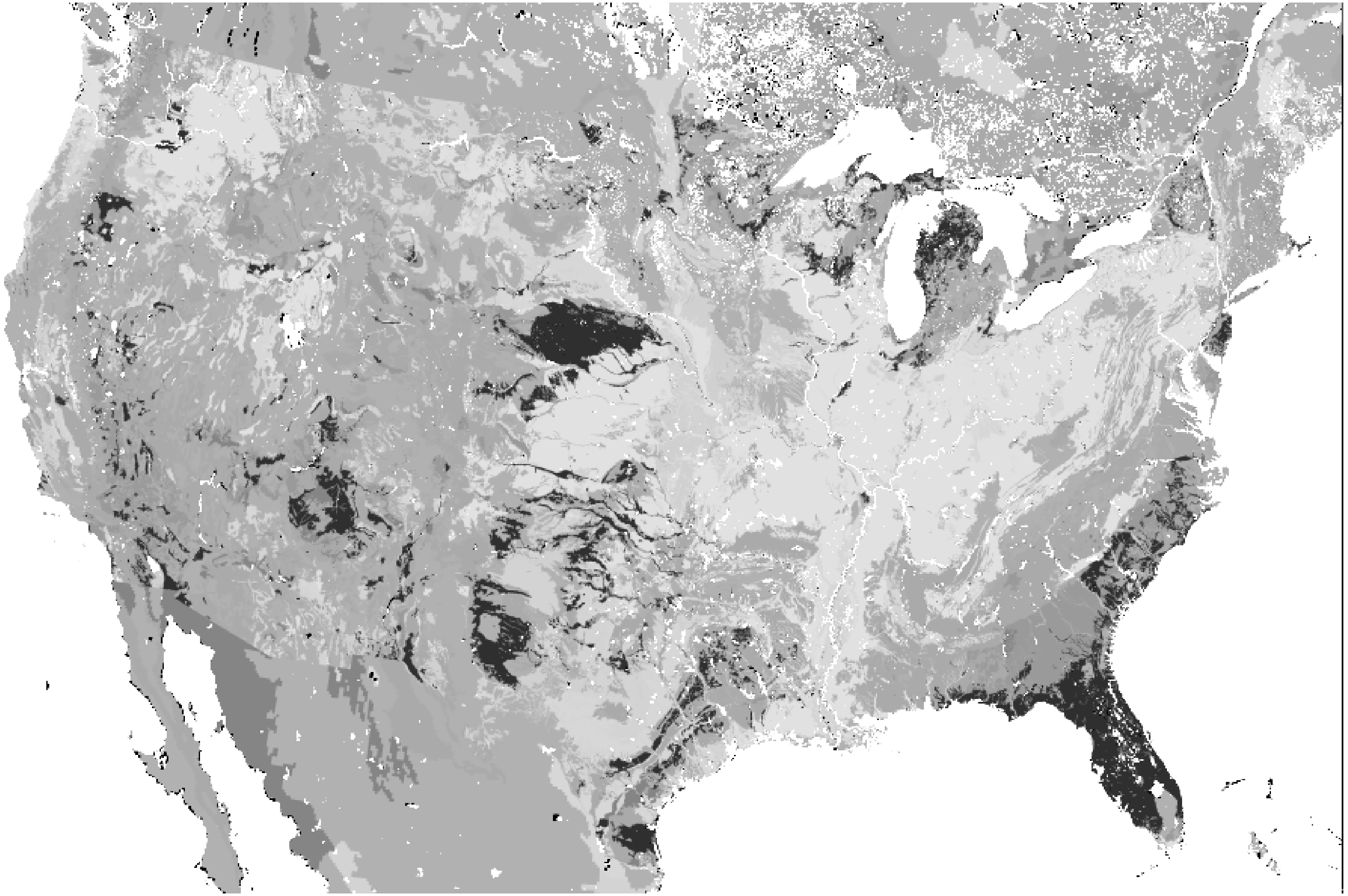
Parameters: Customization

Some capabilities exist within Noah-MP to read spatially-dependent soil and vegetation properties

Allows users who have local information to access it in the model

Soil properties: b, dksat, dwsat, psisat, smcdry, smcmax, smcref, smcwlt, slope, refdk, refkdt, rsurfexp, quartz

Vegetation properties: cwpvt, hvt, mp, vcmx25, mfsno



Example of 2D porosity field in NWM

Conclusions

- Land surface models are used to partition incoming surface energy and water into outgoing/internal fluxes and internal storage
- Land surface models are evolving to better represent reality and to expand user bases
- Evolving land surface model structure is leading to new challenges, e.g., parameters, parameters!
- Knowledge of both model structure and parameter assumptions is essential to properly use an LSM