The Noah-MP Land Surface Model

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Land Surface Models have long been used as stand-alone ecohydrology 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

- **Precipitation**: Leads to condensation on vegetation.
- **Surface Runoff**: Flows from bare soil, impacting soil moisture.
- **Soil Moisture Flux**: Moves through layers (ΔZ = 10 cm, 30 cm, 60 cm, 100 cm).
- **Interflow**: Transfers moisture between layers.
- **Internal Soil Moisture Flux**: Circulates within the soil layers.
- **Gravitational Flow**: Drives the movement of water through the soil and rock matrix.
- **Canopy Water Evaporation**: Transpired by vegetation.
- **Transpiration**: Evaporates from the soil surface.
- **Direct Soil Evaporation**: Evaporates from open water.
- **Snowmelt**: Converts snow to liquid water.
- **Turbulent Heat Flux**: Exchanges heat between snowpack, soil, and plant canopy.
- **Deposition/Sublimation to/from snowpack**: Transfers heat and mass.
- **Evaporation from Open Water**: Evaporates from water bodies.

**Delta Z**:
- ΔZ = 10 cm
- ΔZ = 30 cm
- ΔZ = 60 cm
- ΔZ = 100 cm

**Soil Heat Flux**: Transfers heat within the soil layers.

**External Soil Moisture Flux**: Influences the overall water balance.
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 Xia3

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 Xia3

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Noah-MP Calling Structure: Modularity at the Process Level

Noah-MP

ENERGY
- Canopy resistance
  - Jarvis
  - Ball-Berry
- Radiative Transfer
  - Two-stream
  - Geometric shade

WATER
- Runoff Options
  - Free Drainage
  - 2D Aquifer

CARBON
- Vegetation Growth
  - Prescribed phen.
  - Dynamic Veg.
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
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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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
- \( F_\theta \) 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 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
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
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
MODIS 1km Leaf Area Index Climatology

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

Great Lakes: MODIS July LAI 1000m

Great Lakes: Table July LAI
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
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: $b$, $d_{ksat}$, $d_{wsat}$, $p_{isat}$, $s_{mcdry}$, $s_{mcmax}$, $s_{mcref}$, $s_{mcwlt}$, slope, $ref_{dk}$, $ref_{kdt}$, $r_{surfexp}$, quartz

Vegetation properties: $c_{wpvt}$, $hvt$, $mp$, $v_{cmx25}$, $m_{fsno}$

Example of 2D porosity field in NWM
• 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

Conclusions