The Noah Multi-Physics Land Surface Model: Description and Performance

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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 shortcomings in the Noah LSM.
Noah LSM in NCEP Eta, MM5 and WRF Models
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- Precipitation
- Condensation
- Transpiration
- Canopy Water Evaporation
- Turbulent Heat Flux to/from Snowpack/Soil/Plant Canopy
- Deposition/Sublimation to/from snowpack
- Snowmelt

- Direct Soil Evaporation
- Evaporation from Open Water

- Runoff

- Soil Moisture Flux
- Interflow

- Internal Soil Moisture Flux

- Soil Heat Flux

- Internal Soil Heat Flux

- Gravitational Flow

- Δ Z = 10 cm
- Δ Z = 30 cm
- Δ Z = 60 cm
- Δ Z = 100 cm
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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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 (5 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)

An increasingly large number of permutations can be used as multi-physics ensemble members (>10,000)
Why is it named *Noah*-MP?

- Originally, the concept behind Noah-MP was that one set of options would reproduce Noah results exactly
- Became increasingly difficult from a structural point of view
- Eventually, the separate canopy approach was used as the only canopy structure (no bulk surface option as in Noah)
- Instead, many of the physical processes of Noah are included as options in Noah-MP (e.g., Jarvis resistance, soil moisture factor $\beta$, free drainage runoff)
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
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 and Aquifer

• **Noah-MP contains**
  - Three-layer snow model with liquid water retention
  - Canopy snow interception
  - Options 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 (may be vital for regional climate simulations)
Miguez-Macho & Fan water table dynamics in Noah-MP

Equations:

Mass balance in groundwater storage:

\[
\frac{dS_g}{dt} = \Delta x \Delta y R + \sum_{n=1}^{S} Q_n - Q_r
\]

Darcy’s Law for groundwater – river exchange:

\[
Q_r = rc \cdot (wtd - riverbed)
\]

Darcy’s Law for lateral groundwater flow:

\[
Q_n = w \cdot \left( \int_{wtd}^{SS} K_n \cdot dz + \int_{wtd}^{SS} K \cdot dz \right) \left( \frac{h_n - h}{s} \right)
\]

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**Legend:**
- \(h_{i,j}\): Water table depth (wtd)
- \(Q_{1-8}\): Flow rates
- \(S_g\): Mean sea level
- \(R\): Cross section view
- \(Q_r\): Riverbed
- \(w\): Width of flow
- \(s\): Transmissivity
- \(r\): Head difference divided by distance (water table slope)

Sources:
- Miguez-Macho et al., JGR 2007
- Miguez-Macho & Fan water table dynamics in Noah-MP
- Fan et al, JGR 2007
Depth to Water Table – MMF input

The following results focus on locations with shallow water table (green).

Performed six-month coupled WRF simulations from March – August.
Analysis Regions

- Based on NCDC Regional Climate Zones
- Observations: METAR/SYNOP stations, NCDC daily gridded precip
Regional Groundwater Recharge: 2002
Regional Deep Soil Moisture: 2002
Regional Root Soil Moisture: 2010
Temperature and Dewpoint Verification

- Coupled model results for CONUS domain
- Noah-MP improves cold/dry bias in Noah surface fields
- Inclusion of interactive aquifer also improves results compared to free drainage option

<table>
<thead>
<tr>
<th></th>
<th>Air Temperature Bias (RMSE)</th>
<th>Dewpoint Temperature Bias (RMSE)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MAM Day</td>
<td>MAM Night</td>
</tr>
<tr>
<td>Noah</td>
<td>-3.6 (3.9)</td>
<td>-3.1 (3.4)</td>
</tr>
<tr>
<td>Noah-MP</td>
<td>-1.1 (1.7)</td>
<td>-0.9 (1.9)</td>
</tr>
</tbody>
</table>
Noah-MP water storage change compares well with GRACE

Niu et al. (2011)
Yang et al. (2011)

**Improved biophysical realism:**
- a multi-layer snowpack
- an unconfined aquifer model for groundwater dynamics
- an interactive vegetation canopy layer
Interactive Vegetation Canopy

The model includes a set of carbon mass (g C/m²) balance equations for:
1. Leaf mass
2. Stem mass
3. Wood mass
4. Root mass
5. Soil carbon pool (fast)
6. Soil carbon pool (slow)

Processes include:
1. Photosynthesis (S↓, T, θ, e_air, CO₂, O₂, N…)
2. Carbon allocation to carbon pools
3. Respiration of each carbon pool (T_v, T_root)

\[ \frac{\partial M_{\text{leaf}}}{\partial t} = R_{\text{gain}} - R_{\text{loss}} \]

Carbon gain rate: photosynthesis * fraction of carbon partition to leaf
Carbon loss rate: leaf turnover (proportional to leaf mass)

respiration: maintenance & growth (proportional to leaf mass)

death: temperature & soil moisture

\[ \text{LAI} = M_{\text{leaf}} \times C_{\text{area}} \]

where \( C_{\text{area}} \) is area per leaf mass (m²/g).

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 ($f_{\text{veg}}$ and LAI)

• Implications for regional climate simulations
  • Two distinct vegetation treatments for multi-physics ensembles
  • Interaction between climate and vegetation condition

![Graphs showing LAI and temperature](image-url)
Global Climatology/Real-time MODIS Products: LAI and fPAR

Marks
− Individual value of year
2001  2002  2003  2004  2005  2006  2007  2008
− black: median
− yellow: tile climo (Savanna)

Lines
− black: median
− yellow: tile climo (Savanna)

• Remove suspect data
• Fill missing data
• Smooth

Original Pixel Data

Final Smooth Climatology

Day

Day