The Community Noah LSM with Multi-physics Options

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Prepared for CCSM workshop, June 16, 2009
Backgrounds:

1. Soil moisture and ET and their relationship are critical for land-air interactions at seasonal and inter-annual time scales.

2. No single LSM can adequately simulate soil moisture–ET relationship, but multi-model average performs better (Dirmeyer et al. 2007).

3. Ensemble simulations using multiple cumulus convection schemes provide better climate predictions (Liang et al., 2007)

4. Hydrologists have pursued multi-model ensemble streamflow predictions (Geogakakos et al., 2004; Duan et al., 2007; Clark et al., 2008)
Objectives:

1. Improve short-term climate predictions by coupling with NCEP Global Forecasting System (GFS) and Climate Forecasting System (CFS).

2. Improve weather predictions by coupling with Weather Research and Forecasting (WRF) modeling system.

An LSM with multi-physics options may:

1. facilitate physically-based ensemble climate predictions,

2. identify optimal combinations of parameterization schemes,

3. identify critical processes controlling the coupling strength.
Flaws in Noah:

1. A combined surface layer of vegetation canopy and ground. Such a layer structure impedes further developments on dynamic vegetation model (PAR and canopy T).

2. A bulk layer of snow and soil. The ground heat flux can not be accurately resolved for a thick snowpack.

3. Too shallow soil column (2-meter deep) and free drainage at the soil bottom. Groundwater effects are neglected.

4. Too impervious frozen soil; too strong runoff peaks in cold regions.

5. Neglect of the effects of zero-displacement height ($d_0$) on CH; thus a smaller CH over forest regions.
New features:

1. Major components: 1-layer canopy; 3-layer snow; 4-layer soil
2. Subgrid scheme: semi-tile vegetation and bare soil
3. Iterative energy balance method to predict skin temperatures of the canopy and snow/soil surface.
4. Modified two-stream radiation transfer scheme to consider the 3-D structure of the canopy
5. More realistic snow physics: a thin surface layer, liquid water retention and refreezing, and snowpack densification.
6. A TOPMODEL-based runoff scheme.
7. An unconfined aquifer interacting with soil.
10. A short-term leaf dynamic model.
Multi-physics options:

1. Leaf dynamics (prescribed or predicted)
2. Turbulent transfer (Chen97; M-O)
3. Soil moisture factor for stomatal resistance (Noah; CLM; SSiB)
4. Canopy stomatal resistance (Jarvis; Ball-Berry).
5. Snow surface albedo (BATS; CLASS).
6. Frozen soil permeability (Koren99; NY06).
7. Supercooled liquid water (Koren99; NY06).
8. Radiation transfer:
   - Modified two-stream: $\text{Gap} = F (3D \text{ structure}; \text{ solar angle ...})$
   - Two-stream applied to the entire grid cell: $\text{Gap} = 0$.
   - Two-stream applied to fractional vegetated area: $\text{Gap} = 1 - \text{GVF}$.
9. Partitioning of precipitation to snowfall and rainfall (CLM; Noah).
10. Runoff and groundwater:
    - TOPMODEL with groundwater (SIMGM)
    - TOPMODEL with an equilibrium water table (SIMTOP)
    - Original Noah scheme (Schaake96)
    - BATS surface runoff and free drainage (BATS)
Table 1. Experiments with different combinations of schemes

<table>
<thead>
<tr>
<th></th>
<th>( \theta_{\text{liq, max, j}} )</th>
<th>Frozen soil permeability</th>
<th>( C_H )</th>
<th>Runoff</th>
<th>( r_s )</th>
<th>Leaf Dynamics</th>
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<td>Chen97</td>
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</table>

6 Cold Region River Basins

6 Arid Region River Basins

50 Global River Basins
Soil Moisture over Illinois:
Snow Water Equivalent (in mm)

Snow Depth (in m)
Modeled Tskin (July 12th, 21:00 UTC, 2004)

Noah_MP with Chen97

Noah_MP with M-O

GOES
Modeled Tskin (July, 2004)

Western US (33N, 114W)
**36 Ensemble Experiments:**

Table 3. The first group of 12 experiments and their corresponding options of schemes.

<table>
<thead>
<tr>
<th>Exp.</th>
<th>Dynamic vegetation</th>
<th>$r_s$</th>
<th>$\beta$</th>
<th>Runoff schemes</th>
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Huge uncertainty to represent processes
Modeled GVF Using NLDAS

Runoff scheme is shown as the dominant player in the SM-ET relationship;

Runoff scheme plays as a “provider” of soil water (besides precipitation), while surface schemes plays as a “consumer”. 
Modeled Runoff over 50 River Basins

The mean of 36-member simulations outperforms the simulation from an single member.
Summary:

1. We added many new features and multi-parameterization options for an ensemble representation of processes to Noah.

2. Noah_MP shows improved simulations on runoff, soil moisture, snow, and skin temperature over Noah V3.

3. Runoff scheme play a dominant role in the SM-ET relationship, indicating a dominant role in controlling the coupling strength. It plays as a provider of soil moisture. This may help explain soil moisture simulations.

4. The mean of 36-member ensemble simulations shows potential in hydrological modeling and climate predictions (when coupled with climate models).