Land surface and hydrologic processes

Dennis P. Lettenmaier
Department of Civil and Environmental Engineering
University of Washington

CPPA PIs Meeting

Silver Spring, MD

September 30, 2008
The role of the land surface in earth system models (or, what is the difference between a land surface scheme and a hydrologic model?)

**Hydrologic Model**: Predict $Q$ (and perhaps other variables related to surface and subsurface moisture) given $P$ and $Ep$

**Land surface model**: Predict partitioning of $Rn$ given downward solar and longwave radiation
Typical LSM structure

Variable Infiltration Capacity (VIC) Macroscale Hydrologic Model

Cell Energy and Moisture Fluxes

Grid Cell Vegetation Coverage

Variable Infiltration Curve

Canopy
Layer 0
Layer 1
Layer 2

Variable Infiltration Curve

Baseflow Curve

I. Runoff and Baseflow Routed to Edge of Grid Cell

II. Flow Routed Through Flow Network to Outlet
General situation c. 1990

- **Hydrologic model**: Typically compute $E_p$ given $T$ (and perhaps other variables) but often w/o explicit representation of vegetation. The calibrate for parameters related to soil properties. Often implicit assumption (if needed) is that $T_s = T_a$

- **L/S model**: Given vegetation and associated parameters, iterate for $T_s$ by closing water and energy balances simultaneously. Runoff is essentially residual of $P$, $E$, and storage change.
Trends last 10-15 years

- Hydrology models have been driven toward explicit vegetation representations by the need to predict land cover change implications, among other factors.
- L/S models have been driven to do a better job wrt land surface hydrologic variables via realization that errors in water cycle representation affect surface energy balance, i.e., errors in runoff $\rightarrow$ errors in ET $\rightarrow$ errors in energy partitioning (and timing).
Issues in macroscale land surface modeling (coupled and uncoupled)

• Lack of compatibility of models in coupled and partially/uncoupled applications
• Understanding the differences in model performance
• Parameterization issues
  – Snow
  – Groundwater
  – Water management
  – Surface water storage
  – Soil moisture
The challenge: Different land schemes have different soil moisture dynamics

Model simulated soil moisture at cell
(40.25°N, 112.25°W)
Areas for spatially averaged soil moisture percentiles

Box sizes are 5 x 5 degrees
Model parameterization issues – snow physics

All model results (coupled and uncoupled) use NOAH land scheme, earlier versions (2.7 and prior) have substantial downward bias in SWE, especially for deep mountain snowpacks.
Maurer et al., Forcing 1990s

Noah 2.0

Noah 2.8

Δ: Noah 2.8 – Noah 2.0

Seasonal Snow water storage

Noah 2.8

Noah 2.0
## Model sensitivities

<table>
<thead>
<tr>
<th>Forcings</th>
<th>Maurer: 1990s</th>
<th>MM5 GCM output forcing: 1990s</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean air temp over snow season (Nov – Mar, °C)</td>
<td>1.0</td>
<td>-1.5</td>
</tr>
<tr>
<td>Sensitivity of Mean Apr1. Snow Water Storage to 1° C change Noah 2.8 (over WA)</td>
<td>5.1 km$^3$ / °C (9.5 %)</td>
<td>12.8 km$^3$ / °C (20.6 %)</td>
</tr>
<tr>
<td>Sensitivity of Mean Apr1. Snow Water Storage to 1° C change Noah 2.0 (over WA)</td>
<td>6.2 km$^3$ / °C (18.8 %)</td>
<td>4.4 km$^3$ / °C (27.0 %)</td>
</tr>
<tr>
<td>Sensitivity of Mean Apr1. Snow Water Storage to 1° C change MM5 Snow Output (over WA)</td>
<td>XX.X</td>
<td>13.5 km$^3$ / °C (64.6 %)</td>
</tr>
</tbody>
</table>
Estimates of Mississippi River basin terrestrial water storage from Variable Infiltration Capacity (VIC) model, and GRACE data. Blue and red shading indicates contribution of seasonal snowpack.
Global lake frequency per $10^6$ km$^2$ vs lake area

from Downing et al, 2006
Global Reservoir Database
Location (lat./lon.), Storage capacity, Area of water surface,
Purpose of dam, Year of construction, ...

13,382 dams,

Visual courtesy of Kuni Takeuchi
Model development: Irrigation scheme

\[ ET = K_c \times ET_o \]

\( ET_o \): Reference crop evapotranspiration
Model development: Reservoir model

1\textsuperscript{st} priority: Irrigation water demand
2\textsuperscript{nd} priority: Flood control
3\textsuperscript{rd} priority: Hydropower production

If no flood, no hydropower:
Make streamflow as constant as possible

\[ Q_{\text{min},i} = 7Q_{10} \]

\[ Q_{\text{max},i} = \min \left( S_{i-1} + Q_{\text{ini},i}, \left( S_{i-1} - S_{\text{end}} + \sum_{\text{day}=i}^{365} Q_{\text{in},\text{day}} - \sum_{\text{day}=i+1}^{365} Q_{\text{min},\text{day}} - \sum_{\text{day}=i}^{365} E_{\text{res},\text{day}} \right) \right) \]
Colorado River basin

- Figure: Results for three peak irrigation months (jun, jul, aug), averaged over the 20-year simulation period.
- Max changes in one cell during the summer: Evapotranspiration increases from 24 to 231 mm, latent heat decreases by 63 W m$^{-2}$, and daily averaged surface temperature decreases 2.1 °C
- Mean annual “natural” runoff and evapotranspiration: 42.3 and 335 mm
- Mean annual “irrigated” runoff and evapotranspiration: 26.5 and 350 mm
Lakes and wetlands
Understanding modeled soil moisture – model and RS vs OBS (courtesy R. Koster)

**Mean**
- SMMR vs GSMDB mean
  - \( R^2 = 0.20 \)
- Catchment vs GSMDB mean
  - \( R^2 = 0.25 \)

**Std**
- SMMR vs GSMDB std
  - \( R^2 = 0.37 \)
- Catchment vs GSMDB std
  - \( R^2 = 0.19 \)

**Anomaly std**
- SMMR vs GSMDB anom std
  - \( R^2 = 0.13 \)
- Catchment vs GSMDB anom std
  - \( R^2 = 0.15 \)
Conclusions

• Lots of progress since the onset of the GEWEX era in development of hydrologically realistic land schemes

• Growing recognition of need for realistic off-line predictive capability (e.g. drought) as well as functionality in coupled mode

• Need to be careful not to add too many “bells and whistles” without justification for added complexity (and parameters)

• Data for model evaluation remain a problem, as does parameter estimation