Hydrology in the Community Land Model

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The Community Land Model is a...?

a) Hydrology model

b) Land Surface model

c) Terrestrial Processes model
The movement of **water** is inextricably linked to the flow of **energy** and the life cycle of **vegetation**.
The **modeling** of movement of water is inextricably linked to the **modeling** of the flow of energy and the **modeling** of the life cycle of vegetation.
The Water Balance

\[ P = E + R + \Delta S \]

\begin{align*}
P &= \text{Precipitation} \\
E &= \text{Evapotranspiration} \\
R &= \text{Runoff} \\
S &= \text{Storage}
\end{align*}
Different Models, Different Foci

Flood Forecasting ⇒ R

NWP, Climate Prediction ⇒ E

Drought Monitoring, Groundwater ⇒ S
Different Foci, *Different Models*

1-D $\Rightarrow$ Darcy Flow (Infiltration/Recharge)

2-D $\Rightarrow$ River Routing

3-D $\Rightarrow$ Saturated Flow (Groundwater)
CLM is tasked with simulating all of these phenomena...

...therefore, trade-offs will be made.
CLM Water Balance Operations

Precipitation
  ⇒ Partitioning between rain and snow, or between stratiform and convective
  ⇒ Canopy interception, storage, and throughfall
CLM Water Balance Operations

Evaporation

⇒ Evaporation from Soil / Canopy / Snow / Surface Water

⇒ Transpiration from vegetation
CLM Water Balance Operations

Runoff
⇒ Surface Runoff (Infiltration and/or Saturation Excess)
⇒ Subsurface Runoff (Baseflow)
⇒ River Routing
Runoff Generation and Infiltration

Surface Runoff
Subsurface Runoff
Infiltration
Recharge
Vegetation
Unsaturated Zone
Saturated Zone
River Storage
CLM Water Balance Operations

Storage

⇒ Soil Moisture
⇒ Groundwater and water table depth
⇒ Perched water table
⇒ Canopy water
⇒ Surface water
⇒ Snow
Storage Components
Cold Region Storage Components
CLM Submodels

- Soil hydrology and thermodynamics model
- Snow model
- Photosynthesis model
- Radiation and albedo model
- River Transport model
- Lake model
- Urban model
- Vegetation dynamics model
- Carbon and nitrogen cycle model
- Volatile Organic Compound emissions model
- Dust emissions model
Snow model

Treats processes such as:

- Accumulation
- Snow melt and refreezing
- Snow aging
- Water transfer across layers
- Snow compaction:
  - destructive metamorphism due to wind
  - overburden
  - melt-freeze cycles
- Sublimation
- Aerosol deposition

Up to 5-layers of varying thickness
Snow Radiative Transfer (SNICAR)

- Snow darkening from deposited black carbon, mineral dust, and organic matter
- Vertically-resolved solar heating in the snowpack
- Snow aging (evolution of effective grain size) based on:
  - Snow temperature and temperature gradient
  - Snow density
  - Liquid water content and
  - Melt-freeze cycling
Fractional Snow Covered Area

- Describes sub-gridscale snow cover
- Based on snow water equivalent (SWE)
- Dependent on snow history
- Dependent on snow trajectory
Soil model

Treats processes such as:

- Soil moisture redistribution
  - Infiltration
  - Darcy flow
  - Recharge
- Soil moisture phase change
- Soil temperature redistribution

Default structure has 10 layers of variable thickness, spanning nearly 4 meters depth
  - Thermal calculations use additional deep layers
a) Soil moisture (\% saturation)

b) Soil temperature (°C)

Stippling indicates frozen soil
Groundwater model

- Provides bottom boundary condition to soil column
- Groundwater storage increased by recharge, decreased by subsurface flow and exfiltration
- Calculates water table depth
River model

- Routes runoff to the oceans
- Flow directions are obtained from an input dataset
- Calculates water volume and discharge
Model Validation Tools

Ideally, should be:

• Global
• Directly comparable to modeled process/state/flux
• Same spatial / temporal scale
• High accuracy
• Long record

In reality, no datasets meeting these criteria exist...
Flux Towers
Soil Moisture Networks

Top panel: CLM soil moisture
Bottom: Observed soil moisture
River Discharge

Ob at Salehard

Yenisey at Igarka

Lena at Kusur

Mekong at Pakse

Ganga at Farakka

Mississippi at Vicksburg

OBS

CLM4
FLUXNET-MTE

Annual Mean Evapotranspiration

Top panel: FLUXNET-MTE
Bottom: CLM
FLUXNET-MTE

Columbia River Basin
Evapotranspiration

Red: FLUXNET-MTE
Blue/Green: CLM
GRACE Total Water Storage

Mean Annual Amplitude of Total Water Storage

Top panel: GRACE
Bottom: CLM
GRACE Total Water Storage

Columbia River Basin Total Water Storage

Red: GRACE
Blue/Green: CLM
CLM Application Example:
Anthropogenic Groundwater Withdrawal

Human-induced groundwater changes can be estimated by removing the CLM estimate of TWS from the GRACE estimate of TWS.

- **GRACE TWS**
- **CLM TWS**
- **Groundwater**
Simulation Examples I: Tropical

60W / 5S
Hydrologically Relevant Surface Data

[Maps showing distributions of Dominant PFT and Annual Maximum LAI over South America]
Hydrologically Relevant Surface Data
Time Series

lon:300.0/lat:-5.2

Precipitation

Air Temperature
lon:300.0/lat:-5.2

Precipitation

Runoff

Evapotranspiration
lon:300.0/lat:-5.2

**Precipitation**

**Runoff**

**Total Runoff**

**Surface Runoff**

**Evapotranspiration**
The water table determines the fraction of the area that is saturated.

Saturated areas produce surface runoff.
Example: Effects of Modifying the Water Table

\[ \Delta Z_{WT} = Q_{\text{drainage}} - Q_{\text{recharge}} \]

\[ Q_{\text{drainage}} = A \exp(-f \ z) \]

\[ Q_{\text{surface}} = F \exp(-g \ z) \]
Current and Future Challenges

• Subgrid heterogeneity and covariance of vegetation, soil moisture, surface water and snow
• Within-canopy turbulent fluxes
• Human management and withdrawals
• Variable soil depths
• Canopy storage
• Hydrological response to land cover change