LMWG | Land Model Working Group

The Community Land Model (CLM) is the land model component of the CESM. Information on the latest version of CLM, including technical descriptions, user guides, and download instructions can be found on the CLM web page.

LMWG Liaison Information

- Keith Oleson

LMWG Co-Chair Information

Dr. Charles Koven
3/1/2017 - 2/28/2019
LBNL, 1 Cyclotron Rd., MS 84-314, Berkeley, CA 94720
510-486-6724
Email

Dr. David Lawrence
1/1/2010 - 12/31/2019
NCAR-CGD, P.O. Box 3000, Boulder, CO 80307-3000
303.497.1384
Email

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https://groups.google.com/a/ucar.edu/forum/#!forum/ctsm-dev
Snow processes in CLM
Dave Lawrence, Sean Swenson, and Martyn Clark
More than one-sixth of world’s population dependent on water from seasonal snowpacks
Trends in snow accumulation

(a. Observations) (b. VIC 1950-1997)
Trends in timing of snowmelt runoff

Red - Earlier runoff
Blue - Later runoff

Stewart et al., J. Climate, 2005
Solve the heat diffusion equation for multi-layer snow and soil model

\[ C_p \frac{\partial T}{\partial t} = \frac{\partial}{\partial z} \left( K \frac{\partial T}{\partial z} \right) \]

where \( C_p \) (heat capacity) and \( K \) (thermal conductivity) are functions of:

- temperature
- total soil moisture
- soil texture
- ice/liquid content
Key requirements / decisions in snow modeling

**Water balance**
- Precipitation (partitioning)
- Rain
- Snow

**Energy balance**
- Turbulent Longwave fluxes
- Solar radiation
- (stability)

**Snowpack**
- (thermal conductivity)
- (albedo)
- (drainage parameterization)

Snowpack outflow
Features of CLM snow model

- Up to 12-layers of varying thickness
- Represented processes
  - Accumulation and fresh snow density \( f(T, \text{wind}) \)
  - Snow melt and refreezing
  - Snow aging
  - Water and energy transfer across snow layers
  - Snow compaction
    - destructive metamorphism due to temperature and wind
    - overburden
    - melt-freeze cycles
  - Sublimation
  - Aerosol (black carbon, dust) deposition
  - Canopy snow storage and unloading
  - Canopy snow radiation
  - Snow burial of vegetation
  - Snow cover fraction
- Unrepresented processes
  - Blowing snow
  - Subgrid variations in snow depths
  - Depth hoar

State Variables

\[ N, w_{\text{liq},i}, w_{\text{ice},i}, \Delta z_i, T_i \]
Snow Covered Fraction (SCF)

• Fraction of grid cell covered by snow for a given snow depth
• Based on snow water equivalent (SWE)
• Dependent on snow history
• Dependent on snow trajectory
Snow, Ice, and Aerosol Radiative Model (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

Flanner et al (2007), *JGR*
Flanner and Zender (2006), *JGR*
Flanner and Zender (2005), *GRL*
CLM5: Snow updates

**CLM4.5**
- Snow
- Rain
- Intercepted
- All $H_2O$
- $W_{max}$

1m max SWE
up to 5 layers

**CLM5**
- Snow
- Rain
- Snow Drip,
Throughfall,
& Unloading
- Liquid
- $W_{snow max}$
- $W_{rain max}$

20m max SWE
up to 12 layers
Evergreen Snow Interception Measurements

- More representative of in-situ snow canopy storage
- (previously canopy snow albedo present only in freezing temps).
Subgrid Snowpack and Surface Fluxes

CLM3.5

CLM4+

ΔF3NO

ΔNETRAD

ΔTURB

ΔFGROUND
Improvements to fresh snow density and snow compaction

**CLM4/CLM4.5**
- Pahaut (1976)

**CLM5**
- Slater

- Improved snow densities
- Cooler soil temperatures
- Eliminates spurious Antarctica snow melt
CLM5 snow density

Revised fresh snow density with improved temperature and wind effects lead to increased and more realistic snow density and less thermal insulation.
Snow insulation and permafrost distribution

CLM4.5BGC (GSWP3)
11.5

CLM5BGC (GSWP3)
13.1

kg m$^{-3}$
Partitioning of precip into rain and snow is based on temperature.

In CLM5, the atmosphere model partitioning into rain and snow is ignored. CLM repartitions total precipitation using a linear ramp. For most landunits, this ramp generates all snow below $0^\circ C$, all rain above $2^\circ C$ ($T=1^\circ C$), and a mix of rain and snow in between. For glaciers, the end points are minus $2^\circ C$ and $0^\circ C$, respectively.

Changes to the phase of precipitation are accompanied by a sensible heat flux (positive or negative) to conserve energy.
Uncertainties: Liquid water flow

- The storage and transmission of liquid water parameterized as gravity drainage (note: this is not the function used in CLM)

\[ q = k \left( \frac{\theta_{\text{liq}} - \theta_{\text{res}}}{\phi - \theta_{\text{res}}} \right)^c \]

- Consider three parameter sets
  
  \[ k = 10; \quad c = 1; \quad \theta_{\text{res}} = 0.02 \]
  
  \[ k = 0.015; \quad c = 3; \quad \theta_{\text{res}} = 0.02 \]
  
  \[ k = 0.015; \quad c = 3; \quad \theta_{\text{res}} = 0.06 \]
Thanks. Questions?