Land surface parameterization in climate models

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Snow characteristics to be considered:

- Rainfall vs. snowfall threshold
- (Fractional precipitation coverage of grid cell)
- (Snow redistribution)
- Snow albedo (and emissivity)
- Fresh and old snow densities; (snow grain size and metamorphism, multiple layers)
- Snow interception by vegetation – canopy storage capacity (and unloading rate)
- Surface turbulent transfer (and vapour movement within snow pack)
- Heat conduction within snow pack
- Snow pack melting (and water retention)
- Grid cell fractional coverage of snow
The Canadian Land Surface Scheme (CLASS)

- Monin-Obukhov similarity theory
- Canopy interception
- evaporation
- melt
- condensation
- sublimation
- unloading
- Big Leaf canopy
- Explicit snow layer
- 4th soil layer
- 3 soil layers
- Heat (thermal diffusion)
- Drainage (Darcy’s Law)

Version 3.x

- Mosaic
- Canopy conductance varies with species
- Improved snow algorithms
- Organic soils
- WATFLOOD water routing

(after Verseghy, 2000)
Zero Dimensional

Implicit

Composite Layer

Bulk Layer

Multi-layer

Does heat capacity include soil?

Vertical Complexity

Horizontal Complexity

How does snow access energy from bare ground and vegetation?

Direct

Diffusive

Soil Snow
Prognostic snow variables typically used in land surface models:

- Snow water equivalent
- Density
- Albedo
- Temperature (?)
- Liquid water content (?)
- Snow stored on vegetation
Preliminary SnowMIP Results… CLASS performance comparable to more sophisticated models
CDP_9798: daily snow depth
**Mixed precipitation**

**CLASS 2.7:**
Precipitation is diagnosed as rain or snow using a simple threshold air temperature of 0°C.

**CLASS 3.1:**
The fraction of precipitation that is snow is modelled using a polynomial, which allows mixed precipitation between 0° and 6°C.

(Auer, 1974)
The density of fresh snow, $\rho_{\text{fresh snow}}$, is a constant value at 100 kg m$^{-3}$.

$\rho_{\text{fresh snow}}$ varies with air temperature.

(Hedstrom and Pomeroy, 1998)
Maximum snowpack density

\[ \tilde{\rho}_s(t) = \tilde{\rho}_s(0) \exp(-B \Delta t) \]

where \( \tilde{\rho}_s = \rho_s - \rho_{\text{max},\text{snowpack}} \) and \( B \) is a constant.

**CLASS 2.7:**
Maximum snowpack density, \( \rho_{\text{max},\text{snowpack}} \), is constant at 300 kg m\(^{-2}\).

**CLASS 3.1:**
\( \rho_{\text{max},\text{snowpack}} \) varies with snowpack depth, and is larger for an isothermal snowpack.

(Pomeroy et al. 1998; Tabler et al. 1990)
Results: Snowpack density at BERMS field sites

- $\rho_{\text{snowpack}}$ is overestimated in CLASS 2.7 with respect to the snow surveys.
- $\rho_{\text{snowpack}}$ is much improved in CLASS 3.1, although sometimes overestimated.

- At the cold temperatures found at these sites, fresh snow is less dense in CLASS 3.1.
- At the shallow snowpack depths during this winter, the maximum snowpack density is smaller in CLASS 3.1.

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Modified snow aging scheme in CLASS 3.1 resulted in improved representation of snow depth and improvements to the surface temperature bias.

Above data from Col de Porte, Sleepers River and Weissfluhjoch (SnowMIP experiment)
Conifers have a much larger interception capacity for snow than for water.

Following sublimation and unloading, the canopy is snow-free for much of the winter.
**CLASS 2.7:**
Interception capacity for snow, $I^*$, is treated the same as for rain.

**CLASS 3.1**
$I^*$ is an order of magnitude larger for snow, but varies with snow density, $\rho_{\text{fresh snow}}$, in addition to projected leaf area index, $L$.

(Hedstrom and Pomeroy, 1998)
CLASS 2.7:
All snow landing on canopy is intercepted until the interception capacity, $I^*$, is reached.

CLASS 3.1:
Interception efficiency, $I/P$, decreases with precipitation rate, $P$, and also with the initial snow load on the canopy $I_0$.

(Hedstrom and Pomeroy, 1998)
**Unloading of intercepted snow**

**CLASS 2.7:**
All intercepted snow remains on the canopy until it sublimes or melts.

**CLASS 3.1:**
Intercepted snow load, $I$, decreases over time according to the unloading rate coefficient $U$ (days$^{-1}$).

Snow that unloads from the canopy is added to the snowpack.

(Hedstrom and Pomeroy, 1998)
Observed and modelled snow water equivalent at the BERMS Old Black Spruce stand (2002-2003)

- CLASS 3.1 shows better agreement with measurements
- Most of the improvement in this model run comes from the ability to unload snow from small snowfall events before the snow sublimates.
Observed and modelled cumulative latent heat flux at the BERMS Old Black Spruce stand (2002-2003)

- CLASS 2.7 overestimates sublimation losses while CLASS 3.1 performs better.
- CLASS 3.1 is able to unload snow from the canopy to the forest floor where it is sheltered and less likely to sublimate.
Cold bias observed in snow surface temperatures under stable conditions

\[ Q_H = [ \rho_a c_p C_H U_z + E_0 ] (T_{sfce} - T_z) \]

Windless exchange coefficient 1-2 W m\(^{-2}\) K\(^{-1}\) used in a number of snow models. 

Significant improvement in snow surface temperatures with \( E_0 = 2\) W m\(^{-2}\) K\(^{-1}\) and albedo modified to represent observed values (CLASS albedo too low by \( \sim 0.15 \) at this site)
Points to ponder:

- When comparing satellite-derived data with model output, need to take into account how the model is parameterizing the surface.
- Need to consider surface heterogeneity, both actual and modelled; presence of vegetation, fractional snow coverage of landscape.
- Precipitation is highly variable in space and time; problem of blowing snow.