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

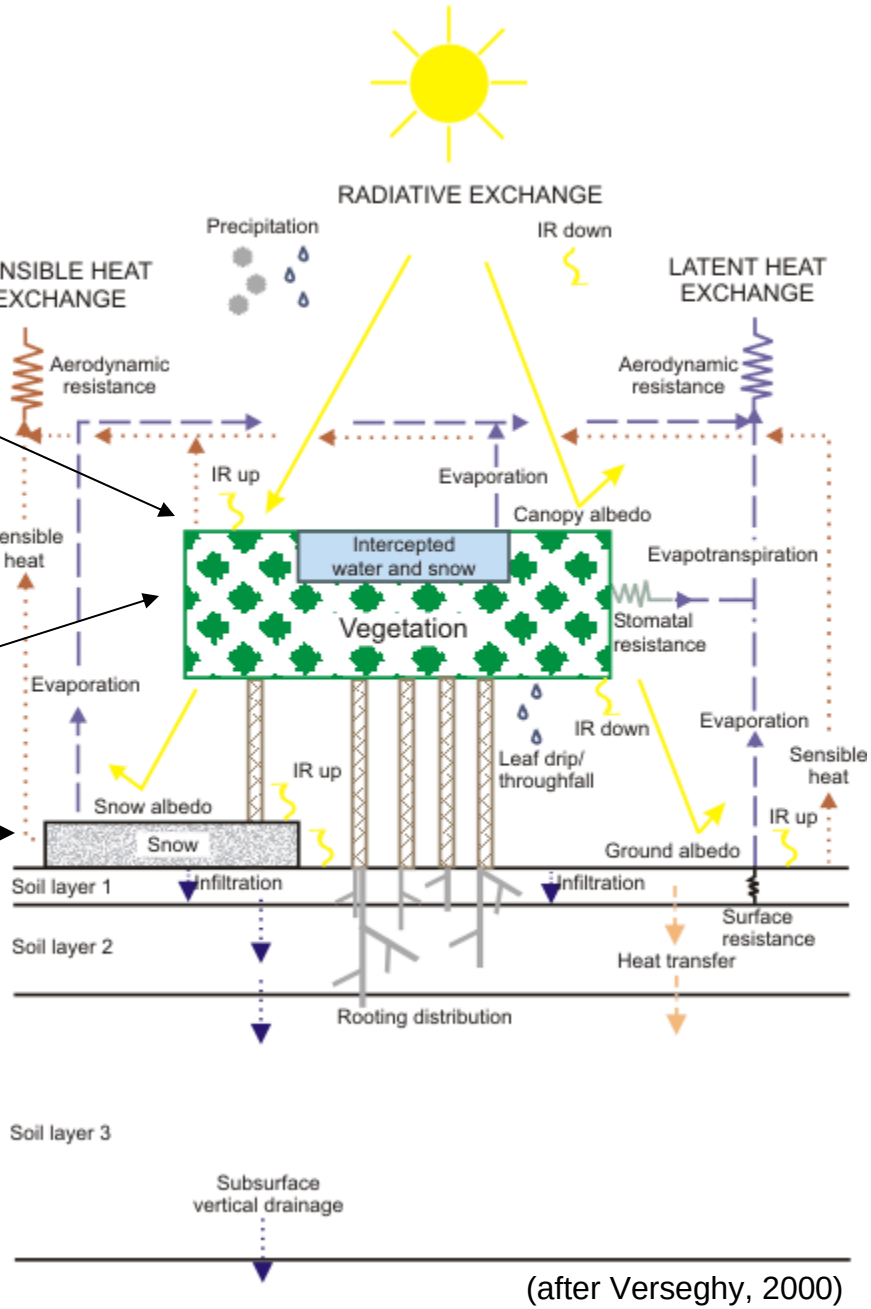
Big Leaf canopy

Explicit snow layer
4th soil layer

3 soil layers

Heat (thermal diffusion)

Drainage (Darcy's Law)



(after Verseghy, 2000)

Version 3.x

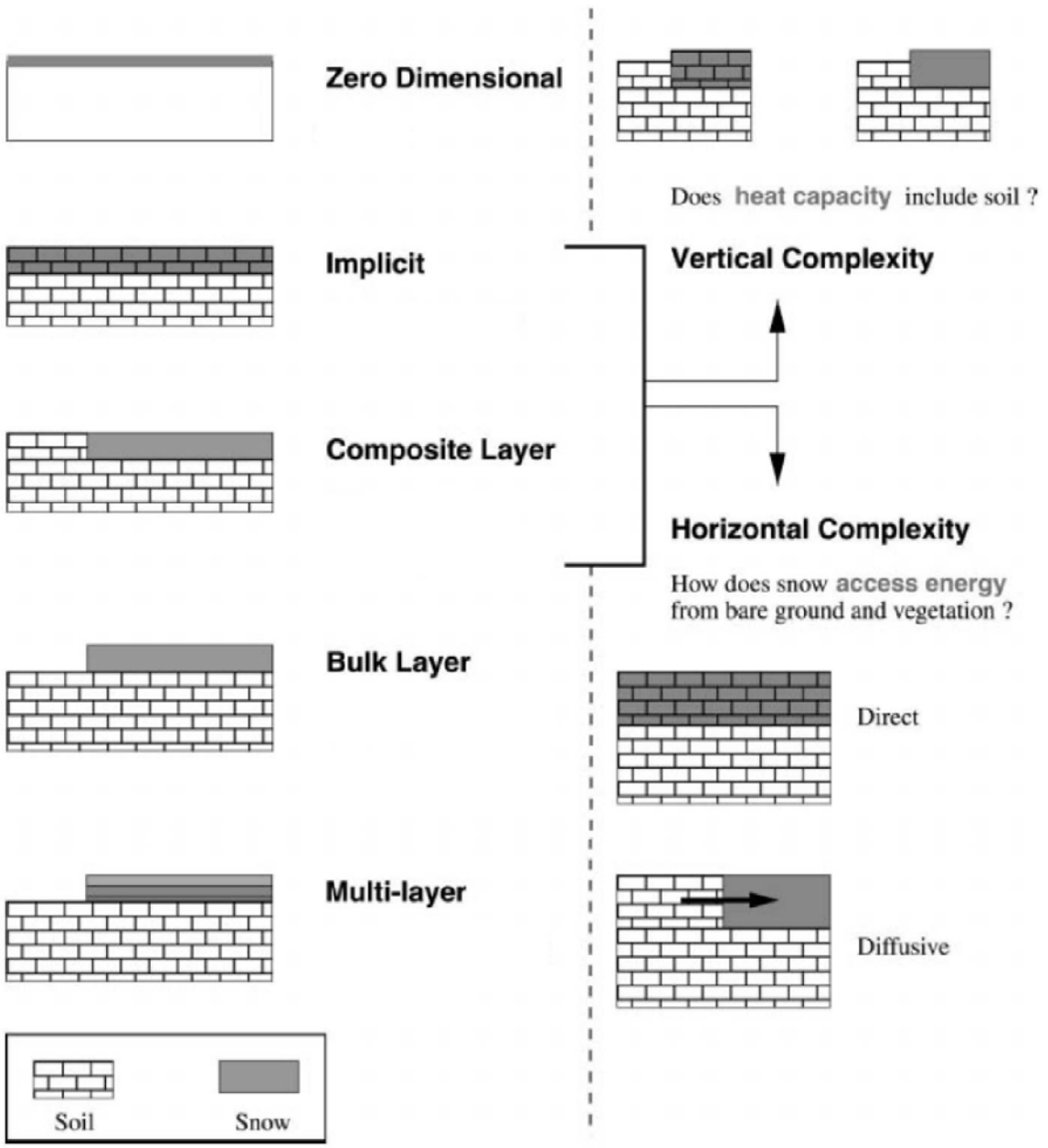
Mosaic

Canopy conductance varies with species

Improved snow algorithms

Organic soils

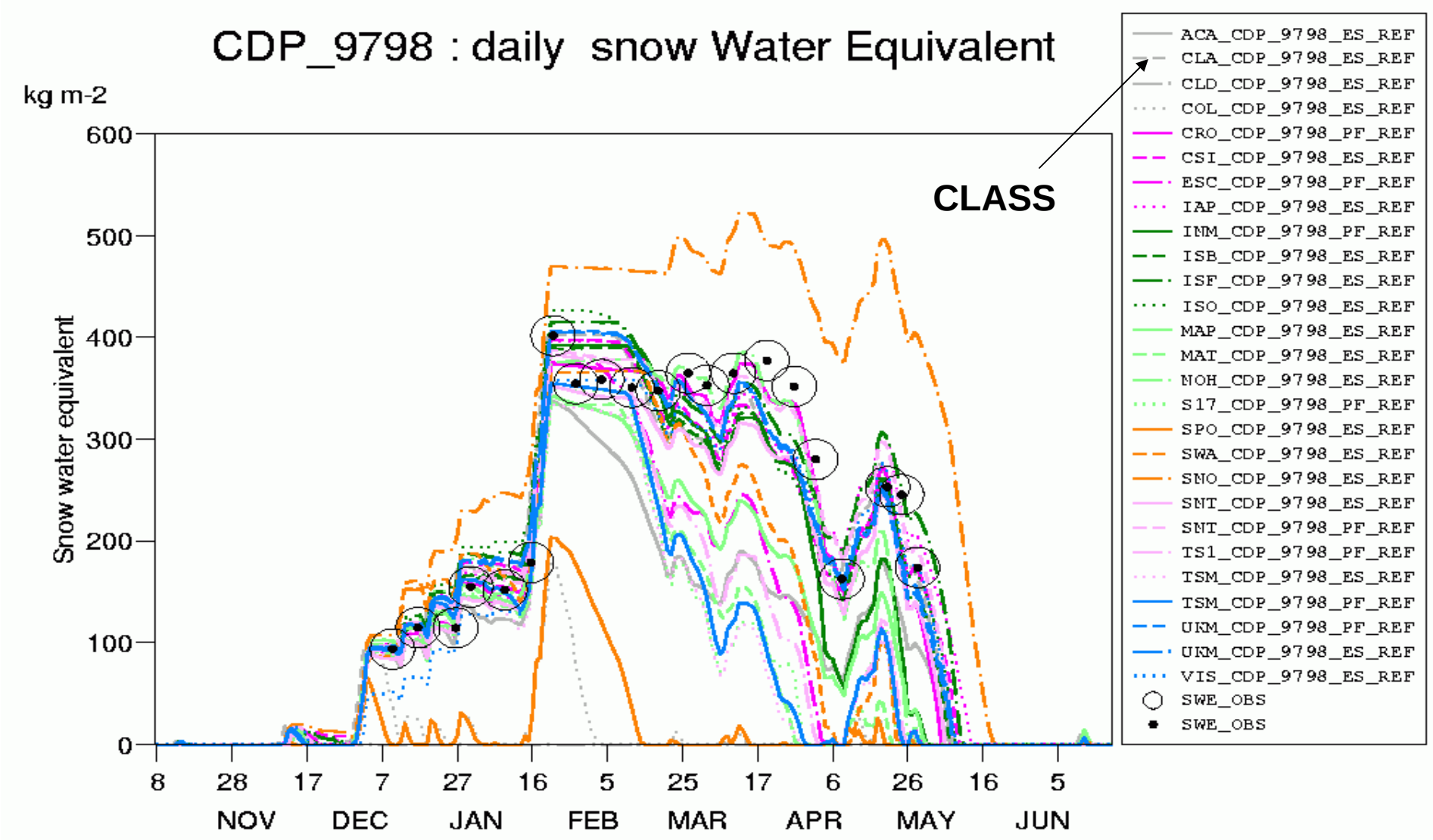
WATFLOOD water routing

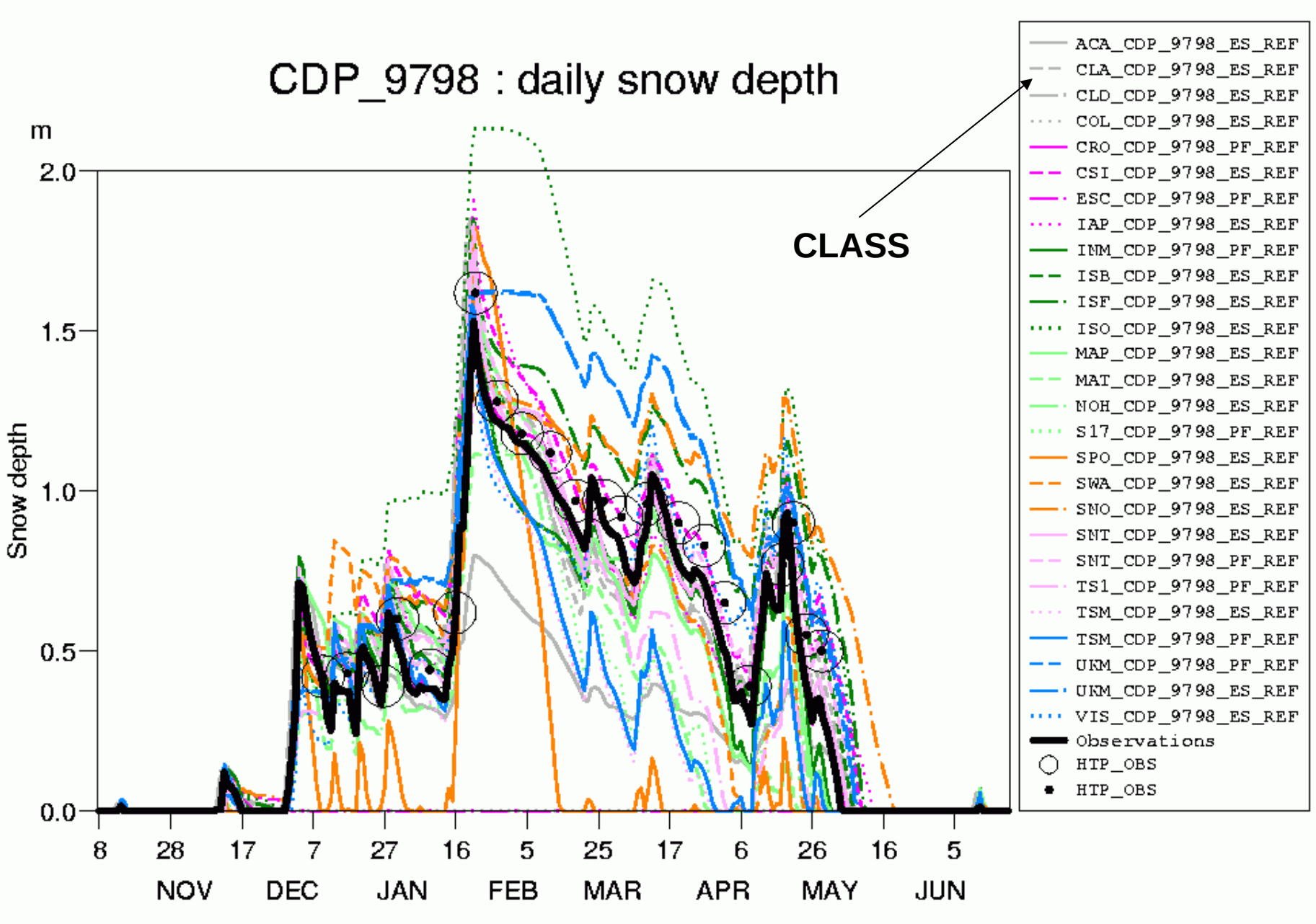

Zero Dimensional
Does heat capacity include soil ?
Implicit
Vertical Complexity
Composite Layer
Horizontal Complexity
How does snow access energy from bare ground and vegetation ?
Bulk Layer
Direct
Multi-layer
Diffusive
Soil
Snow

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
m
Snow depth
2.0
1.5
1.0
0.5
0.0
8
28
17
7
27
16
5
25
17
6
26
16
5
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
CLASS
ACA_CDP_9798_ES_REF
CLA_CDP_9798_ES_REF
CLD_CDP_9798_ES_REF
COL_CDP_9798_ES_REF
CRO_CDP_9798_PF_REF
CSI_CDP_9798_ES_REF
ESC_CDP_9798_PF_REF
IAP_CDP_9798_ES_REF
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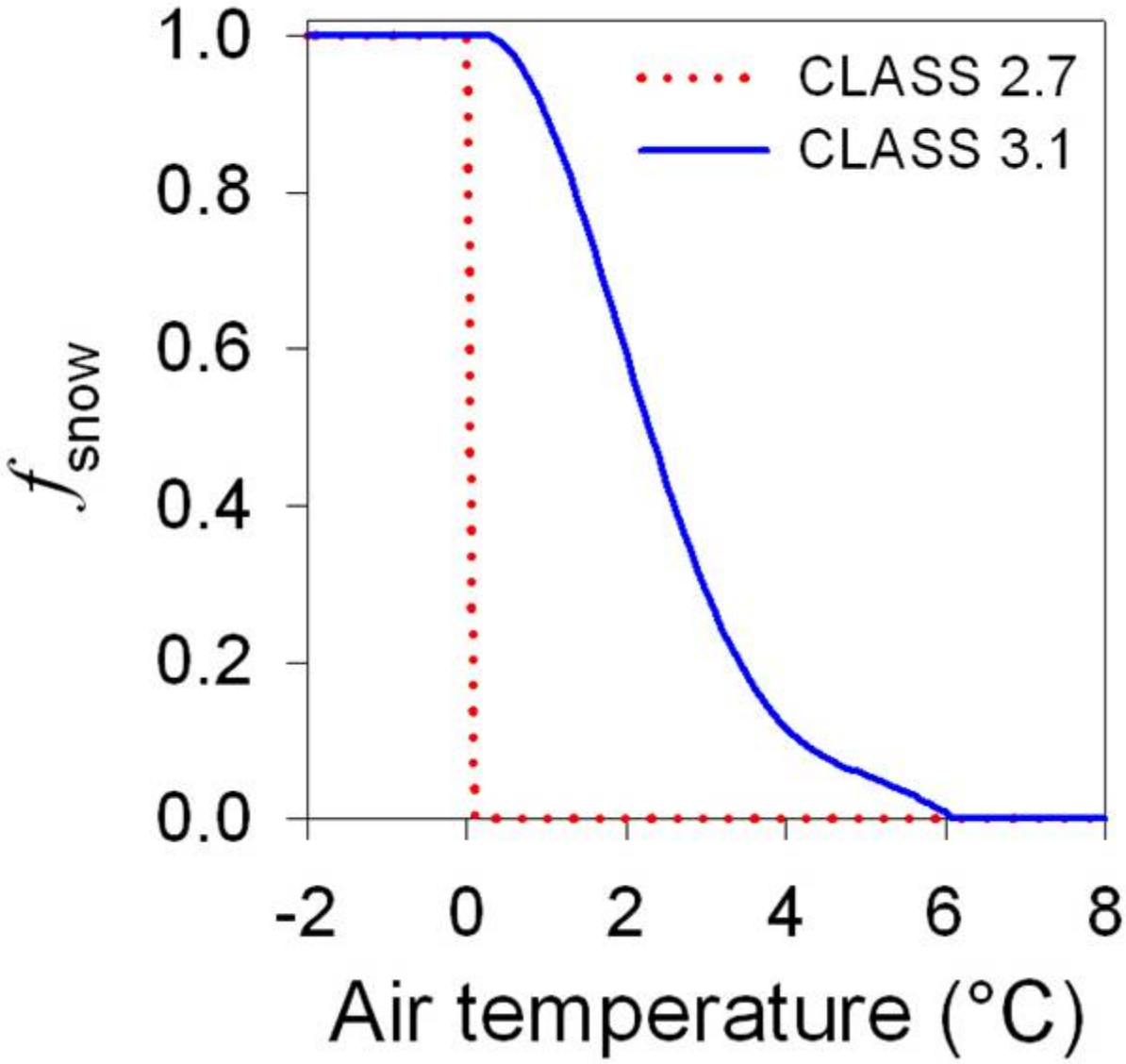
SNT_CDP_9798_PF_REF
TS1_CDP_9798_PF_REF
TSM_CDP_9798_ES_REF
TSM_CDP_9798_PF_REF
UKM_CDP_9798_PF_REF
UKM_CDP_9798_ES_REF
VIS_CDP_9798_ES_REF
Observations
HTP_OBS
HTP_OBS

Mixed precipitation

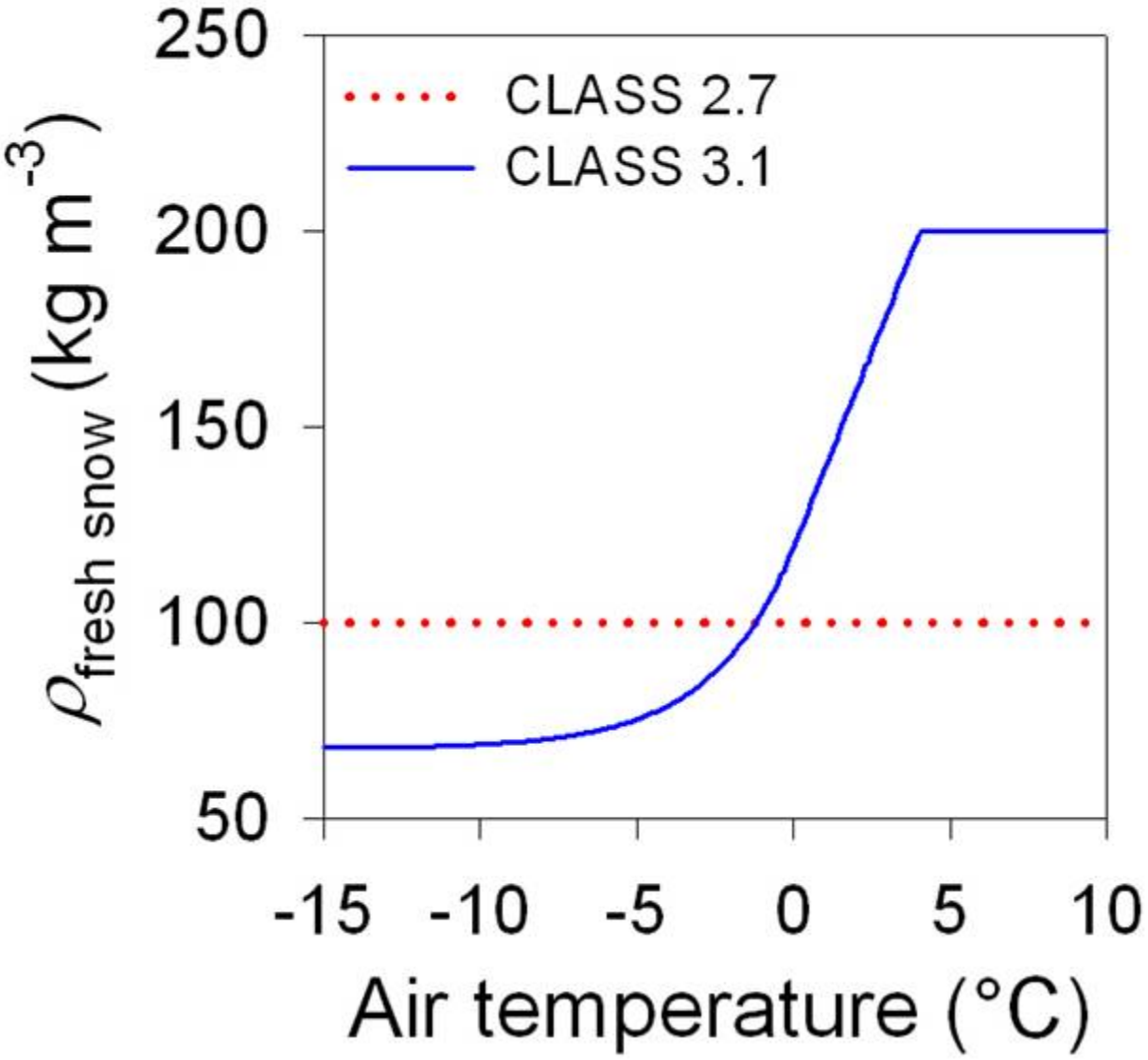


CLASS 2.7:
Precipitation is diagnosed as rain or snow using a simple threshold air temperature of 0°C.

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)

Density of fresh snow



CLASS 2.7:

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

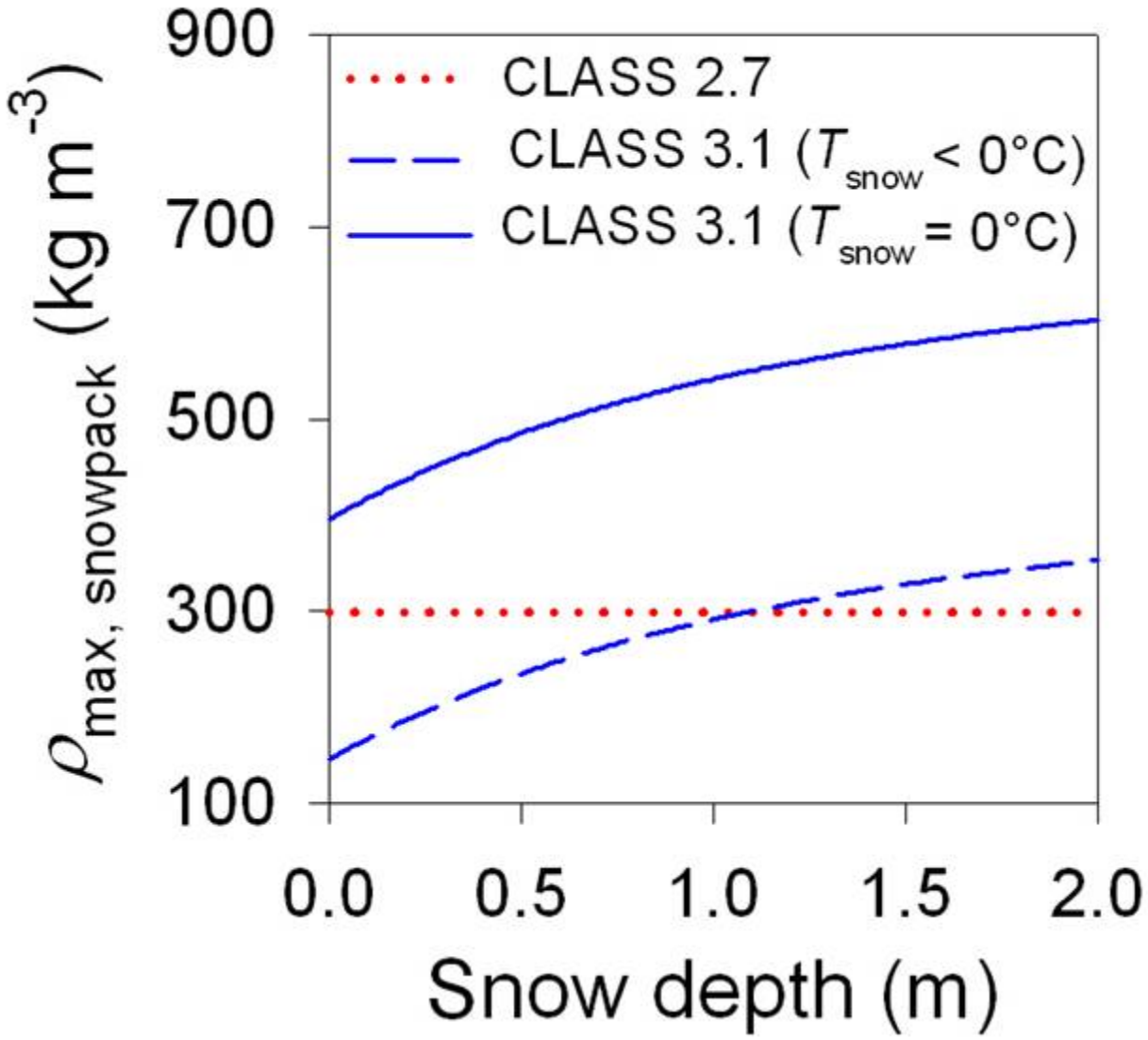
CLASS 3.1:

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

(Hedstrom and Pomeroy, 1998)

Maximum snowpack density

$$\hat{\rho}_s(t) = \hat{\rho}_s(0)\exp(-B\Delta t)$$ where $\hat{\rho}_s = \rho_s - \rho_{\max,\text{snowpack}}$ and B is a constant.



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

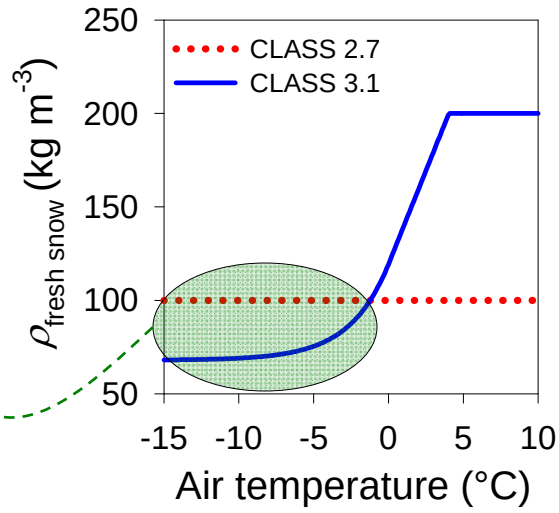
CLASS 3.1:
$\rho_{max,snowpack}$ varies with snowpack depth, and is larger for an isothermal snowpack.

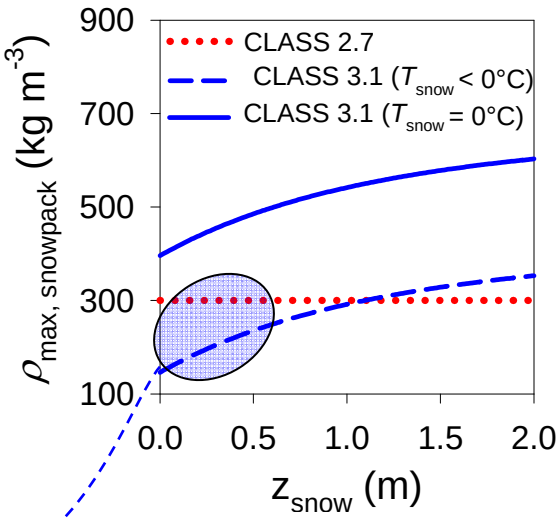
(Pomeroy *et al*. 1998; Tabler *et al*. 1990)

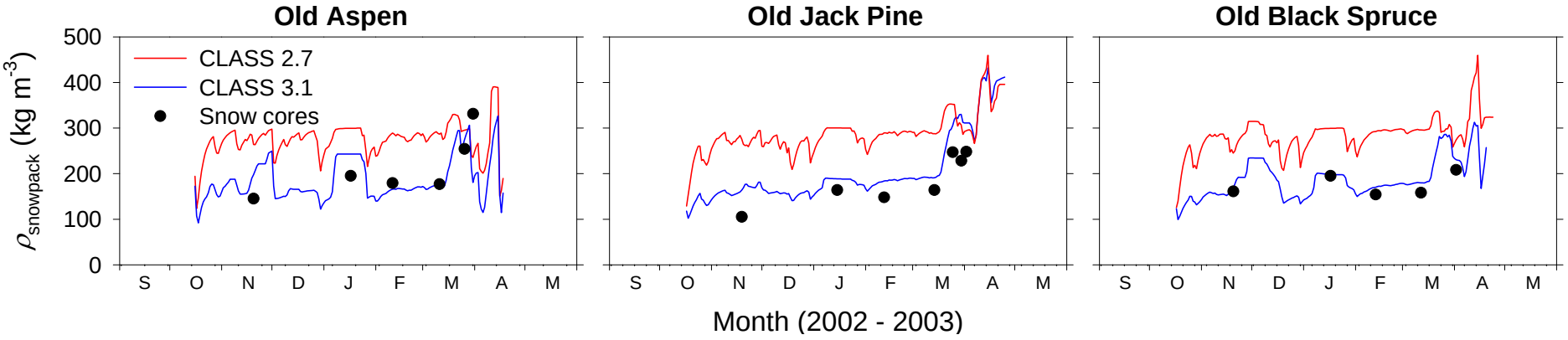
Results: *Snowpack density at BERMS field sites*

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

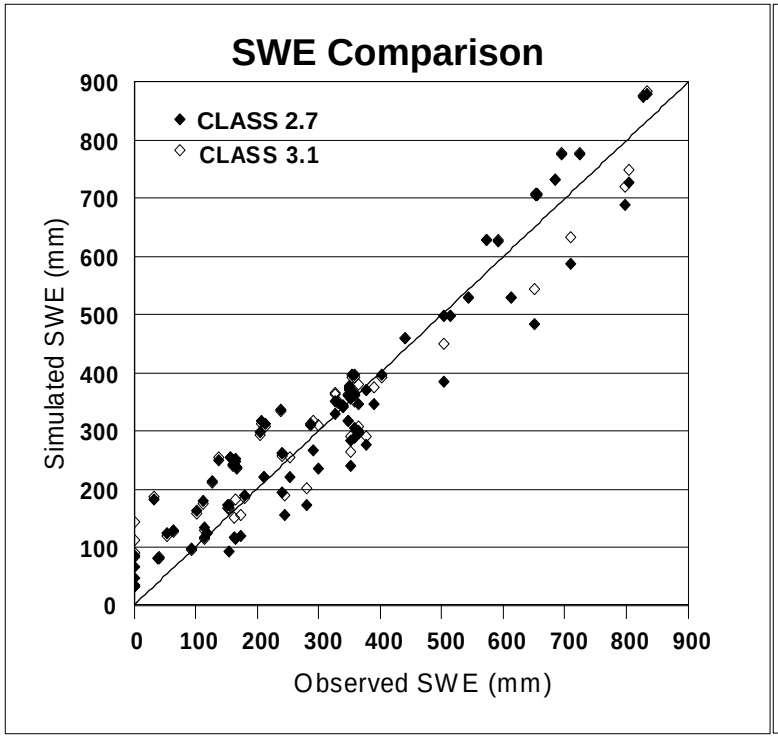
- At the cold temperatures found at these sites, fresh snow is less dense in CLASS 3.1.
- At the shallow snowpack depths during this winter, the maximum snowpack density is smaller in CLASS 3.1.

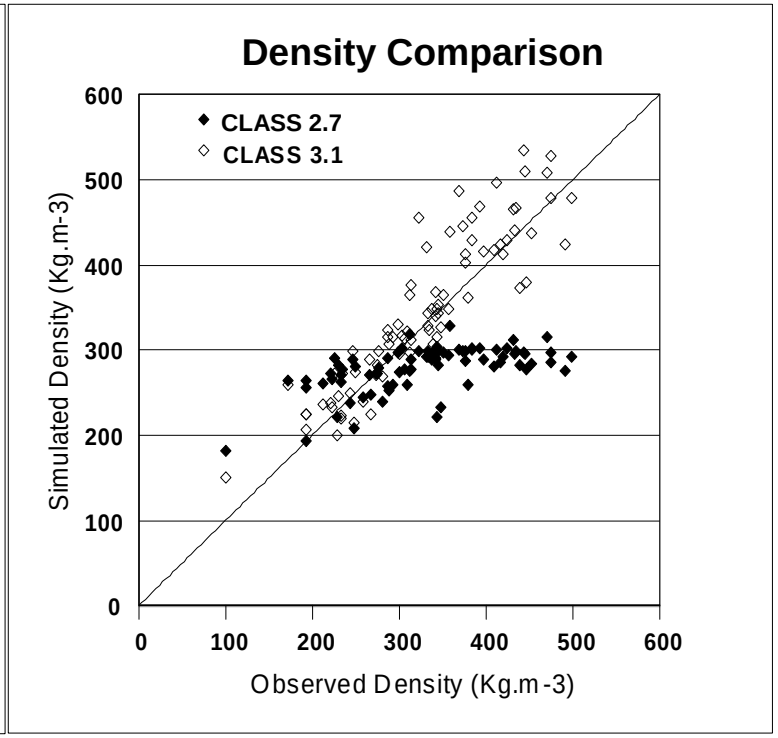




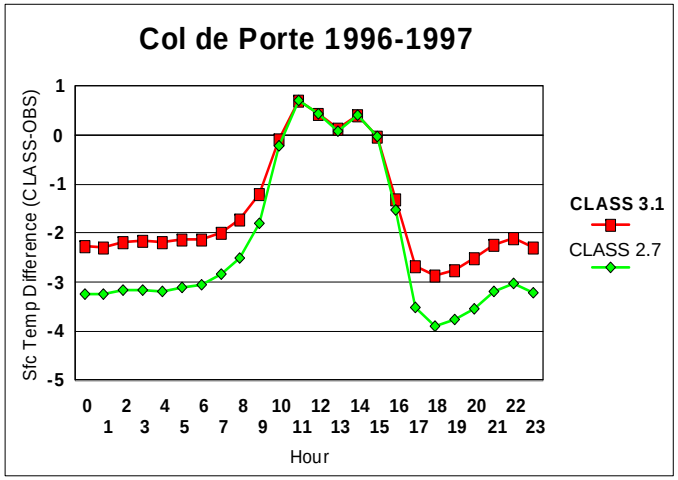


Modified snow aging scheme in CLASS 3.1 resulted in improved representation of snow depth and improvements to the surface temperature bias





Snow surface temperature bias



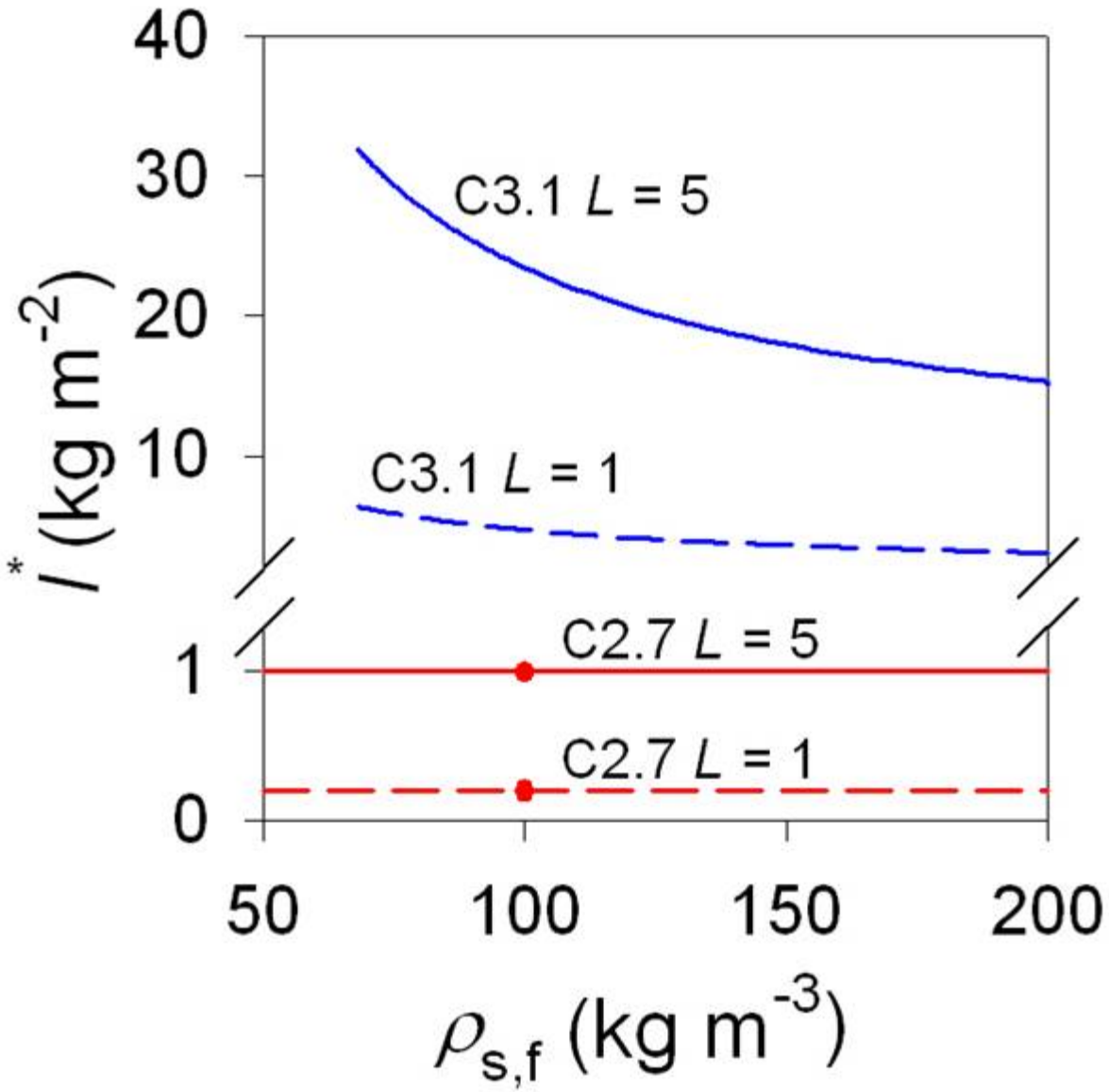
Above data from Col de Porte, Sleepers River and Weissfluhjoch (SnowMIP experiment)

BERMS Old Black Spruce canopy (from tower)

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

Interception capacity

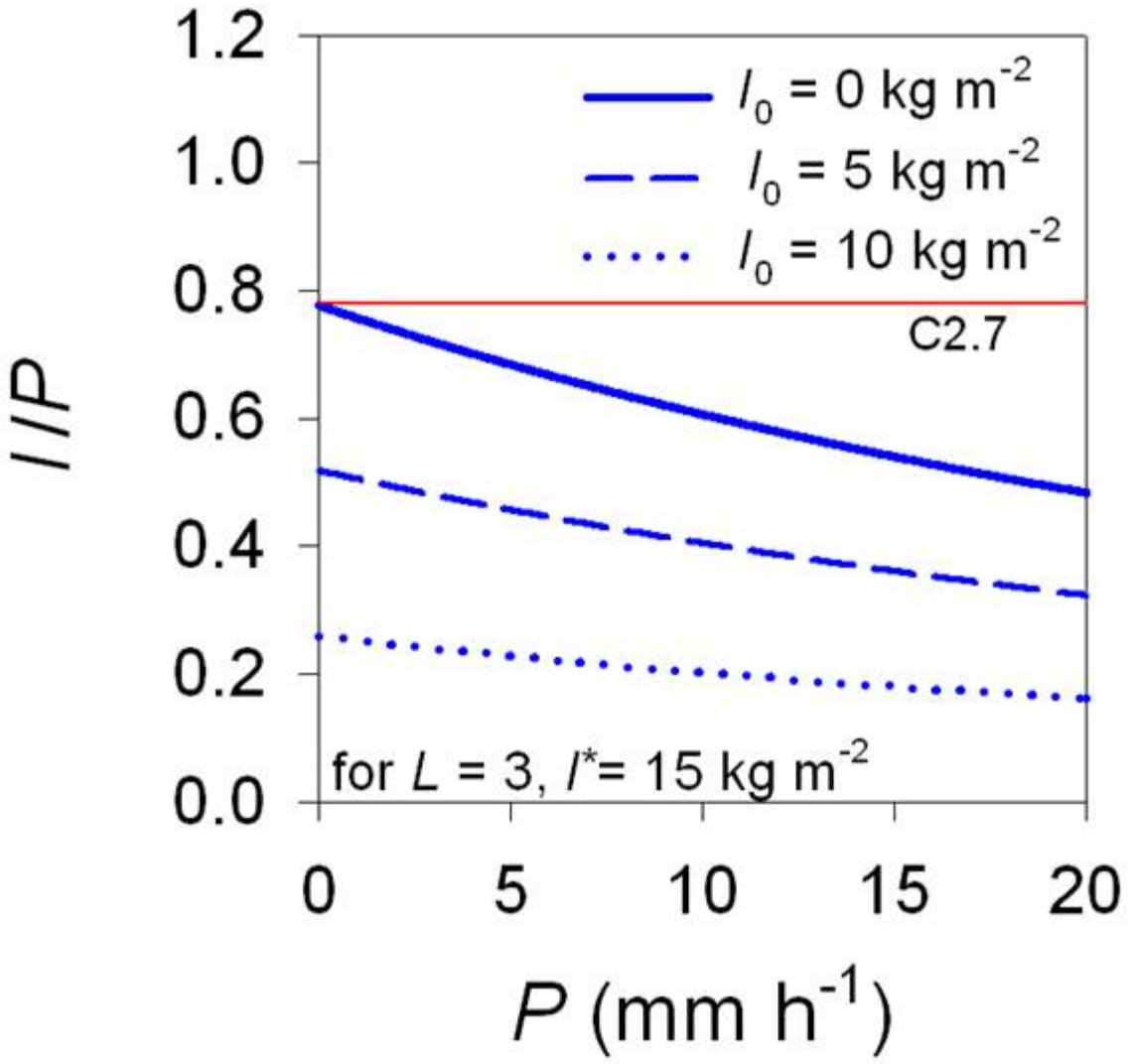


CLASS 2.7:
Interception capacity for snow, I^*, is treated the same as for rain.

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)

Interception efficiency

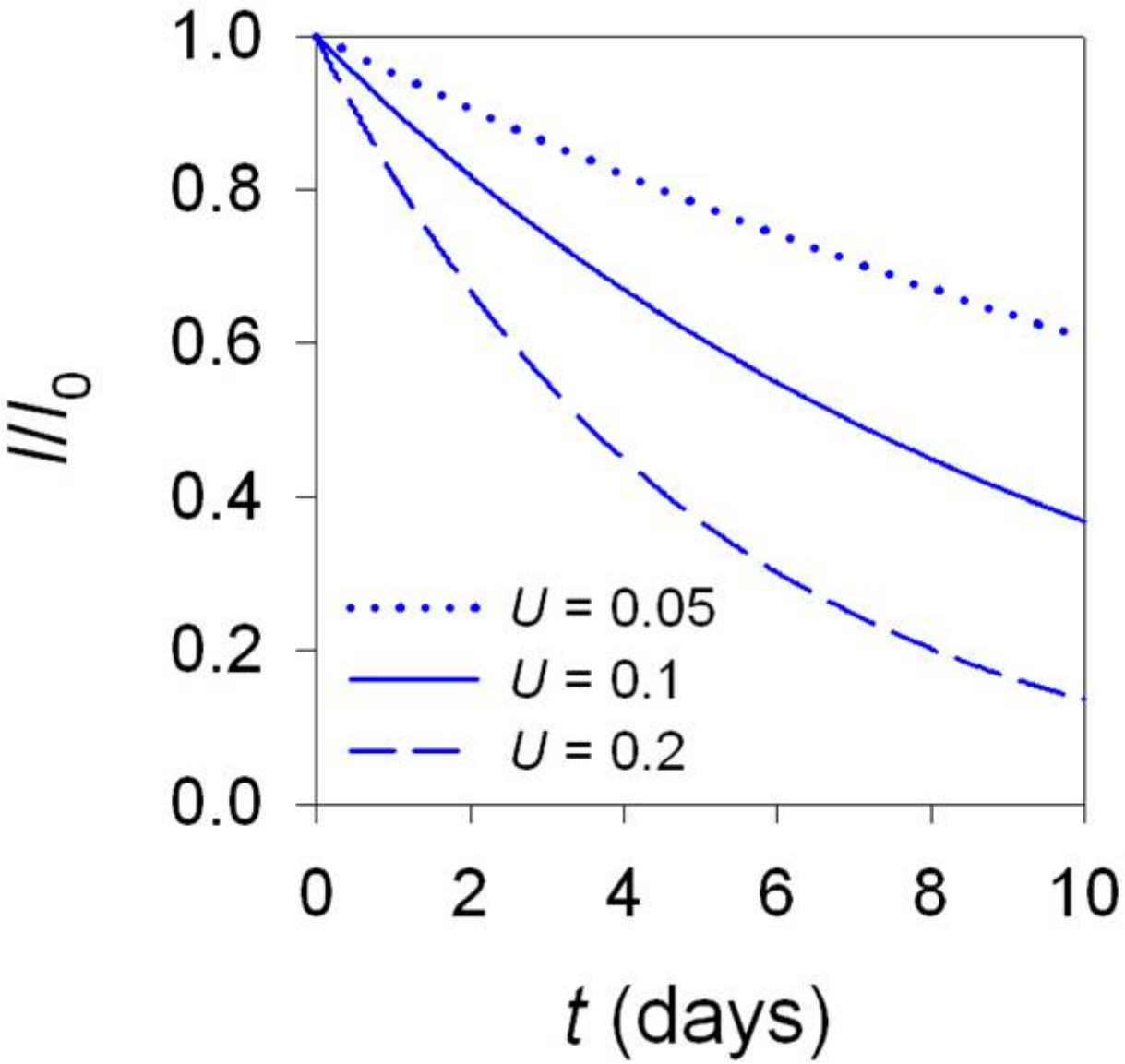


CLASS 2.7:
All snow landing on canopy is intercepted until the interception capacity, *I**, is reached.

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



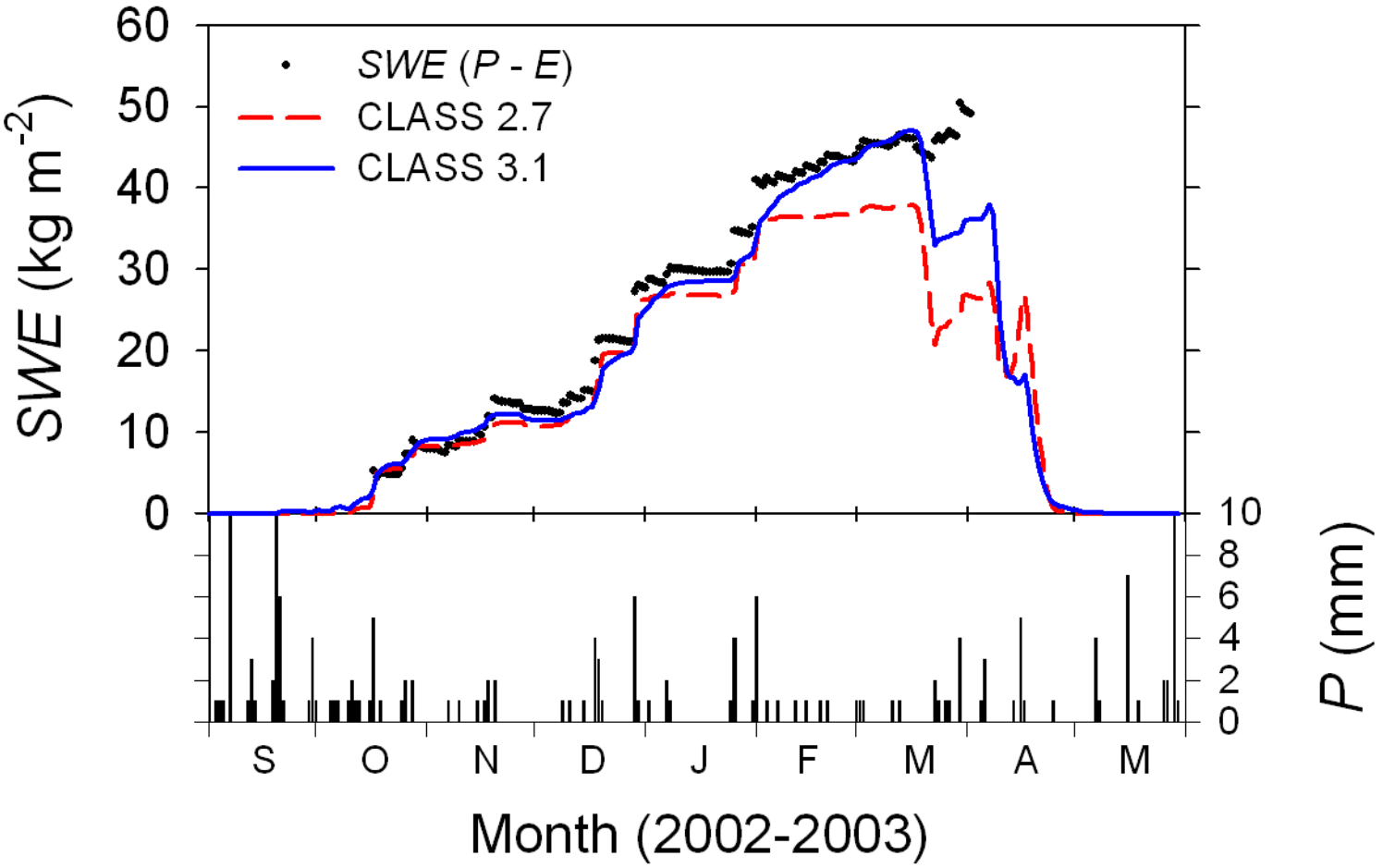
CLASS 2.7:
All intercepted snow remains on the canopy until it sublimates or melts.

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.

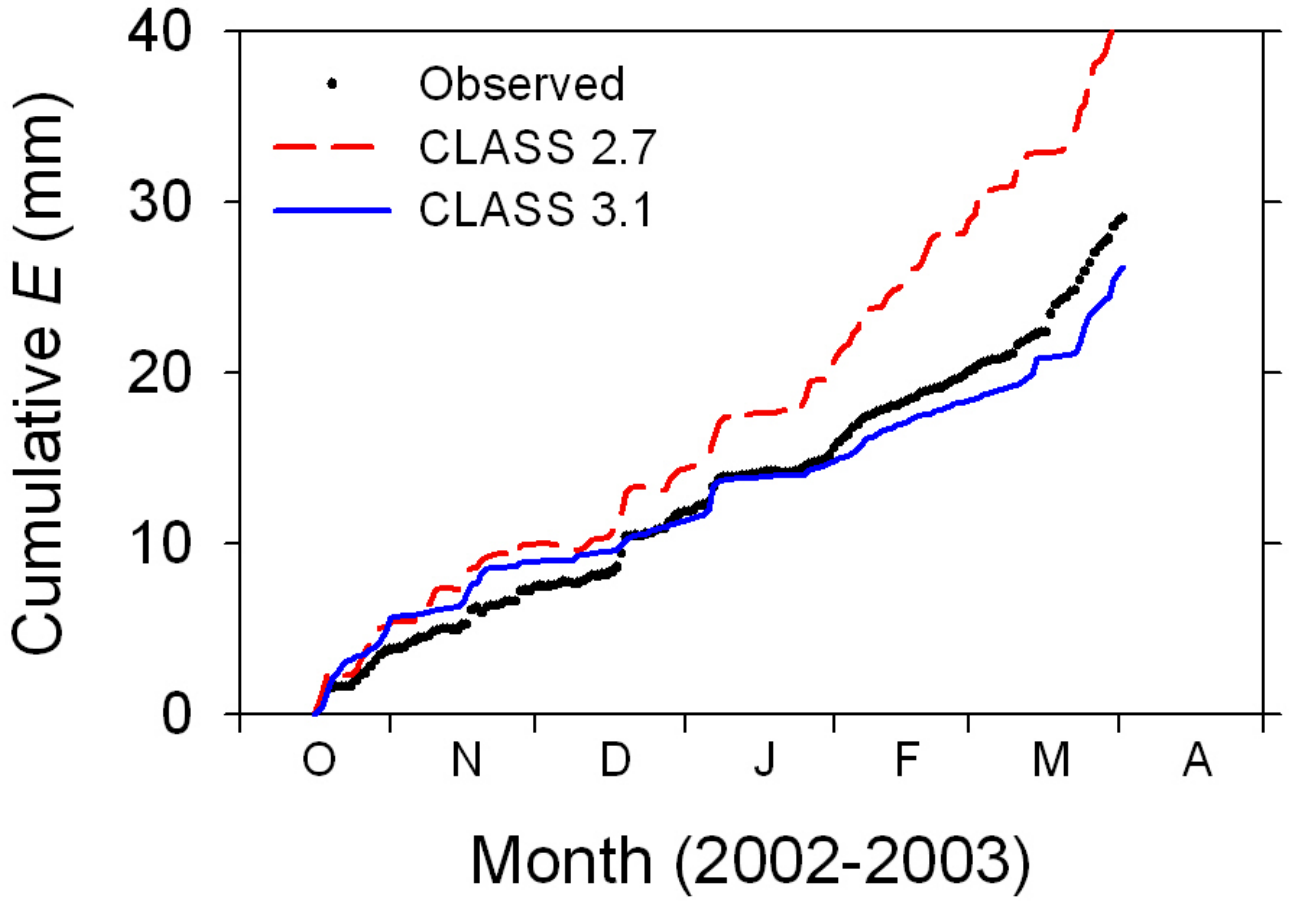
(Hedstrom and Pomeroy, 1998)

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



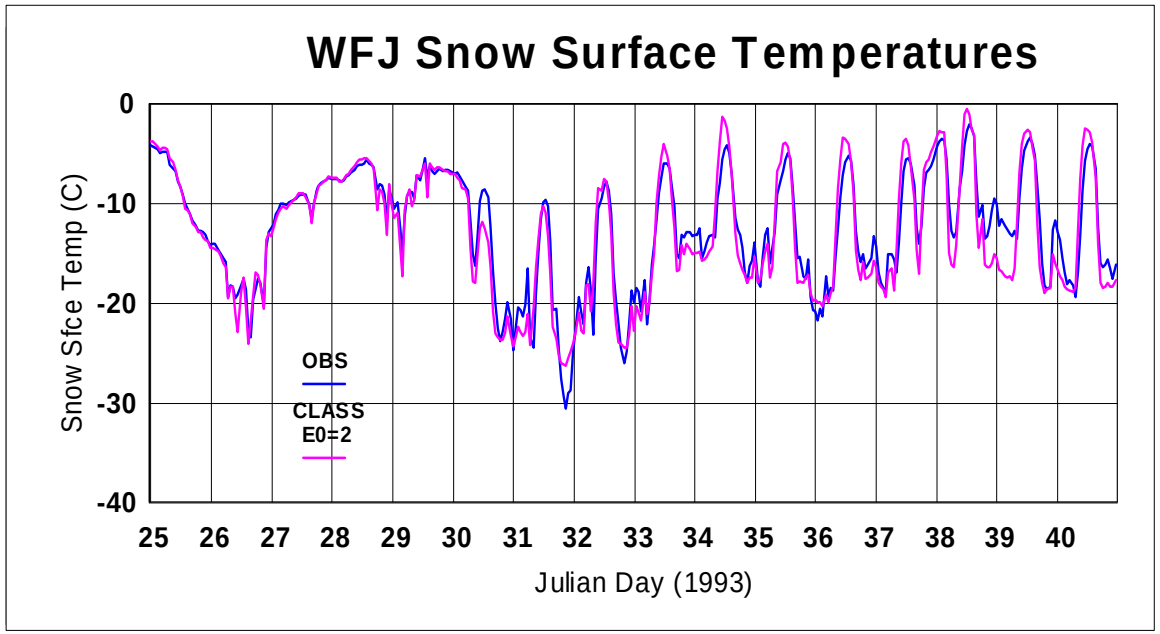
- CLASS 3.1 shows better agreement with measurements
- Most of the improvement in this model run comes from the ability to unload snow from small snowfall events before the snow sublimates.

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.

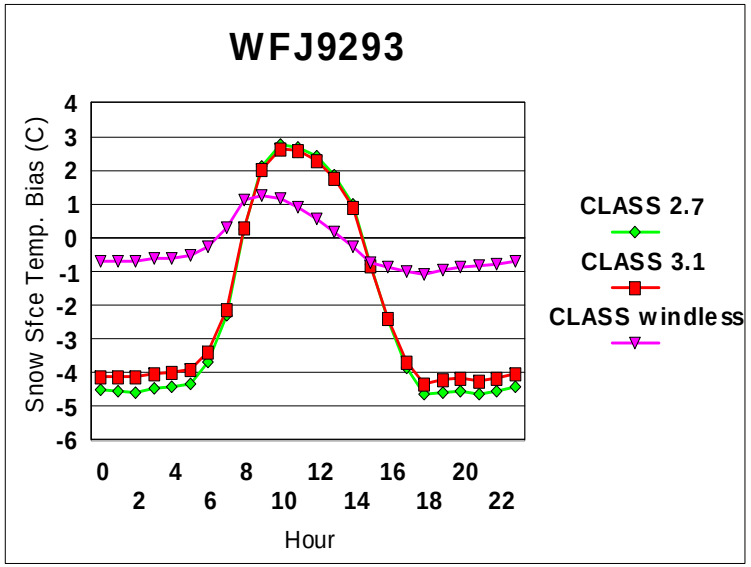
Cold bias observed in snow surface temperatures under stable conditions



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 ~0.15 at this site)

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

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



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.