CLASS – History and Current Developments

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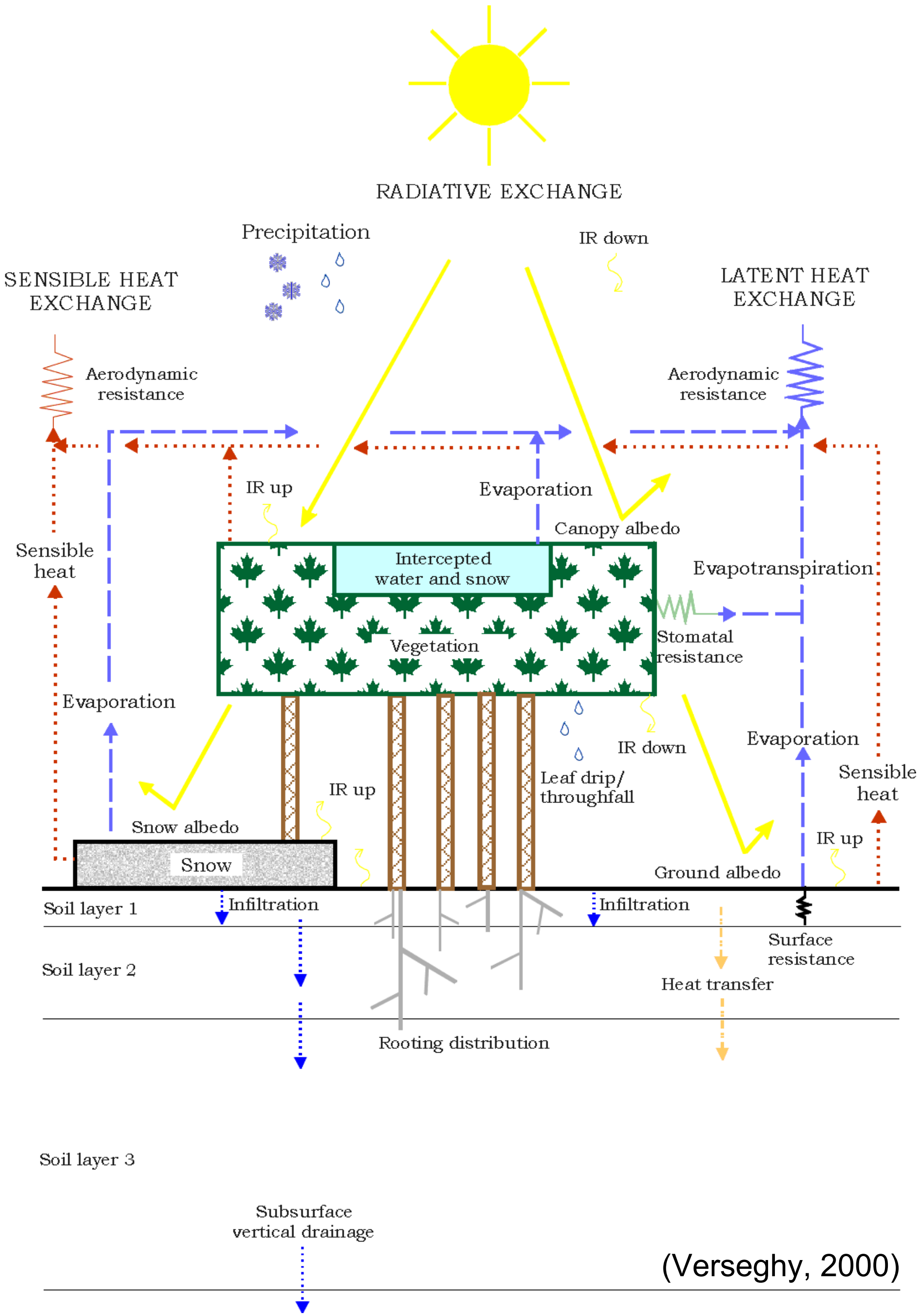


(Verseghy, 2000)

The Canadian Land Surface Scheme (CLASS)

Originally developed for the CGCM; treats fluxes of energy and water at the land surface

Thermally separate vegetation canopy, snow cover and three soil layers.

Four main vegetation structural types identified (needleleaf trees, broadleaf trees, crops and grass); parameters are aggregated at each time step to define representative canopy characteristics.

Up to four subareas allowed over each model grid cell: vegetation covered, bare soil, snow with vegetation and snow over bare soil.

One soil type for each grid cell.

History of CLASS

Version / Release date		*Major features and enhancements*
1.0	April ’89	Basic thermal and hydrological model of soil and snow.
2.0	August ’91	Addition of vegetation thermal and hydrological model.
2.1	May ’93	Full vectorization of code to enable efficient running on vector computers.
2.2	April ’94	Augmentation of diagnostic calculations; incorporation of in-line comments throughout. Development of a parallel stand-alone version of the model for use in CRN land surface node.
2.3	December ’94	Revisions to diagnostic calculations; new near-surface atmospheric stability functions.
2.4	August ’95	Complete set of water budget diagnostic calculations; parameterizations of organic soils and rock soils; allowance for inhomogeneity between soil layers; incorporation of variable surface detention capacity.
2.5	January ’96	Completion of energy budget diagnostic calculations.
2.6	August ’97	Revisions to surface stability function calculations.
2.7	December ’97	Incorporation of variable soil permeable depth; calculation of soil thermal and hydraulic properties based on textural composition; modified surface temperature iteration scheme.

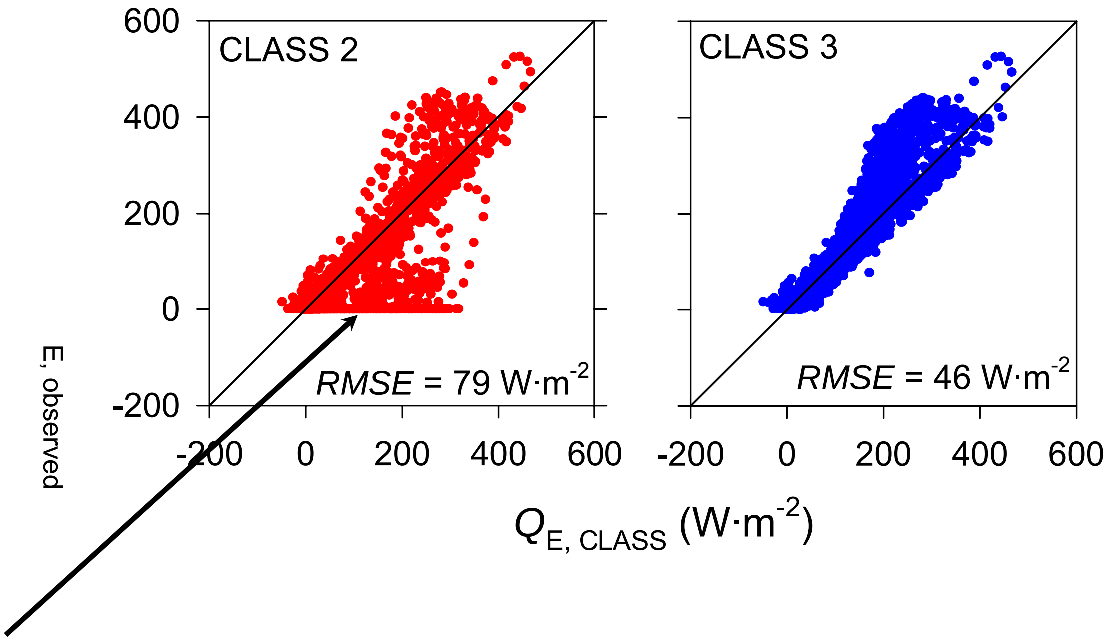
CLASS version 3.0
(Completed in December, 2002)

Major enhancements:

1) From the Canadian Climate Research Network (1993-99) (*Atmosphere-Ocean* special issue, March 2000)

- New soil evaporation parameters (UBC, Queen's)
- Ability to handle thermal and hydraulic properties of organic soils (McGill)
- Reworked canopy conductance formulation (UBC,Queen's)
- Algorithms derived from WATFLOOD to calculate lateral flow of water in soils (U. of Waterloo)

Evaporation from bare soil at Agassiz, British Columbia



- In CLASS 2 modelled evaporation from the soil surface suffers from periods of underestimation (including zero values), caused by an underestimation of moisture at the ground surface.
- In CLASS 3, the underestimation in modelled evaporation has been eliminated.

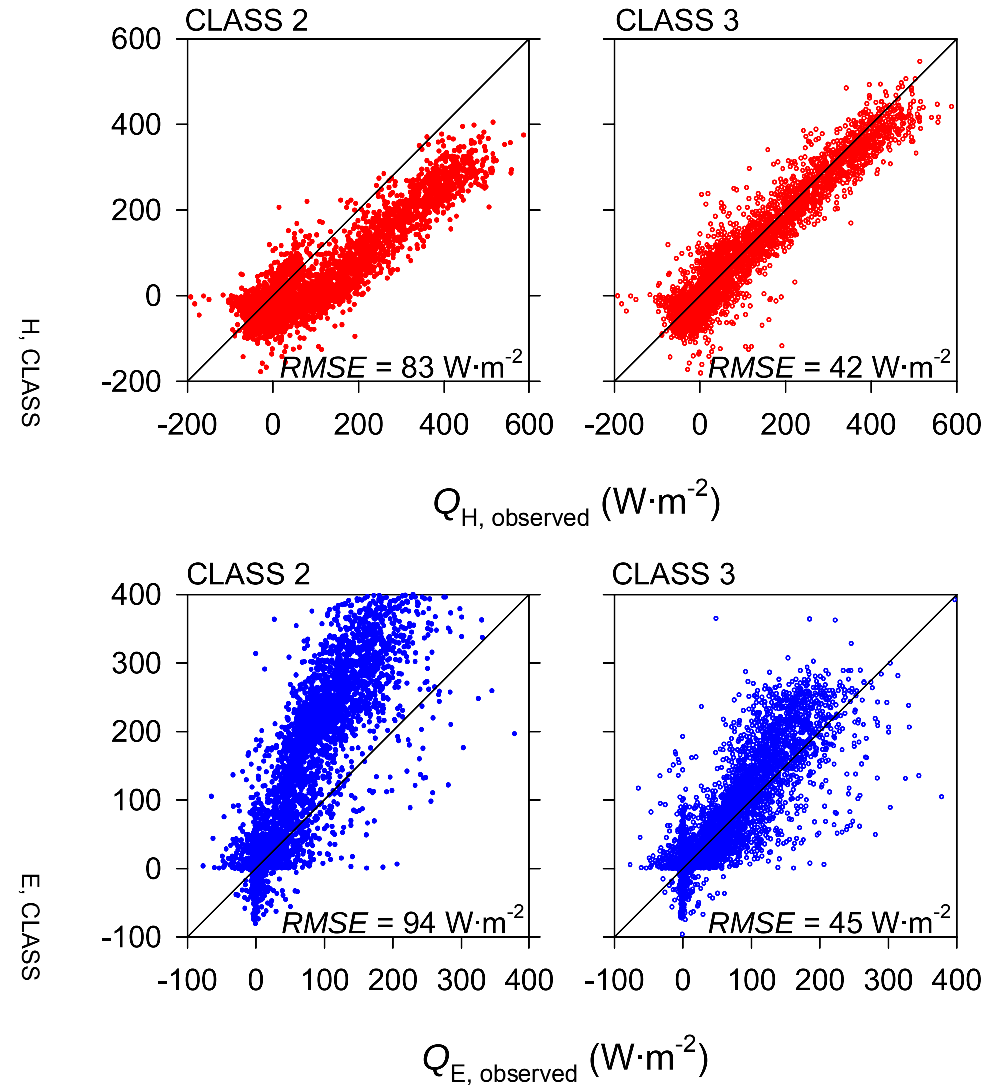
Performance of canopy conductance code for CLASS 2 and 3 at a boreal old black spruce stand in Manitoba

- In CLASS 2, canopy conductance was modelled using the same hard coded algorithm for all vegetation.

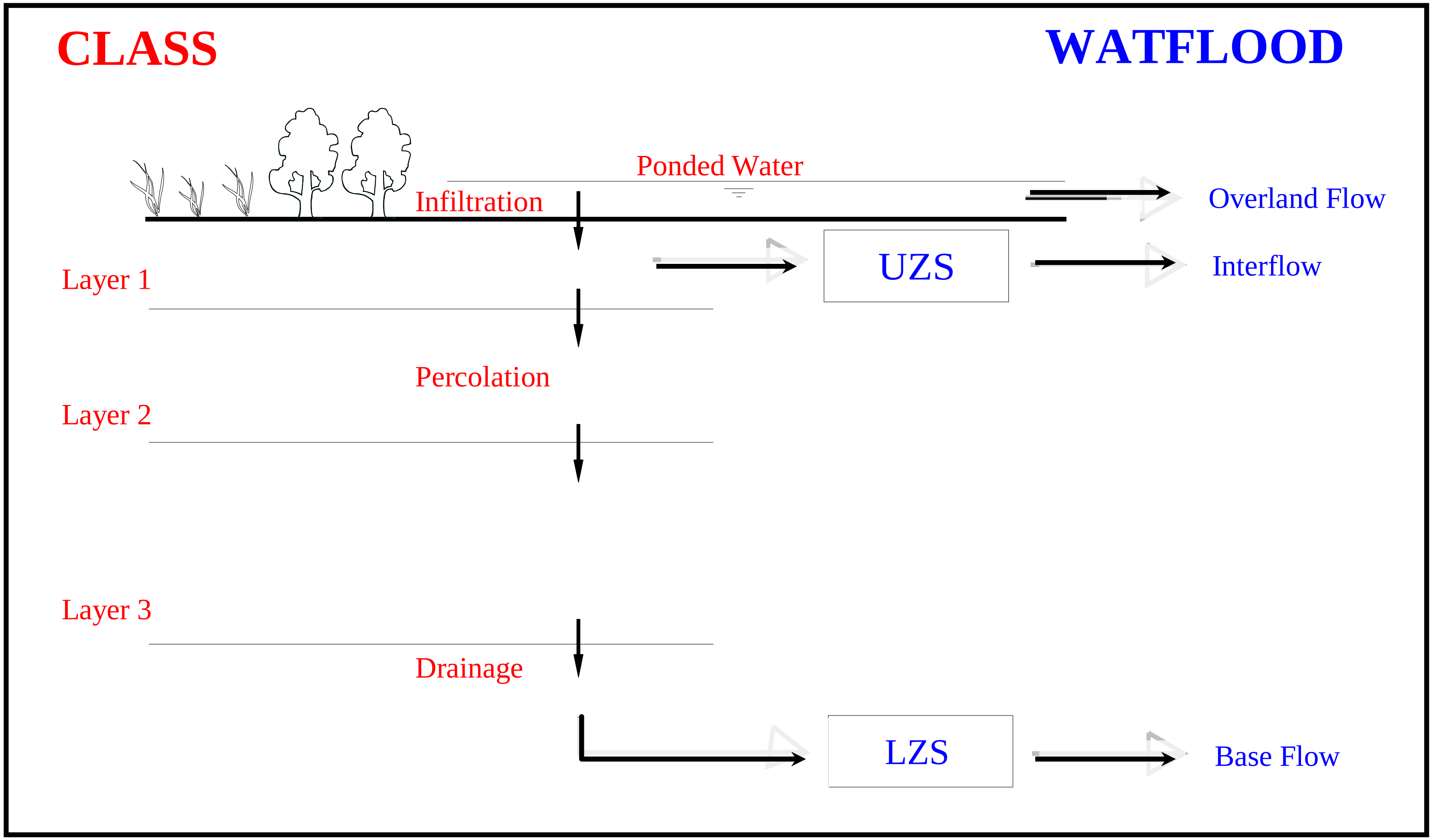
- Modelled canopy conductance was too large in the boreal forest.

- CLASS 2 overestimated the evaporation rate from boreal forests, and underestimated the sensible heat flux (left).

- In CLASS 3, the updated canopy conductance algorithm can represent a variety of vegetation types, and produces more realistic fluxes of heat and water (right).



WATCLASS Model



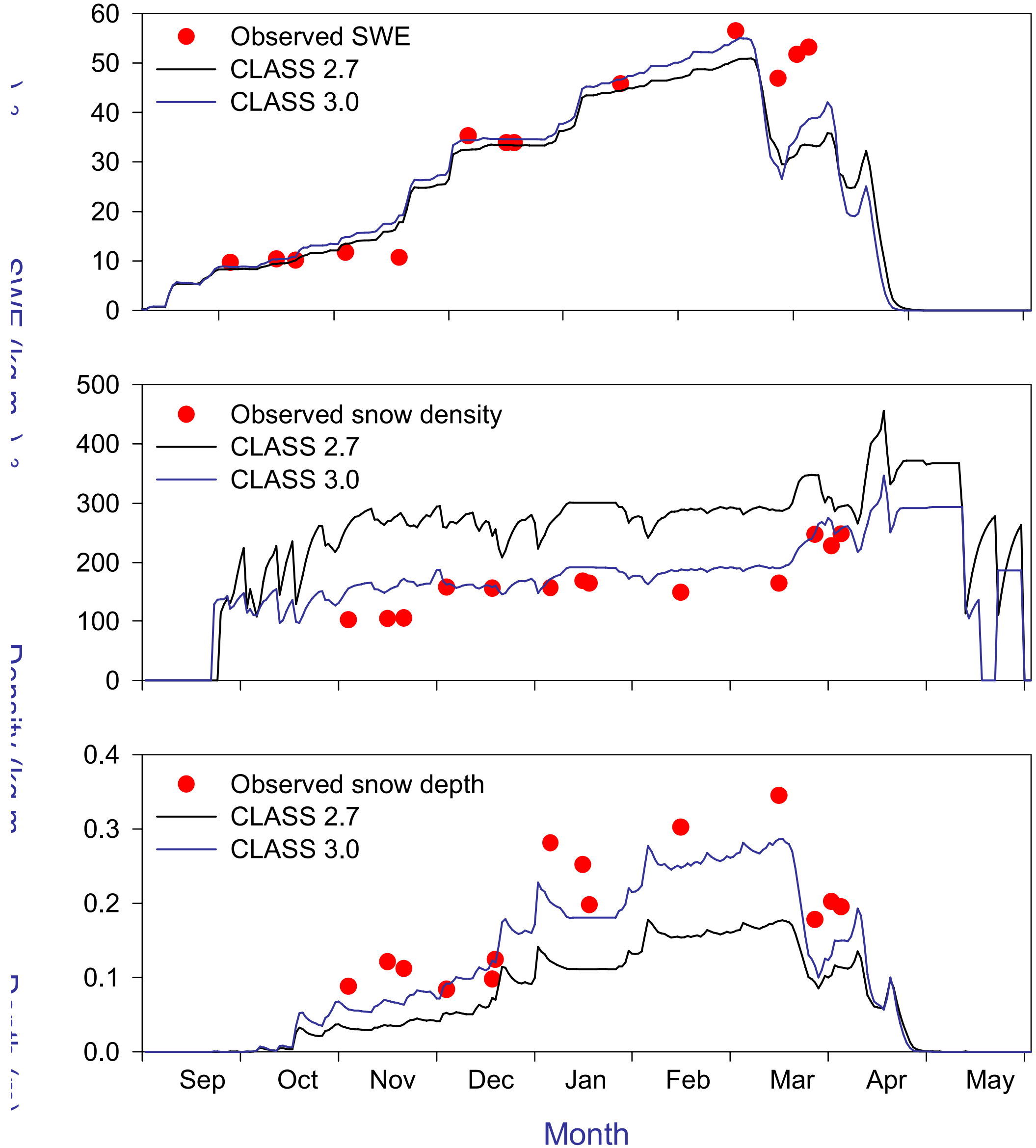
CLASS version 3.0

Major enhancements (continued):

2) Additional features

- Improved snowfall, snow density and snow interception algorithms (Bartlett, Brown, Fassnacht)
- Improved treatment of turbulent transfer from vegetation canopies (Verseghy, Delage)
- Convergence with developments at RPN (Delage) and CCCma (Lazare)

SWE, density and depth observed at BERMS – OJP for winter 2002-2003 and modelled using CLASS versions 2.7 and 3.0

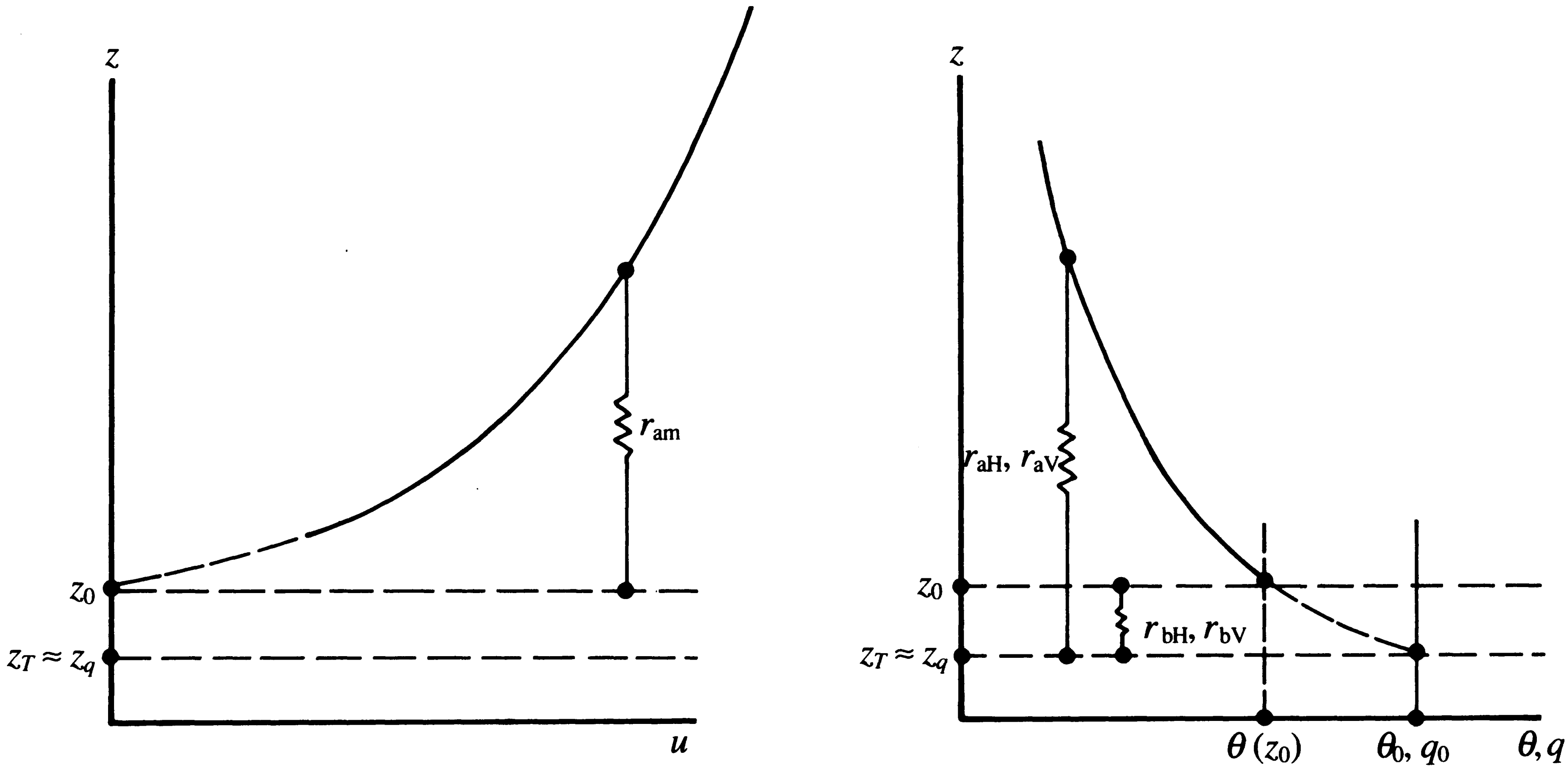


SWE is modelled well using both CLASS 2.7 and CLASS 3.0.

Snow density is overestimated by CLASS 2.7, whereas CLASS 3.0 incorporates improved algorithms, and performance is improved.

As a result of its overestimation of snow density, CLASS 2.7 under-estimates snow depth, while CLASS 3.0 performs better.

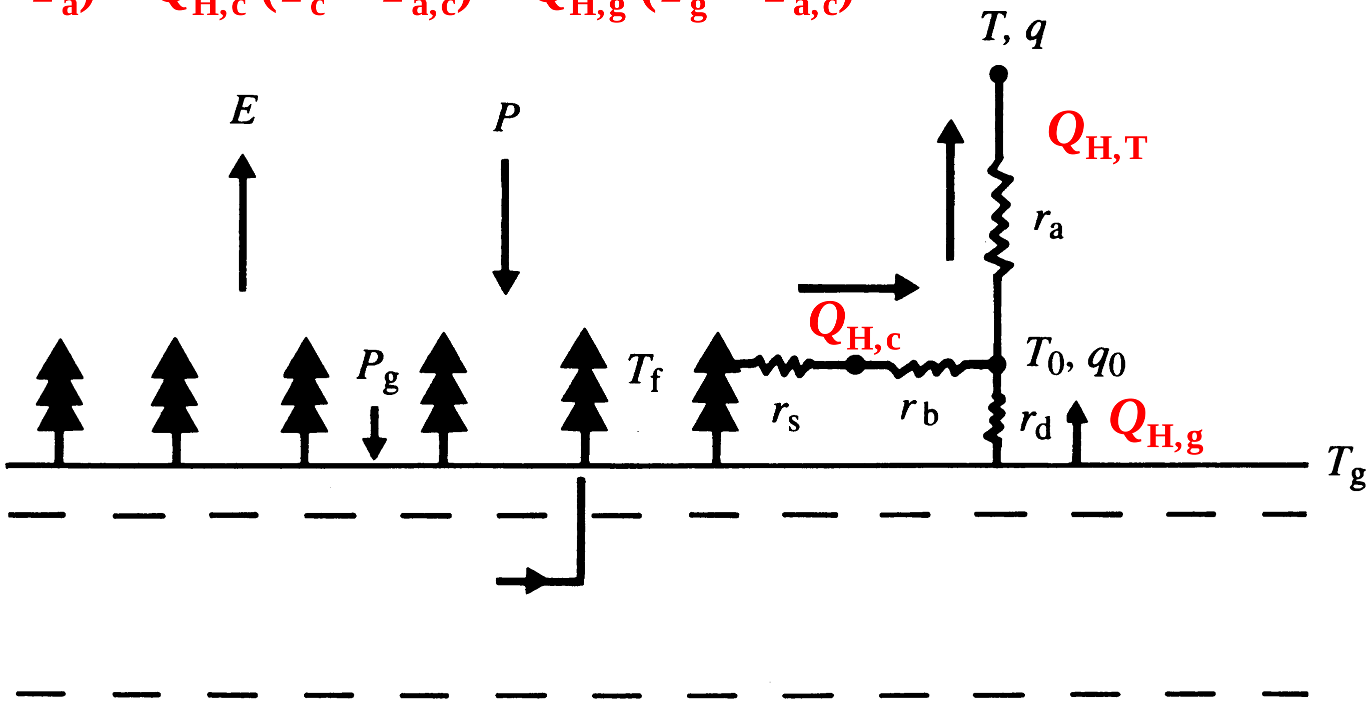
Testing continues at BERMS sites and in the Mackenzie Basin.



Schematic representation of aerodynamic resistances to the transfer of momentum and to the transfer of scalar properties, showing the excess resistance r_b due to molecular effects and the relation between the surface temperature θ_0 and the temperature $\theta(z_0)$.

(From J.R. Garratt, "The Atmospheric Boundary Layer")

$$Q_{H,T}\,(T_{a,c} - T_a) = Q_{H,c}\,(T_c - T_{a,c}) + Q_{H,g}\,(T_g - T_{a,c})$$



Schematic representation of the main elements of a non-isothermal or two-component canopy model. Linked to the atmosphere (via resistances r_s, r_b and r_a), to the soil or undergrowth (via resistance r_d) and the deep soil (via evapotranspiration), the canopy and upper soil layer are at temperatures T_f and T_g. P_g is the precipitation reaching the soil surface.

(From J.R. Garratt, "The Atmospheric Boundary Layer")

CLASS version 3.0

Major enhancements (continued):

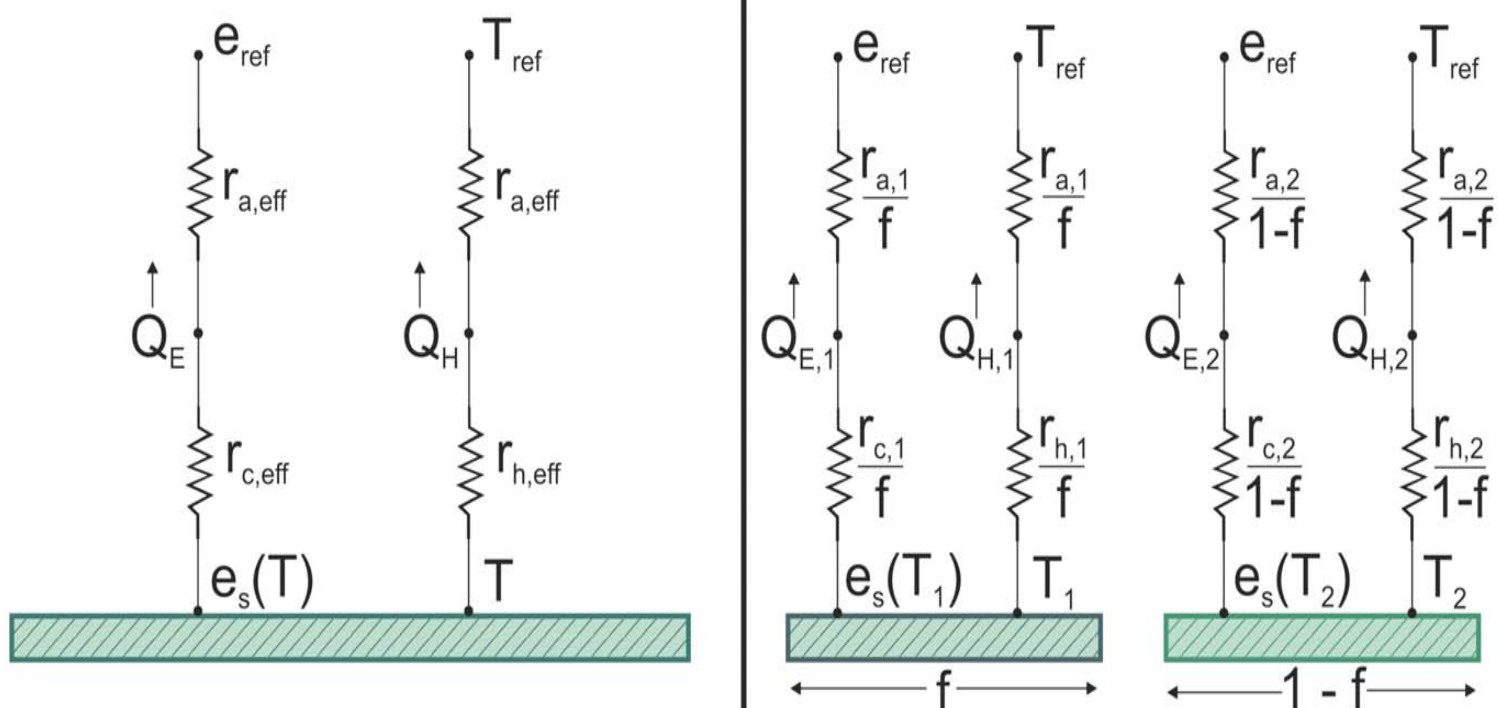
3) Revised model structure

Optional “mosaic” formulation of land surface, allowing separate treatment of:

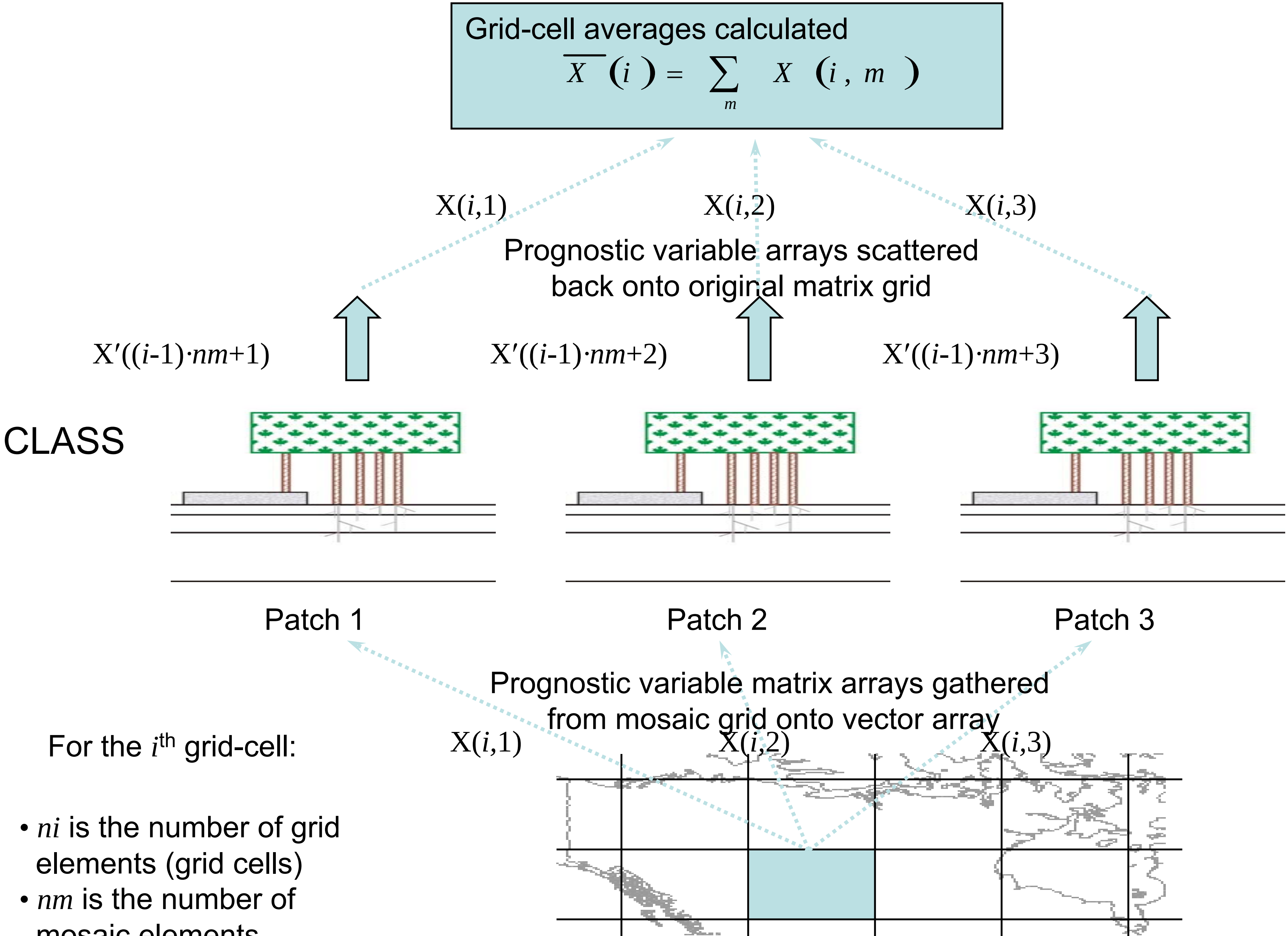
- Vegetation type (forest, agriculture, grassland, tundra etc.)
- Soil type (mineral, organic, rock)
- Ice sheet
- Lakes

Aggregated: one patch containing dominant or aggregated surface parameters

Mosaic: multiple patches, each containing individual surface parameters



e	vapour pressure
$e_s(T)$	saturation vapour pressure at T
f	fraction of grid-cell occupied by patch 1
Q_E	latent heat flux
Q_H	sensible heat flux
r_a	aerodynamic resistance
r_c	canopy resistance to latent heat
r_h	resistance to sensible heat transfer
T	temperature
eff	denotes an effective value
ref	denotes a reference height
1, 2	refers to patch 1 or patch 2



For the i^{th} grid-cell:

- ni is the number of grid elements (grid cells)
- nm is the number of mosaic elements (patches in each grid-cell)

CLASS VERSION 3.1
(Completed in April, 2005)

Change to operational use of F90:

- Modified data declaration routines
- Add “IMPLICIT NONE” throughout

From collaboration with RPN:

- Revise code to protect against roundoff error in 32-bit runs
- Faster iteration scheme for soil and vegetation surface temperatures

From P. Bartlett:

- Refinement of leaf boundary layer resistance algorithm
- Corrections to treatment of snow interception
- Modification to snow sublimation from canopy

From CCCma scientists (Arora, Lazare):

- Adjusted determination of leaf-out date
- Corrected mass balance diagnostics for ice sheets

From WATCLASS users:

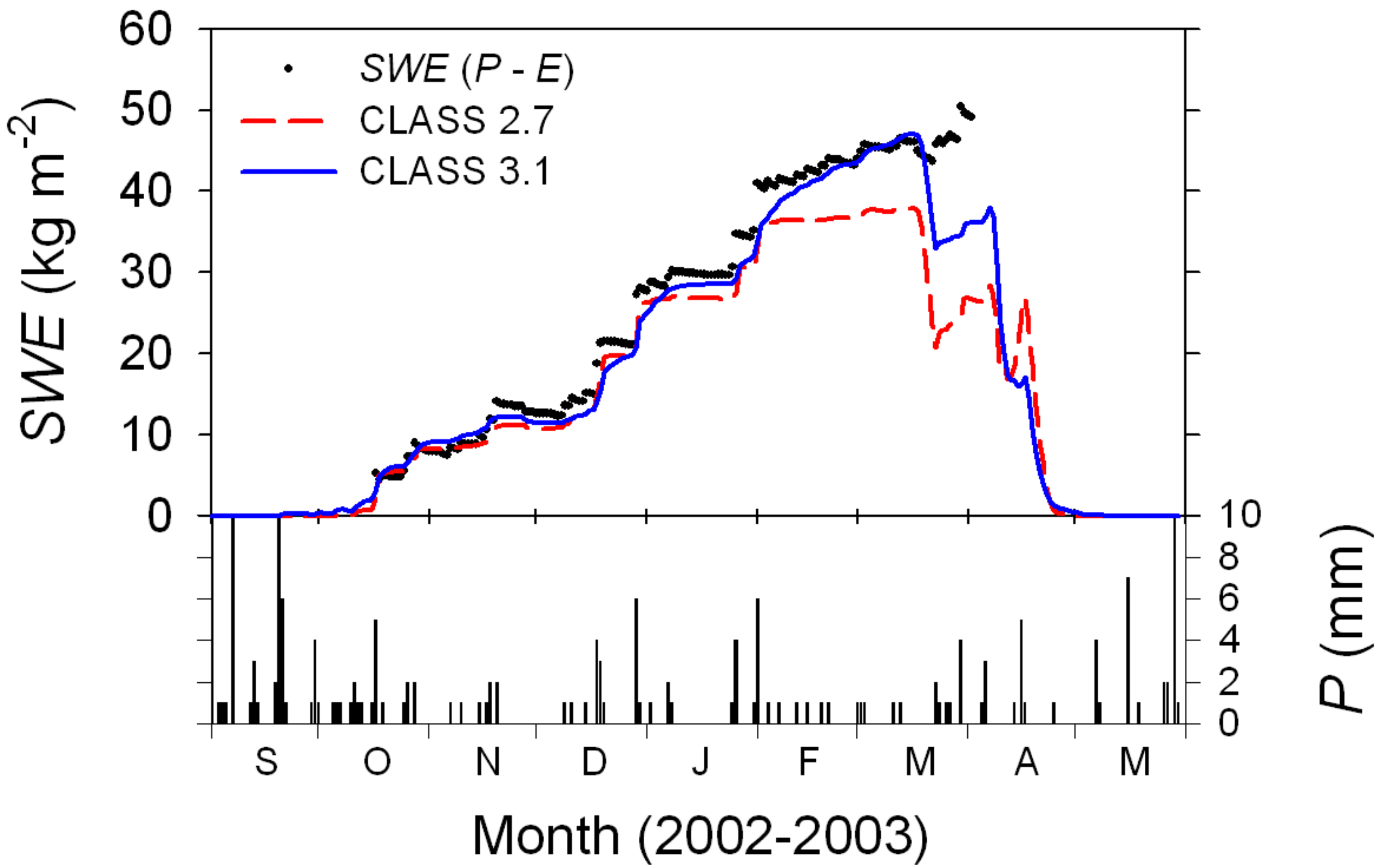
- Updated lateral flow algorithms

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

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.

CLASS VERSION 3.2
(Scheduled completion in early 2006)

- Optional finer vertical subdivision of third soil layer
- Freezing depth / active layer calculation
- Diagnostic calculation of surface soil moisture
- Modelled water content of snow pack
- Revised radiation transmission code for canopy
- Incorporation of surface slope into net radiation calculation

Other ongoing CLASS-related activities:

- Lake modelling (Mackay)
- C-CLASS (CLASS + carbon cycle components) (Arain, Grant)

Modelling Environmental Community System
Système de Modélisation Environnementale Communautaire
Système MEC System

Meteorological Service of Canada

Ocean-Ice
(Models and Assimilation)
DFO/MPO (IML) — RPN/ARMA
UQAR/ISMER — CMC
CMEP/Dalhousie — CIS

Land-Hydrology
(Models and Assimilation)
NWRI — RPN/CRB
Waterloo U. — CMC/WSC
Hydro-Québec — HAL Lab.

Coupler
CERFACS — RPN
Atlan. Lab.

Waves and Storms Surge
(Models)
Dalhousie U. — RPN
CMC
Atlan. Lab.

Atmospheric
(Models and Assimilation)
RPN/ARMA/CMC

MEC System
(Developements)
RPN/CMC/Collaborators

Environmental Forecasts
(CMC Operations)

Hydrological Forecasts
Hal Lab.
WSC

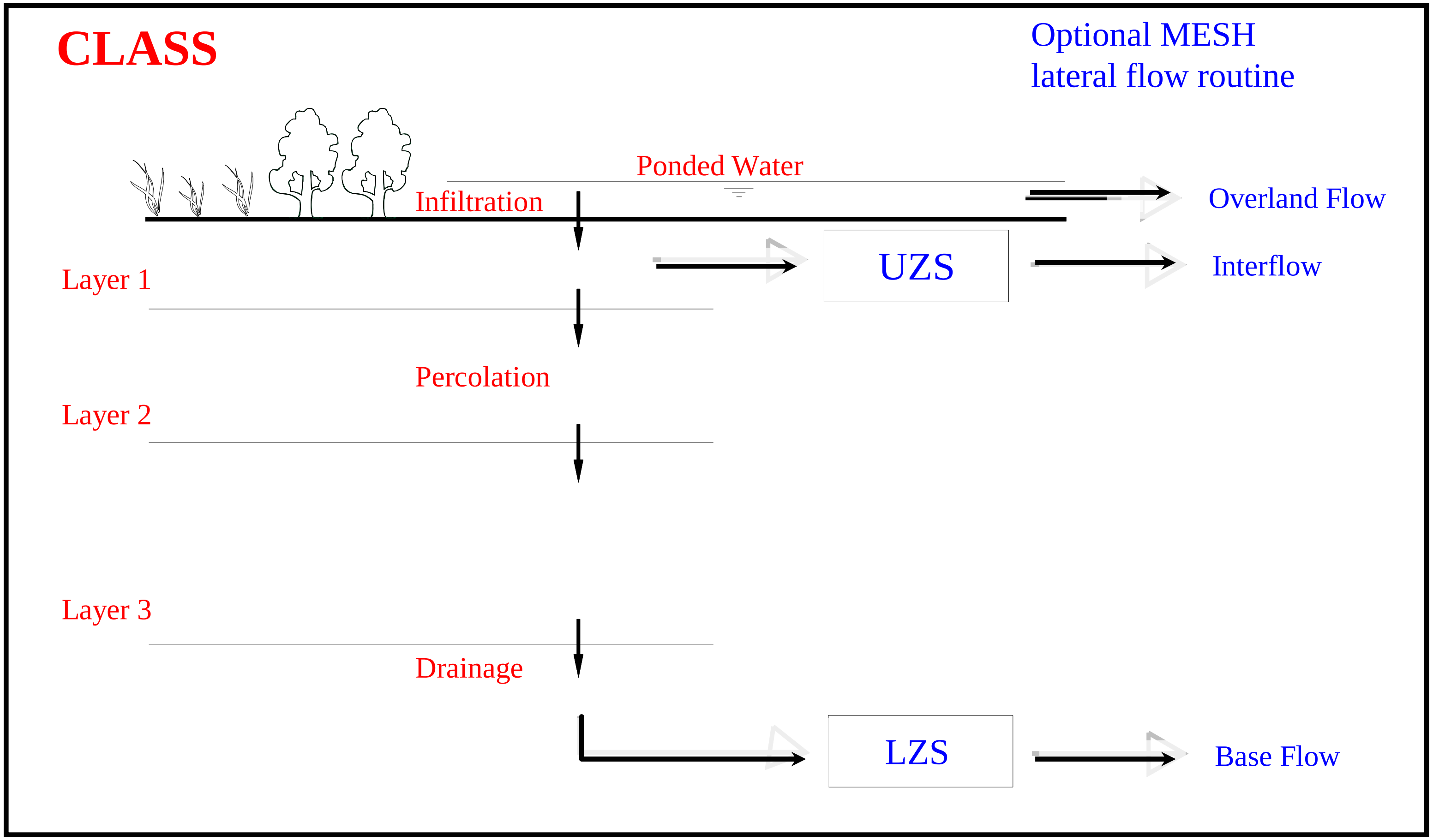
Environmental Emergencies
(Forecasts)

Ocean, Ice and Water Levels Forecasts
DFO/MPO
CCG
CHS

Hydrological Forecasts
Provincial Agencies
Hydro-Québec

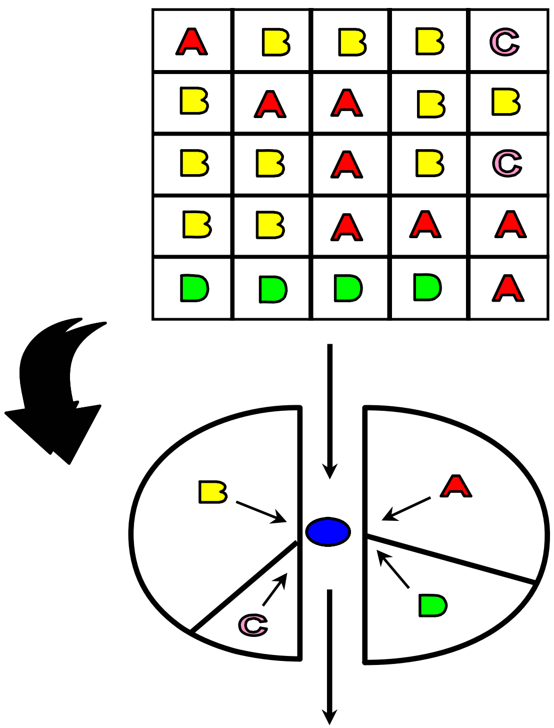
Environment Canada — Environnement Canada
Fisheries and Oceans Canada — Pêches et Océans Canada
University of Waterloo
Hydro Québec
Dalhousie University — Inspiring Minds
ISMER
Université du Québec à Rimouski
CERFACS

CLASS in MESH
"MEC Surface Hydrology" Scheme

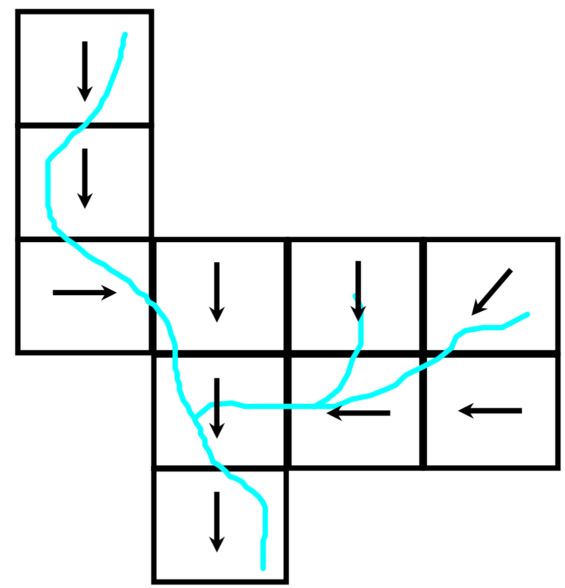


Horizontal flow in MESH

Tile connector
(WATFLOW)

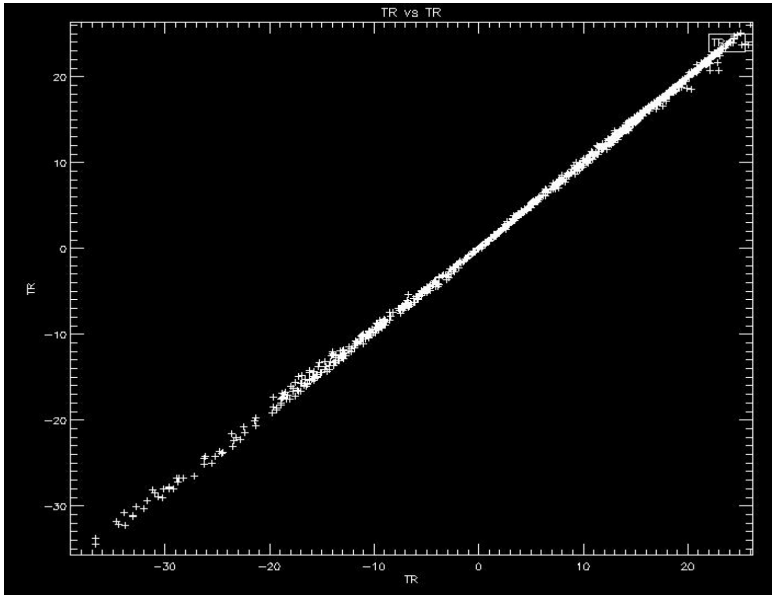


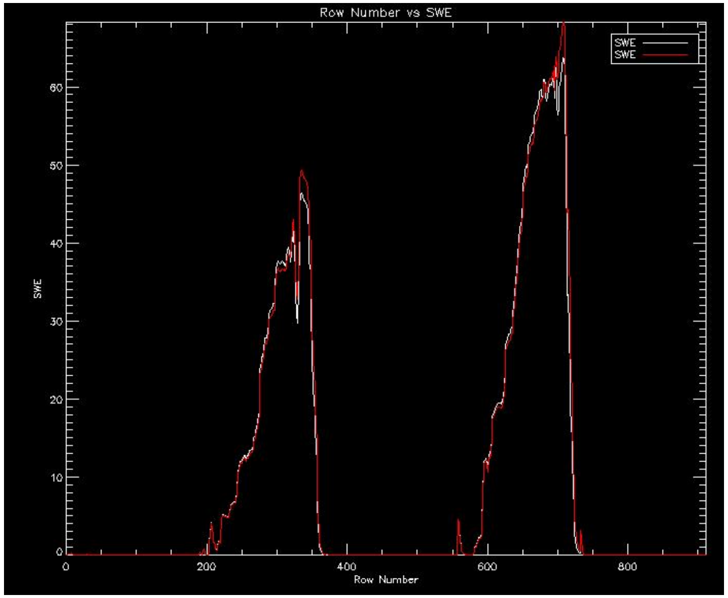
Grid connector
(WATROUTE)

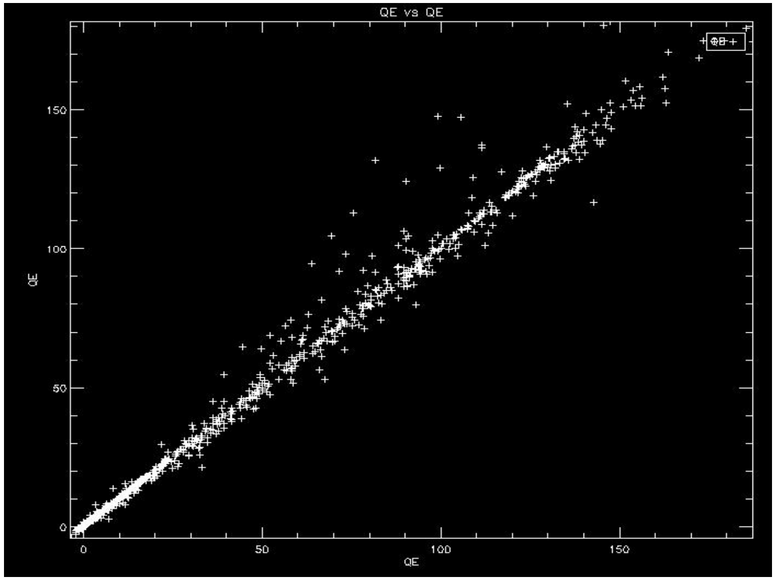


Multiple-layer tests of CLASS

- Pairs of parallel off-line simulations
  - 3-layer version [original quadratic T(z)]:
    Δz values of 0.10, 0.25, 3.75 m
  - 9-layer version [linear T(z)]: Δz values of 0.10, 0.25, 0.25, 0.25, 0.25, 0.50, 0.50, 1.0, 1.0 m
- Forcing extracted from selected grid cells in a CRCM run over western Canada: April 1997- August 2000

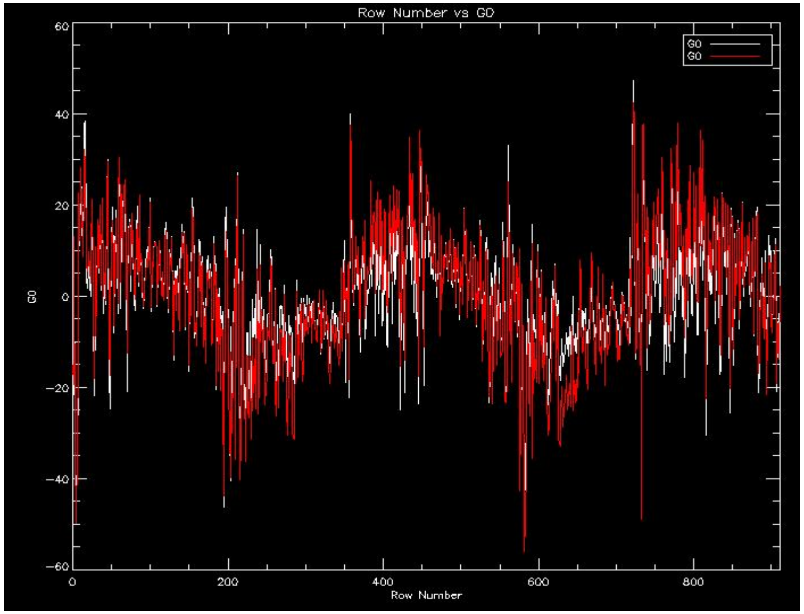


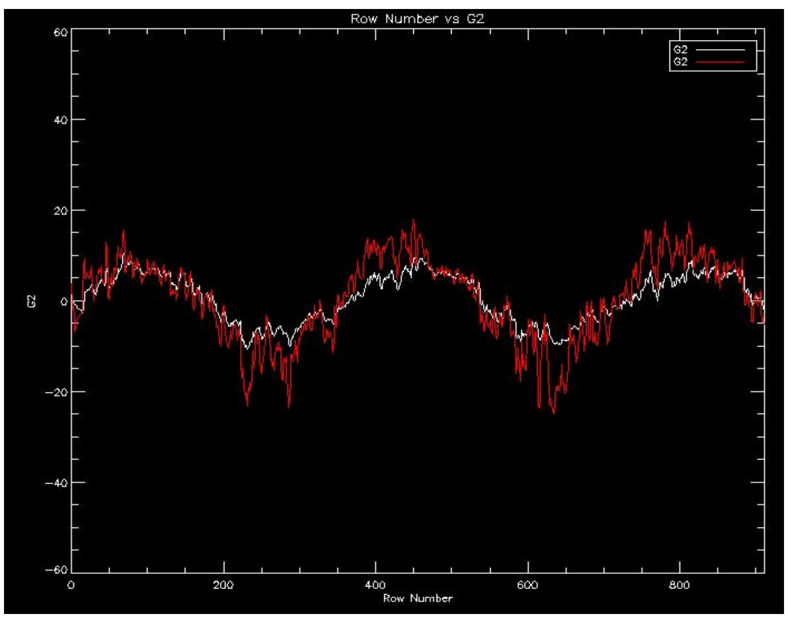




Sample grid cell, located over Regina:

- Plots of surface skin T, SWE, QE
- 9 levels (y axis, red) vs. 3 levels (x axis, white).
- Surface fluxes are relatively insensitive to subsurface resolution of soil layers.

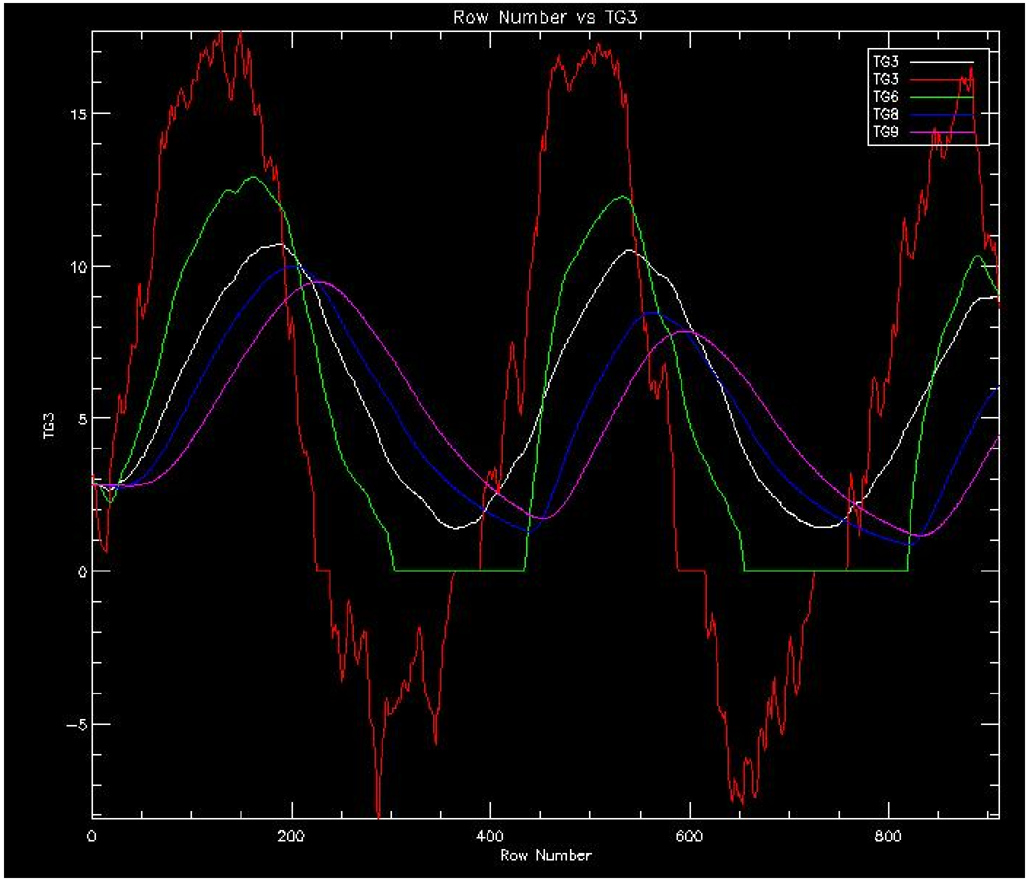




Heat flux into the soil surface (top frame) shows no systematic differences for three soil layers (white line) vs. nine (red line).

However, heat flux at greater depth, e,g, into the third soil layer, is consistently damped in the three layer run, owing to the large thermal inertia of the third soil layer.

Although there is little effect on the surface fluxes and near-surface soil temperatures, deeper soil temperatures will reflect this bias.



White line: T of soil layer 3 in three-layer run.

Red, green, blue and violet lines: T of soil layers 3, 6, 8 and 9 in nine-layer run.

Average temperature of layer 3 in three-layer run does not fall below zero. The depth of the zero isotherm could in principle be obtained from the quadratic temperature profile, but this neglects the heat sink of the phase change of water in the upper part of the layer.

Thus, for an accurate determination of the freezing depth or active layer depth in soil, multiple subdivisions of the third soil layer are necessary.

Another point to consider is how deep it is necessary to extend the soil column. CLASS currently places the bottom at 4.1 m, at which depth the heat fluxes drop to a few W m^{-2}, and are therefore treated as negligible. However, if it is desired to model the change in depth of permafrost, it may be necessary to extend the profile much deeper. From the analytical solution of a sinusoidal forcing applied at the soil surface, it can be shown that the amplitude of the temperature variation at a depth *z* is smaller than the amplitude at the surface by a factor exp[-z/D], where D, the damping depth, is given by

$$D=[2k/C\omega]^{1/2}$$

For an average mineral soil, the damping depth can range from 6 to 10 m. Thus if the annual temperature amplitude at the surface is, say, 50 K, and it is desired to reach a depth where the annual amplitude is 1 K, it will be necessary to extend the temperature profile to roughly 30 m depth.

Results of multiple-layer tests:

- The standard 3-layer version of CLASS is adequate for normal climate runs, where the surface fluxes are chiefly of interest.
- For hydrological and other studies where the subsurface heat and water budgets are important, a finer subdivision of the third soil layer seems indicated.
- It may be necessary to extend the bottom boundary of the soil profile for studies involving small heat fluxes at large depths over long periods.