Explicit Diffusion and Cold Season Processes

1) Explicit diffusion Option CISBA=DIF

A) Thermal Transfer and the surface Energy Budget (NP89 or PL98 thermal conductivity, DEF or MLCH surface heat capacity)

B) Hydrological Transfer (DEF or option KXP: expo. Ksat, WDRAIN 2D variable input)

2) Cold Season Processes CSNOW

A) Soil Phase changes

- i) Phase changes based on water content (DEF)
- ii) Phase changes based on water content and temperature (LWT)

B) Snowpack

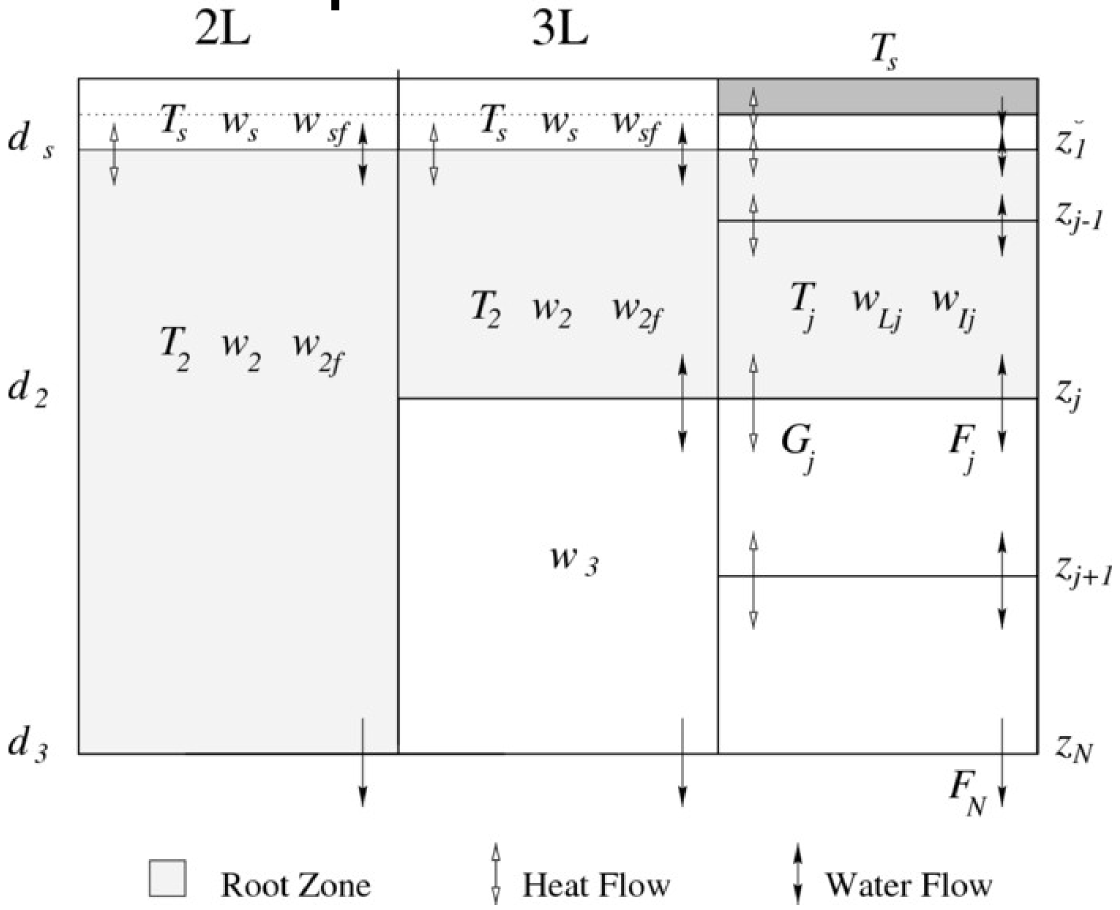
- i) Single-layer bulk snow (EBA)
- ii) Composite snow (DEF)
- iii) Explicit Snow (3-L)
  - DEF or RIL Rich. Number limit

Options

In red

Explicit Diffusion and Cold Season Processes

Explicit soil DIFfusion Option: Downgradient thermal transfer and Richard's Eq.



Comparison: 2 force restore soil options verses DIFusion grid

Explicit Diffusion and Cold Season Processes

Explicit soil DIFfusion Option: Downgradient thermal transfer and Richard's Eq.

3 Prognostic equations: N-layers for temperature, liquid water and soil ice:

$$c_h \frac{\partial T_g}{\partial t} = \frac{\partial G}{\partial z} + \Phi_g$$

$$\frac{\partial w_l}{\partial t} = -\frac{\partial F}{\partial z} - \frac{\Phi_g}{L_f \rho_w} - \frac{S_l}{\rho_w} \qquad (w_{min} \leq w_l \leq w_{sat} - w_i)$$

$$\frac{\partial w_i}{\partial t} = \frac{\Phi_g}{L_f \rho_w} - \frac{S_i}{\rho_w} \qquad (0 \leq w_i \leq w_{sat} - w_{min})$$

$w = w_l + w_i$ Total soil water

Explicit Diffusion and Cold Season Processes

Vertical heat transfer:

- Simple down-gradient thermal transfer
- heat capacity and thermal conductivity based on texture, soil moisture (and possibly mulch in uppermost layer)

$$G = \lambda \frac{\partial T}{\partial z}$$

Flux

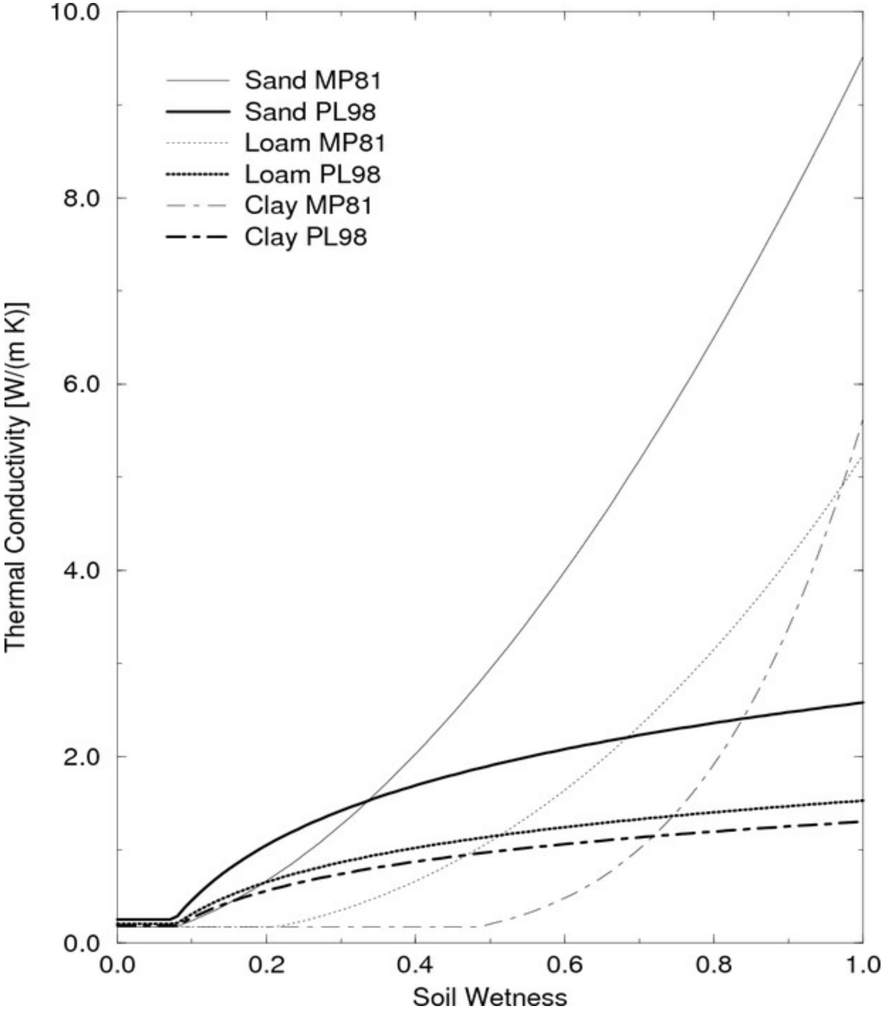
$$c_{g\,j} = (1 - w_{sat}) C_{soil} \rho_{soil} + w_{l\,j} c_w + w_{i\,j} c_i$$

Heat capacity

Explicit Diffusion and Cold Season Processes

Soil Thermal conductivity: CSCOND
NP89: based on McCumber and Pielke (used implicitly in FR option)
- no explicit accounting for soil ice

PL98: Peters-Lidard: shown to be more accurate for dry and wet soils, and includes soil ice.
- lower thermal wave penetration for wetter soils



Explicit Diffusion and Cold Season Processes

The prognostic temperature equation for each layer also includes a phase change term (described later):

$$\Delta z_j c_{h\,j} \frac{\partial T_{g,j}}{\partial t} = G_{j-1} - G_j + \Delta z_j \Phi_{g\,j}$$

The Heat capacity is:

$$c_{h\,j} = \begin{cases} c_{g\,j} & (j = 2, N) \\ 1/\left(C_T\,\Delta z_1\right) & (j = 1) \end{cases}$$

So for the uppermost thin layer (surface energy budget):

$$\frac{1}{C_T}\frac{\partial T_s}{\partial t} = \underline{R_n - H - LE} - G_1 + \Delta z_1 \Phi_{g\,1}$$

Upper BC

C_T takes into account soil and vegetation

Explicit Diffusion and Cold Season Processes

The heat flux between the surface layer and the underlying soil is simply:

$$G_1 = 2\,\overline{\lambda}_1 \frac{(T_s - T_{g,2})}{\Delta z_1 + \Delta z_2}$$

$$\overline{\lambda}_1 = \frac{\Delta z_1 + \Delta z_2}{(\Delta z_1/\lambda_s) + (\Delta z_2/\lambda_2)}$$

Interfacial (AVG) thermal conductivity

$$\lambda_s = [1 - veg\,(1 - f_v)]\,\lambda_1$$

The surface thermal conductivity is reduced when *veg* is large: assumed to result owing to a mulch/organic layer. Option CDIFSFCOND = MLCH

- Has an insulating effect (decoupling of sfc-deep layers)

Explicit Diffusion and Cold Season Processes

Vertical soil water transfer:

- Flux includes Darcy's Law, vapor diffusion (dry soils), and a linear drainage term (WDRAIN option). This is “mixed form” Richard's flux (using matric potential gradient)

$$F = -k \frac{\partial}{\partial z}(\psi + z) - \frac{D_{\nu\psi}}{\rho_w}\frac{\partial \psi}{\partial z} - K_d$$

$$F = -\eta \frac{\partial \psi}{\partial z} - \zeta$$

With no linear drainage and moist unfrozen soils, the above collapses into usual Darcy's law:

$$F = -k \frac{\partial}{\partial z}(\psi + z)$$

Explicit Diffusion and Cold Season Processes

The linear drainage Is usually OFF, but can be turned on by giving a non-zero value for *Wdrain*...can maintain a nearly constant flow (to rivers...) even for fairly dry conditions.

$$K_d = k_{sat}\left[(w_{fc} + w_{drain})\,/\,w_{sat}\right]^{2b+3} \times \left\{ \frac{\left[\min\left(w_{fc}, w_l\right) - w_{min}\right]}{\left(w_{fc} - w_{min}\right)} \right\}$$

$$F_N = -\zeta_N = -k_N - K_d$$

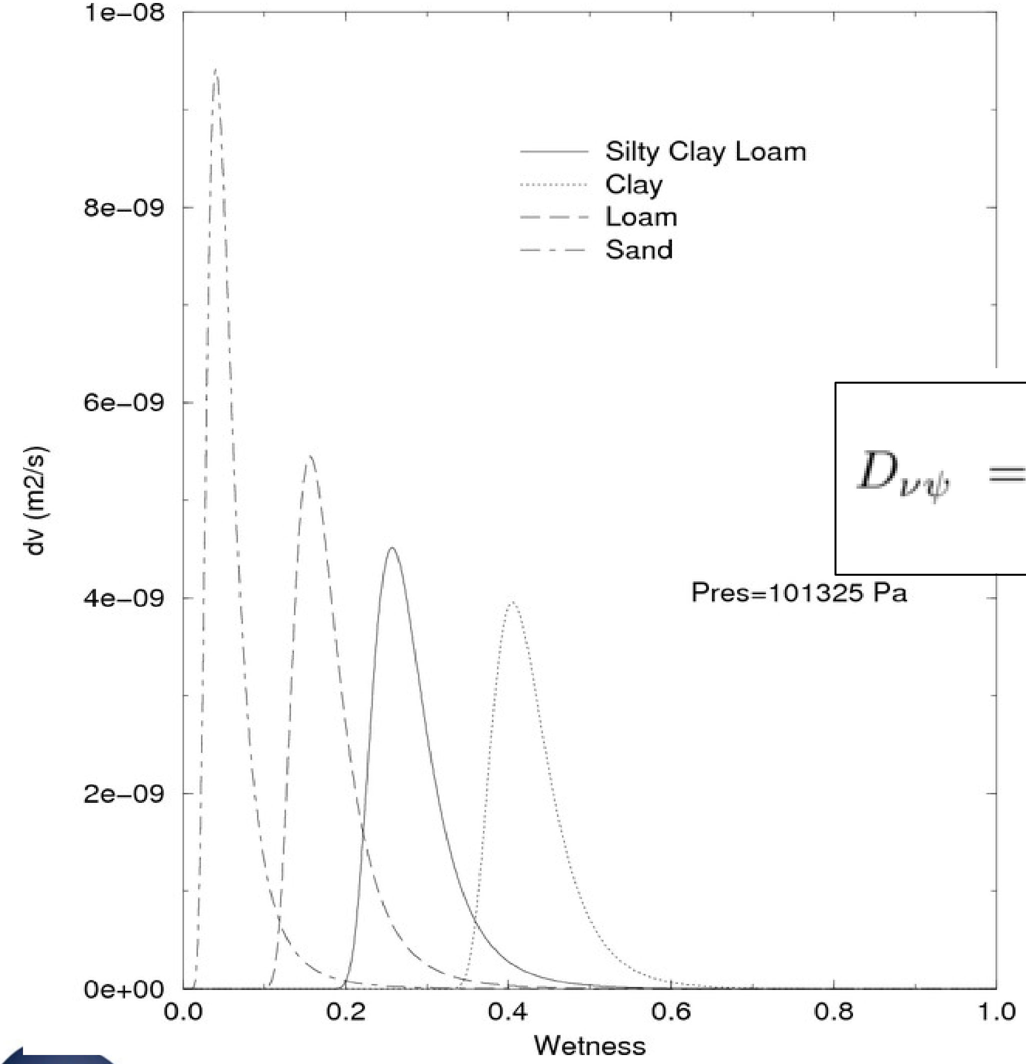
$$I = -F_0 = \min(R_t - Q_r, -F_{max\,0})$$

$$F_{max\,0} = k_{sat}$$

Water Flow Boundary Conditions:

Infiltration is the lesser of a maximum infitration rate and throughfall less sub-grid surface runoff...
Lower BC is free drainage.

Explicit Diffusion and Cold Season Processes



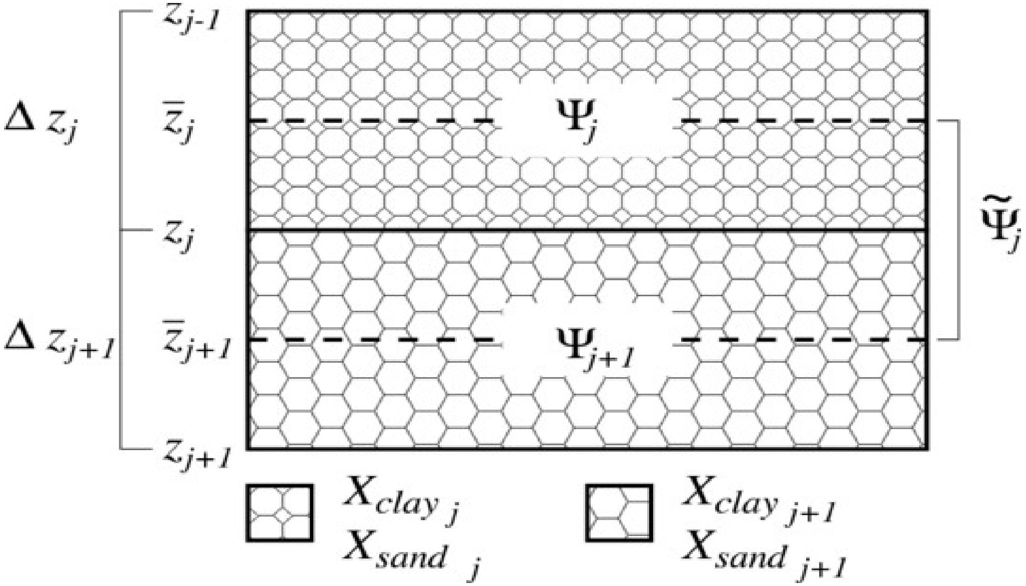
Explicit Vapor diffusion:
Only significant just above wilting point water content, with a maximum at roughly half this value.

$$D_{\nu\psi} = \frac{\alpha_\nu\, p}{(p - p_\nu)} \frac{D_{\nu a}\, f_{\nu a}\, \chi_{sat}\, g\, p_{\nu\, sat}\, h_\nu}{(R_\nu\, T)^2}$$

Function mainly of temperature and soil moisture

Explicit Diffusion and Cold Season Processes

Mixed-Form Richard's equation permits the use of heterogeneous soil texture profiles (since *psi* is continuous while water content is NOT under such conditions)



Vertical interpolation is based on the upper layer value in the presence of a wetting front, and relaxation to hydrostatic equilibrium otherwise

$$\partial\psi/\partial z = -1$$

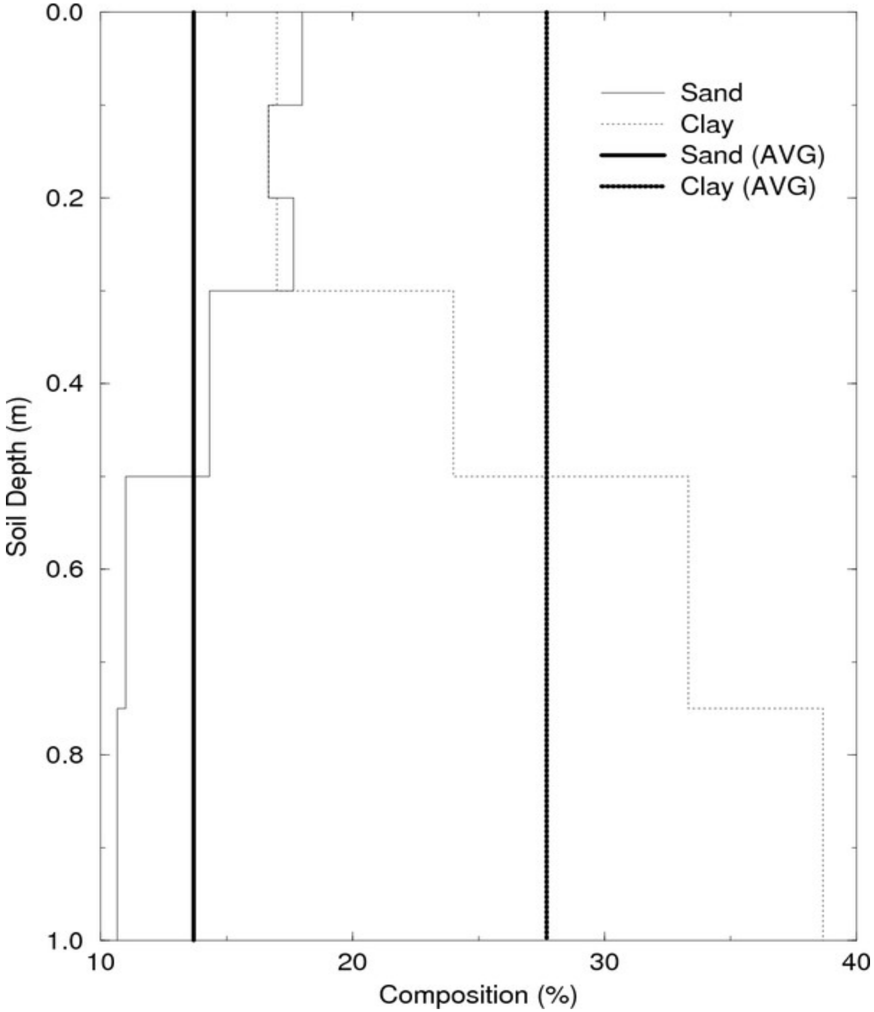
(Noilhan and Planton, Koster and Suarez...etc...)

Explicit Diffusion and Cold Season Processes

Example of heterogeneous Profile Application:

Soil texture profile at MUREX: (thick lines represent vertical averages)

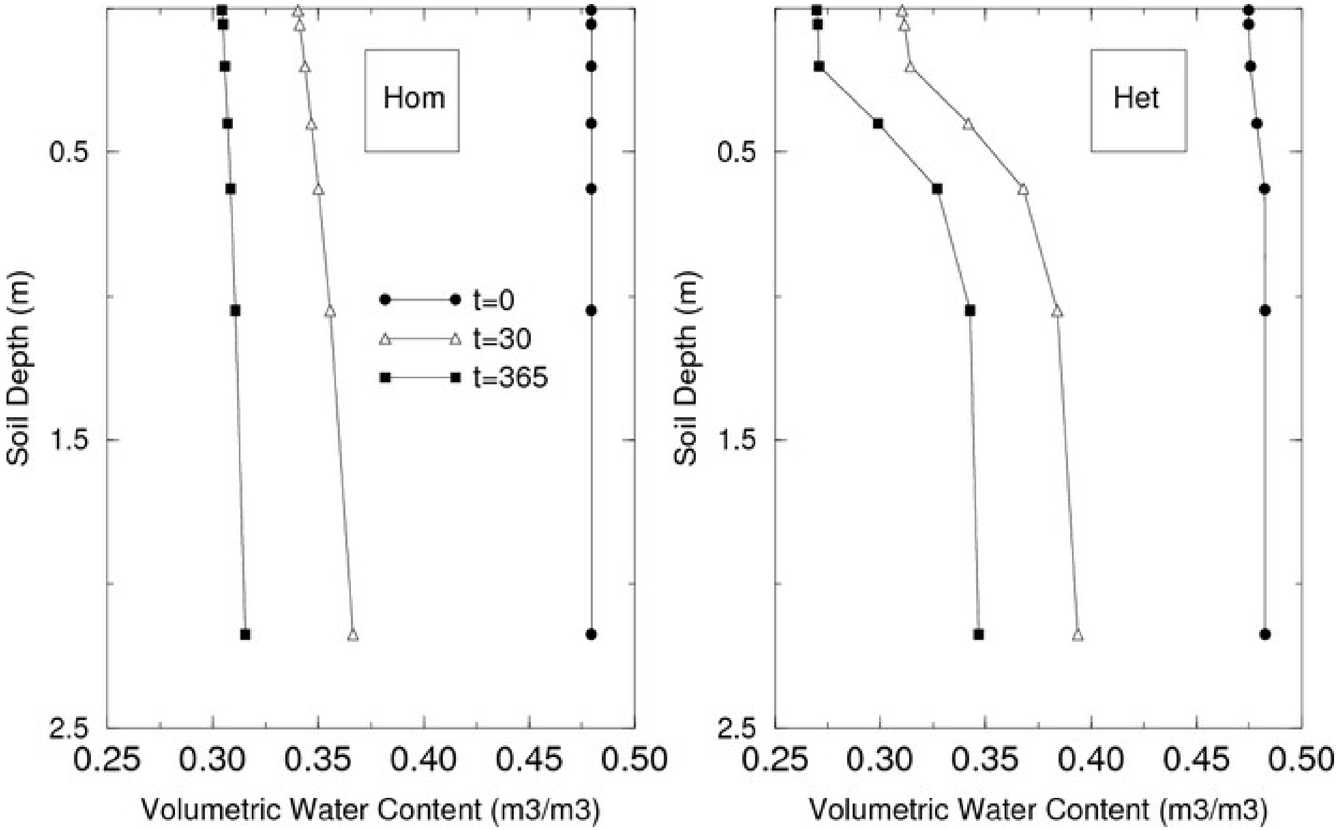
- Result is significant gradient of hydrological parameters...



Explicit Diffusion and Cold Season Processes

Using DIF with 7 layers (corresponding to each horizon plus thin upper layers for numerical reasons)

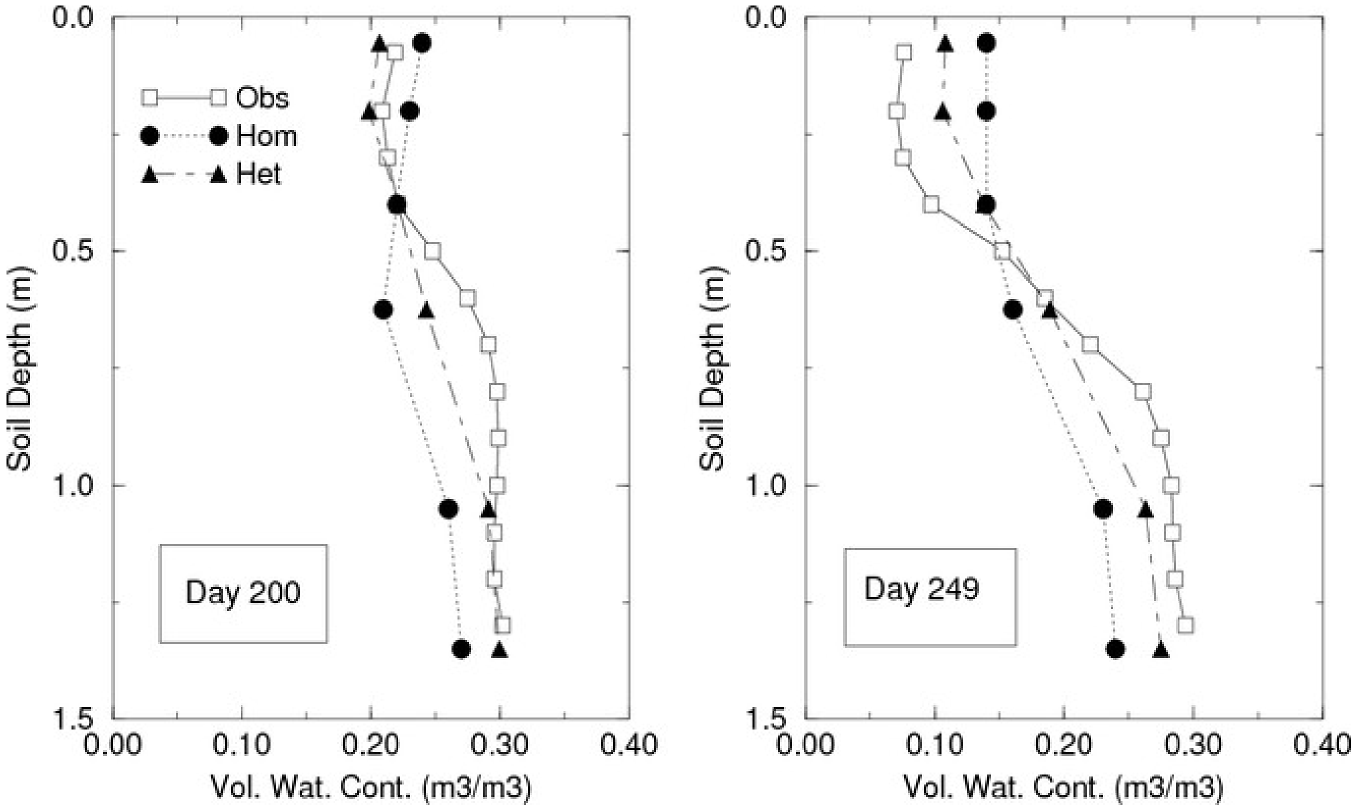
- Equilibrium soil water profiles using homogeneous and heterogeneous texture profiles



Explicit Diffusion and Cold Season Processes

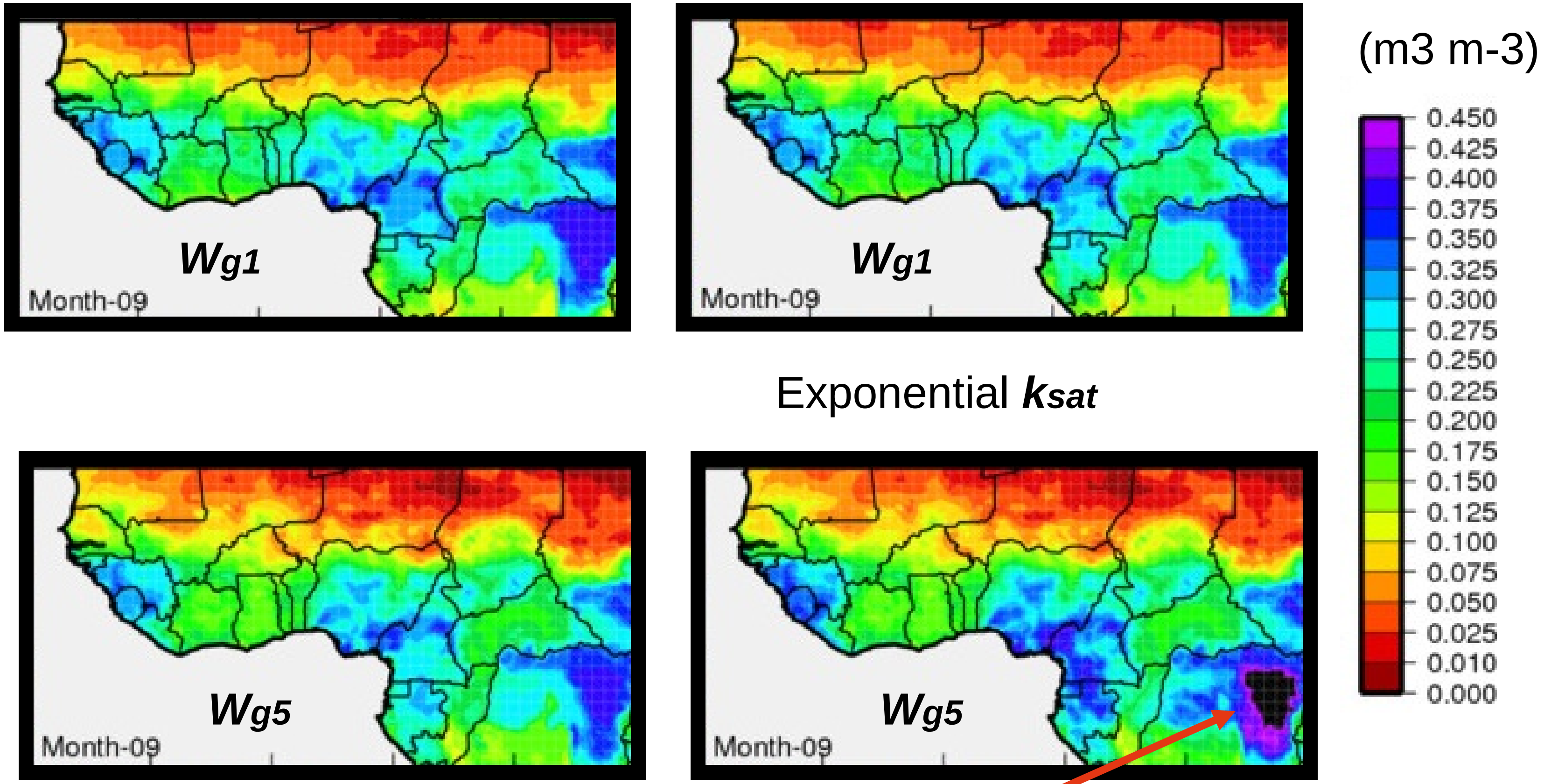
Heterogeneous Profiles better agree with observed soil moisture profile.

No options to specify: just prescribe sand and clay fractions by layer in NAMELIST



Explicit Diffusion and Cold Season Processes

AMMA (ALMIP) Aug. 2006 : ISBA-DIF – volumetric water content



Exponential ***k*sat**

Lowest layer is saturated

Explicit Diffusion and Cold Season Processes

Hydrological Effect of soil ice:

Ice is assumed to become part of the solid soil matrix....

$$\Theta = \frac{w - w_i}{w_{sat} - w_i} = \frac{w_l}{w_{sat\,l}} \qquad (0 \leq \Theta \leq 1)$$

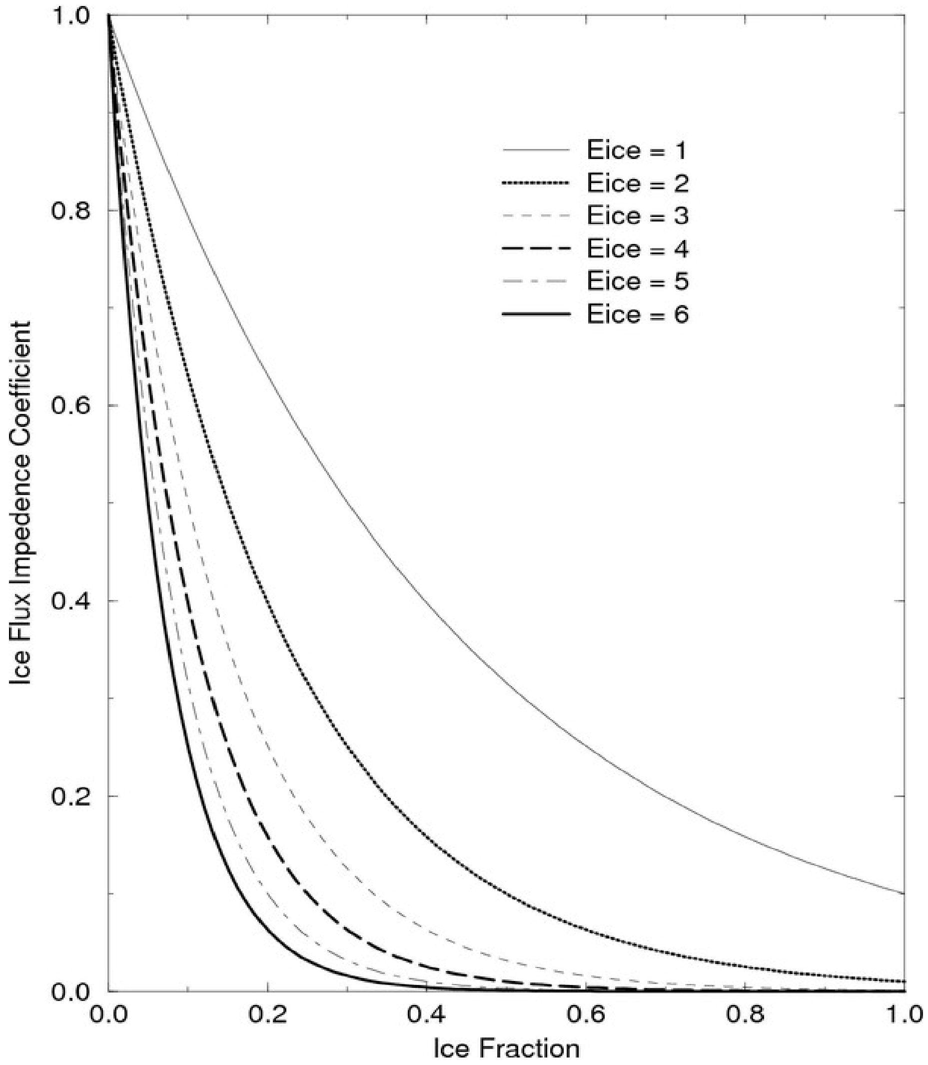
$$k = k_{sat}\,\Theta^{2b+3}$$

$$\psi = \psi_{sat}\,\Theta^{-b}$$

$$\wp = 10^{-a_{\wp}\,w_i/w}$$

When a layer freezes, this can create strong liquid water gradients, so a diffusion impedance term is used

Explicit Diffusion and Cold Season Processes



Reduction factor for vertical soil water diffusion for different values of parameter *Eice* as a function of ice fraction in the soil.

Explicit Diffusion and Cold Season Processes

Phase Changes in the Soil: CSOILFRZ=DEF option

The freeze/thaw rates are proportional to the temperature depression and the available liquid/ice.

$$\Phi_{f\,j} = \min\Big[K_s \epsilon_f \max\left(0,\, T_f - T_j\right) c_i,\; L_f \rho_w \max\left(0,\, w_{l\,j} - w_{\min}\right)\Big] / \tau_i$$

$$\Phi_{m\,j} = \min\left[K_s \epsilon_m \max\left(0,\, T_j - T_f\right) c_i,\; L_f \rho_w w_{i\,j}\right] / \tau_i$$

$$\epsilon_j = \begin{cases} w_{l\,j} / \left(w_{sat} - w_{i\,j}\right) & \left(T_j \leq T_f\right) \\ w_{i\,j} / \left(w_{sat} - w_{\min}\right) & \left(T_j > T_f\right) \end{cases} .$$

$$K_s = \left(1 - \frac{veg}{K_2}\right)\left(1 - \frac{LAI}{K_3}\right) \qquad \left(0 < K_s \leq 1\right)$$

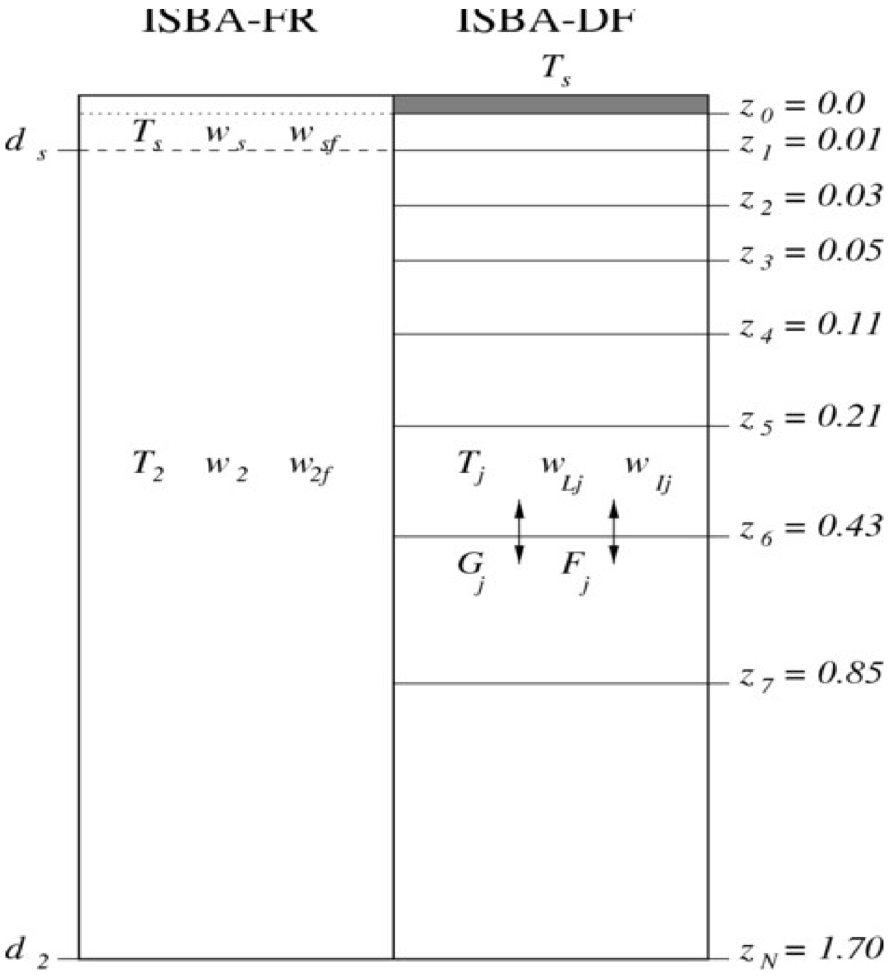
Rate of freeze thaw a function of efficiency and vegetation (Bazile)

Explicit Diffusion and Cold Season Processes

Example setup for Illinois:

Test soil freezing impact on soil temperatures, surface fluxes...

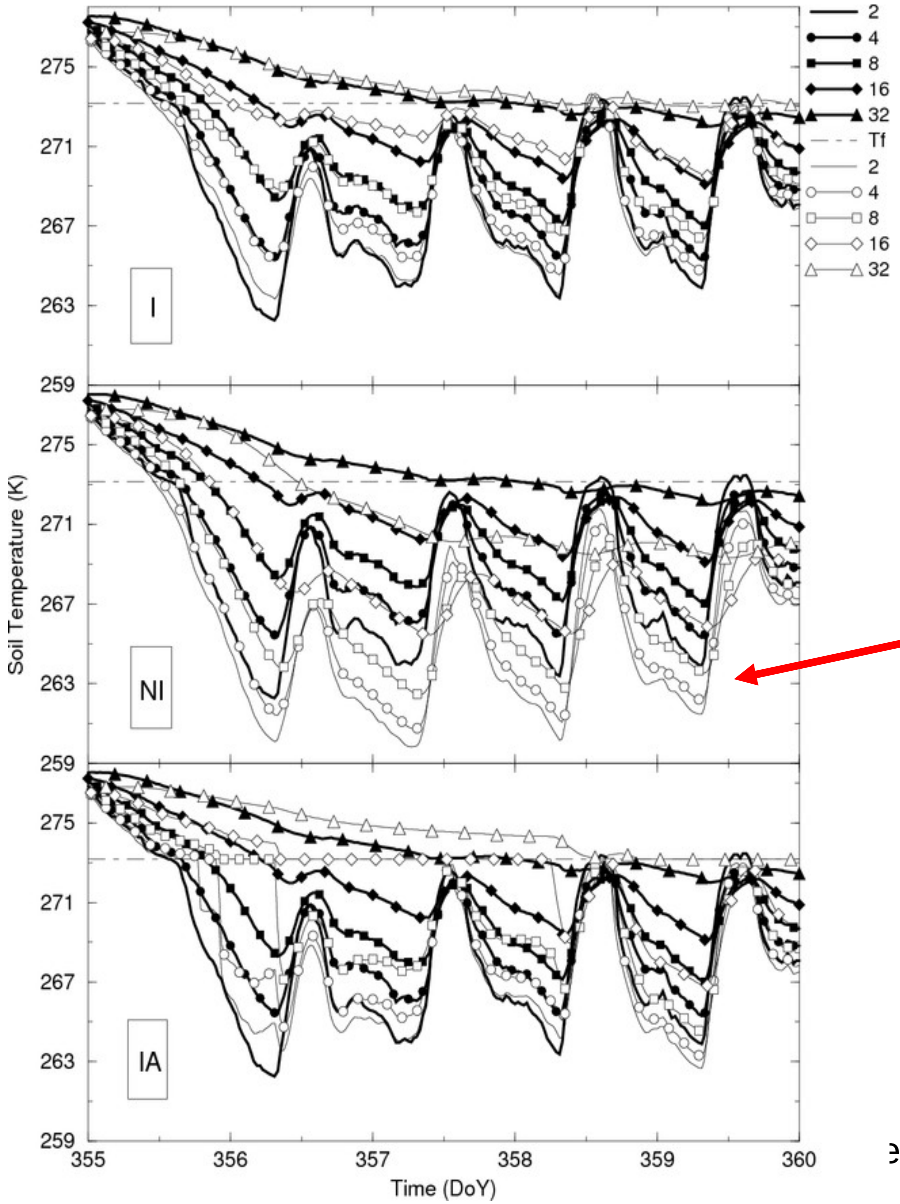
Examine 2 cold periods in 98-99



Explicit Diffusion and Cold Season Processes

With soil ice

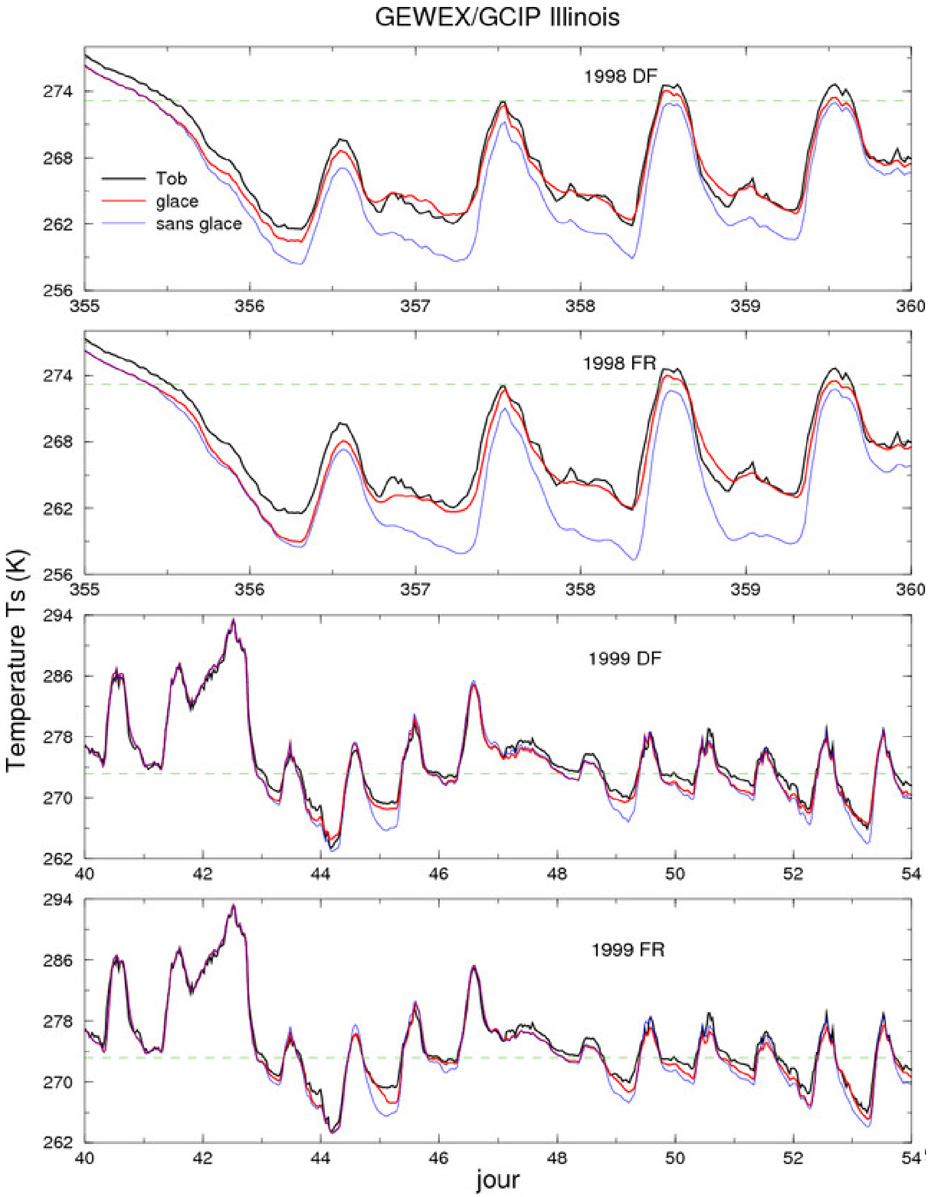
No soil ice



With soil freezing: significantly warmer compared to obs

Old default: no soil freezing: cold bias

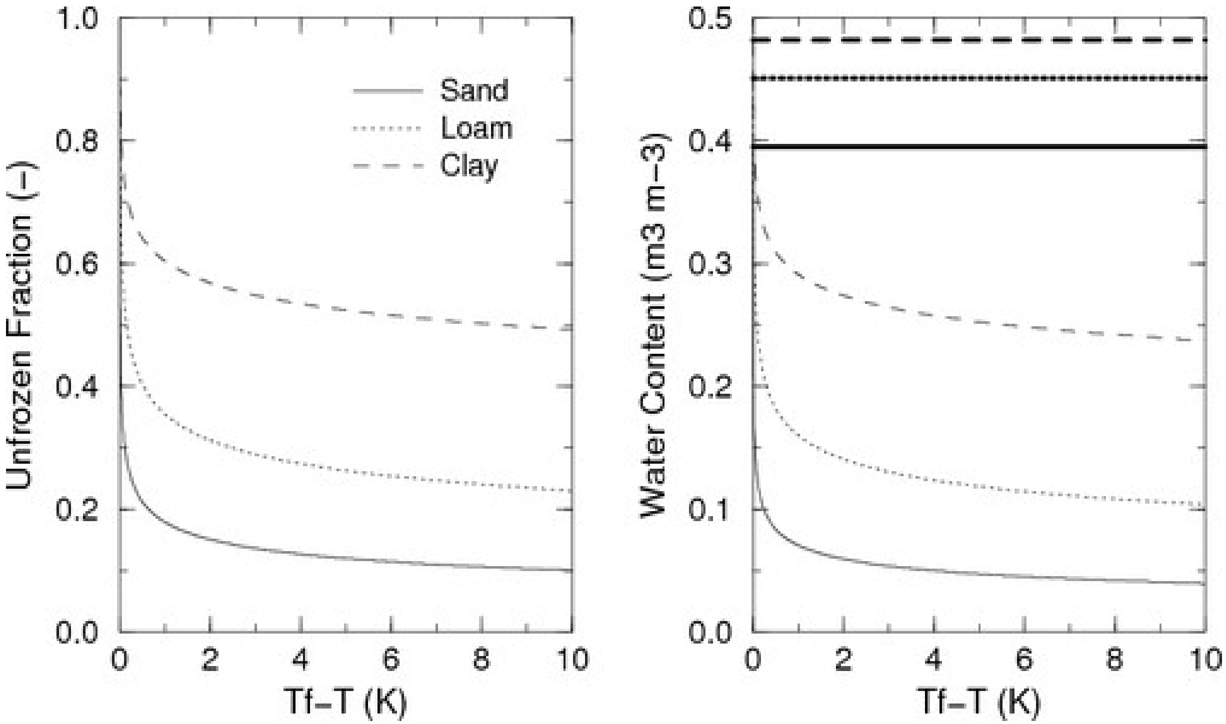
Explicit Diffusion and Cold Season Processes



Impact of soil freezing on **surface temperatures** during 2 cold periods...night-time cold bias all but removed

METEO FRANCE
Toujours un temps d'avance

Explicit Diffusion and Cold Season Processes



Option CSOILFRZ=LWT:
As opposed to potentially freezing ALL liquid water, this method uses the freezing curve method. The maximum liquid water content for a given texture is a function of T...

More physical...
also avoids numerical problems since liquid water content stays above minimum numerical threshold

Explicit Diffusion and Cold Season Processes

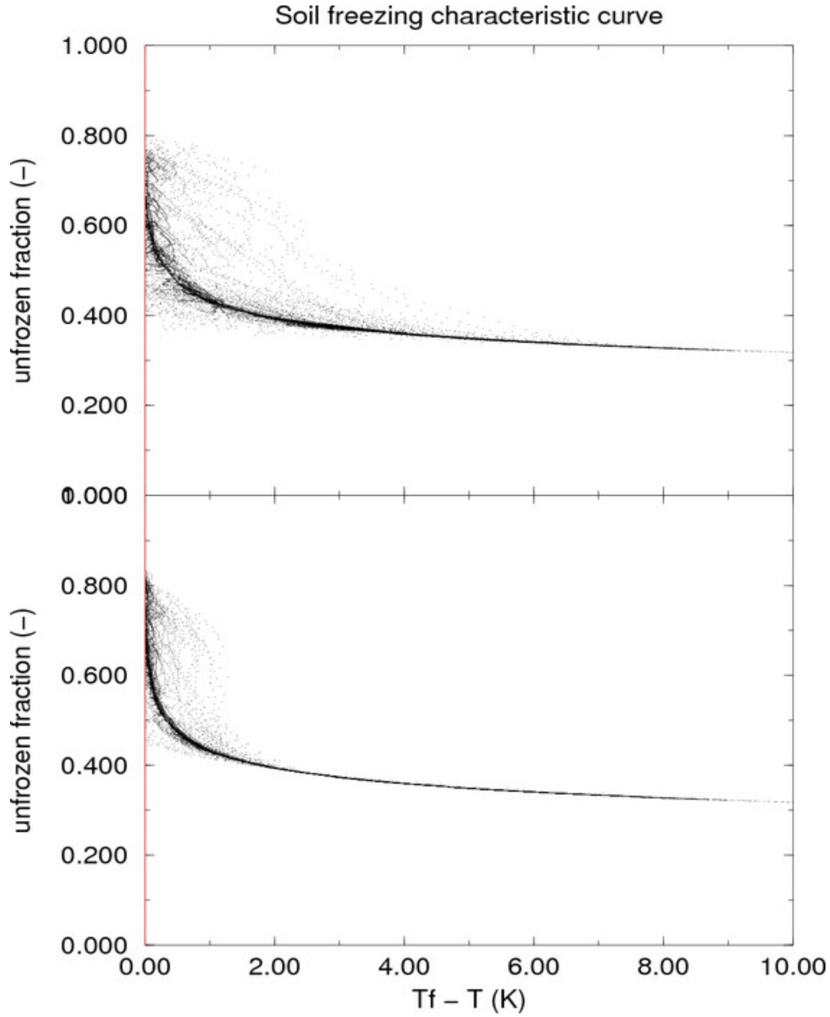
From Gibbs free energy concept

$$\psi^* = \frac{L_f\,(T - T_f)}{g\,T}$$

And Clapp and Hornberger, we get:

$$w_{l\,\mathrm{max}} = w_{\mathrm{sat}} \left(\frac{\psi^*}{\psi_{\mathrm{sat}}} \right)^{-1/b}$$

$$T_{\mathrm{max}} = \frac{L_f\,T_f}{(L_f - g\,\psi)}$$



Example for Goose Bay, Canada...lower panel both coefficients set to unity. All 5 soil layers shown together. For a winter season

Explicit Diffusion and Cold Season Processes

Snow scheme options: CSNOW

EBA - Bazile composite scheme, 2 prognostic variables NWP usage and improved fcst scores

DEF - Douville composite scheme, 3 prognostic variables Extensive use in offline and GCM

3-L* - Boone (ISBA-ES: Explicit Snow), 4 prognostic variables (3-N layer variables, 1 single layer var) Offline and Mesoscale modelling, operational Hydro

*** Ongoing developments:** new modifications with snow grain variables, history variables, 10 layers....coupling with vegetation canopy

Explicit Diffusion and Cold Season Processes

DEF - Composite snow scheme
EBA - Composite (**no** density prognostic eq)

$$\frac{\partial W_n}{\partial t} = P_n - E_n - F_n$$

$$\frac{\partial \rho_n}{\partial t} = \frac{\tau_f}{\tau}\left(\rho_{\max} - \rho_n\right) \qquad \left(\rho_{\min} \leq \rho_n \leq \rho_{\max}\right)$$

$$\frac{\partial \alpha_n}{\partial t} = \frac{-1}{\tau}\left[\delta_\alpha\, \tau_f \left(\alpha_n - \alpha_{\min}\right) + \left(1 - \delta_\alpha\right) \tau_a\right] + \frac{P_n}{W_{crn}}$$

$$\left(\alpha_{\min} \leq \alpha_n \leq \alpha_{\max}\right)$$

Explicit Diffusion and Cold Season Processes

DEF - Composite snow scheme
EBA - Composite (**no** density prognostic eq)

$$\frac{\partial W_n}{\partial t} = P_n - E_n - F_n$$

$$\frac{\partial \rho_n}{\partial t} = \frac{\tau_f}{\tau}\left(\rho_{\max} - \rho_n\right) \qquad \left(\rho_{\min} \le \rho_n \le \rho_{\max}\right)$$

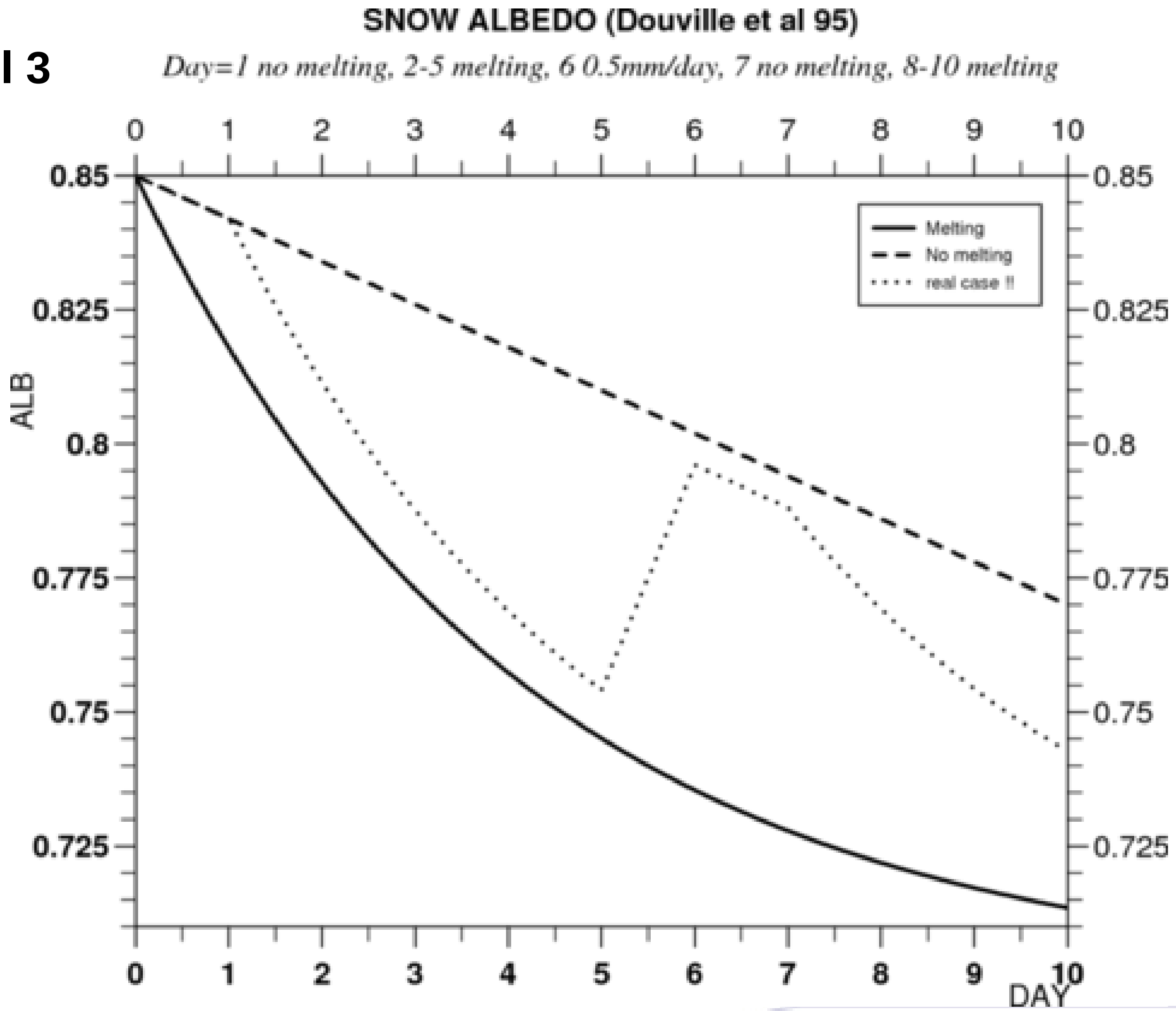
$$\frac{\partial \alpha_n}{\partial t} = \frac{-1}{\tau}\left[\delta_\alpha \, \tau_f \left(\alpha_n - \alpha_{\min}\right) + \left(1 - \delta_\alpha\right) \tau_a\right] + \frac{P_n}{W_{crn}}$$

$$\boxed{\begin{aligned} F_n &= p_n \frac{(T_n - T_f)}{C_n L_f \Delta t} \qquad (F_n \ge 0) \\ T_n &= (1 - veg) T_s + veg \, T_2 \end{aligned}}$$

Comoposite=
Single soil-vegetation-snow energy budget

Explicit Diffusion and Cold Season Processes

Albedo scheme **in all 3 model** options



Explicit Diffusion and Cold Season Processes

Default **snow fraction** for baresoil (p_{ng}) for all models,
p_{nv} used for 3-L and DEF (EBA based on *LAI* and *age* also,
results in significantly improved T2m air temperatures over
Northern Hemisphere)

soil →

$$p_{ng} = W_n / \left(W_n + W_{crn}\right) \qquad \left(W_{crn} = 10\ \mathrm{kg\,m}^2\right)$$

veg →

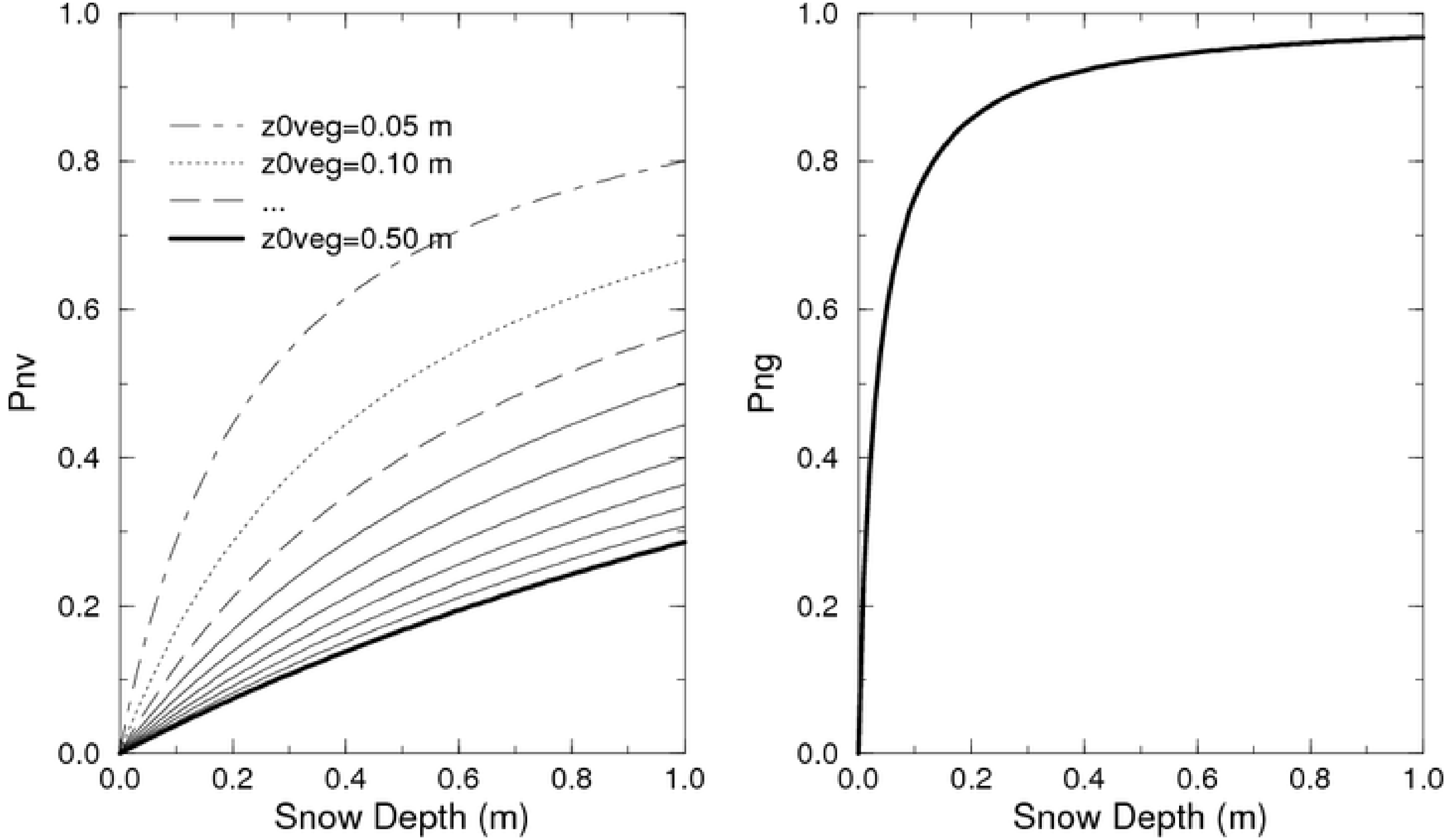
$$p_{nv} = h_n / \left(h_n + 5 z_0\right)$$

$$p_n = veg\, p_{nv} + (1 - veg)\, p_{ng}$$, TOTAL snow cover fraction

* Loosely physically based...mostly empirical...but...rather standard! Future developments may include topographic index/exposition, improvements using satellite-based data...

Explicit Diffusion and Cold Season Processes

Basic ideas: cover bare-ground faster...and taller vegetation with lower pnv



Explicit Diffusion and Cold Season Processes

3-L: ISBA-ES is more detailed:

- an N-layer scheme (default 3)
- explicit compaction (and melt densification)
- radiative transfer
- explicit energy budget: prognostic vars = albedo, density, SWE and ***H***
- liquid water content (using enthalpy concept)

$$\boxed{H_{s\,i} = c_{s\,i}\, D_{s\,i}\, (T_{s\,i} - T_f) \,-\, L_f\, (W_{s\,i} - W_{l\,i})}$$

New prog. variable

2 prognostic variables "for the price of one"...

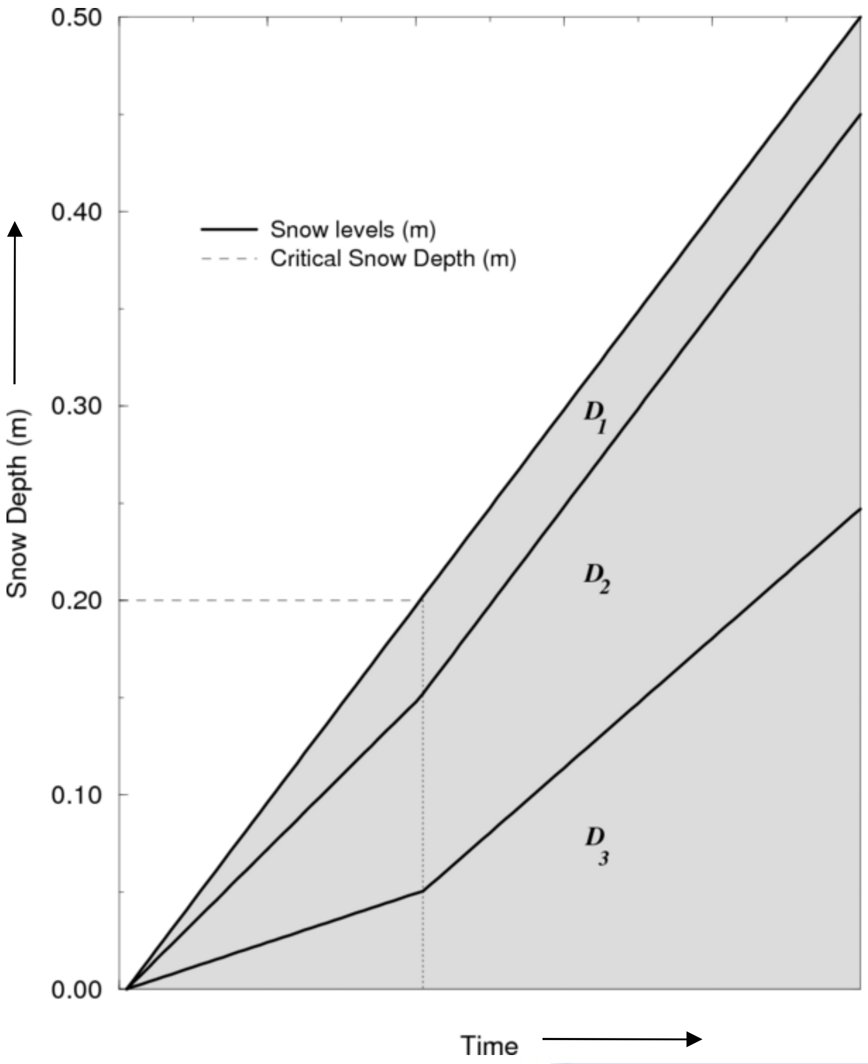
$$T_{s\,i} = T_f + (H_{s\,i} + L_f\, W_{s\,i}) \,/\, (c_{s\,i}\, D_{s\,i}) \qquad (W_{l\,i} = 0)$$

$$W_{l\,i} = W_{s\,i} + (H_{s\,i}/L_f) \qquad (T_{s\,i} = T_f)$$

Explicit Diffusion and Cold Season Processes

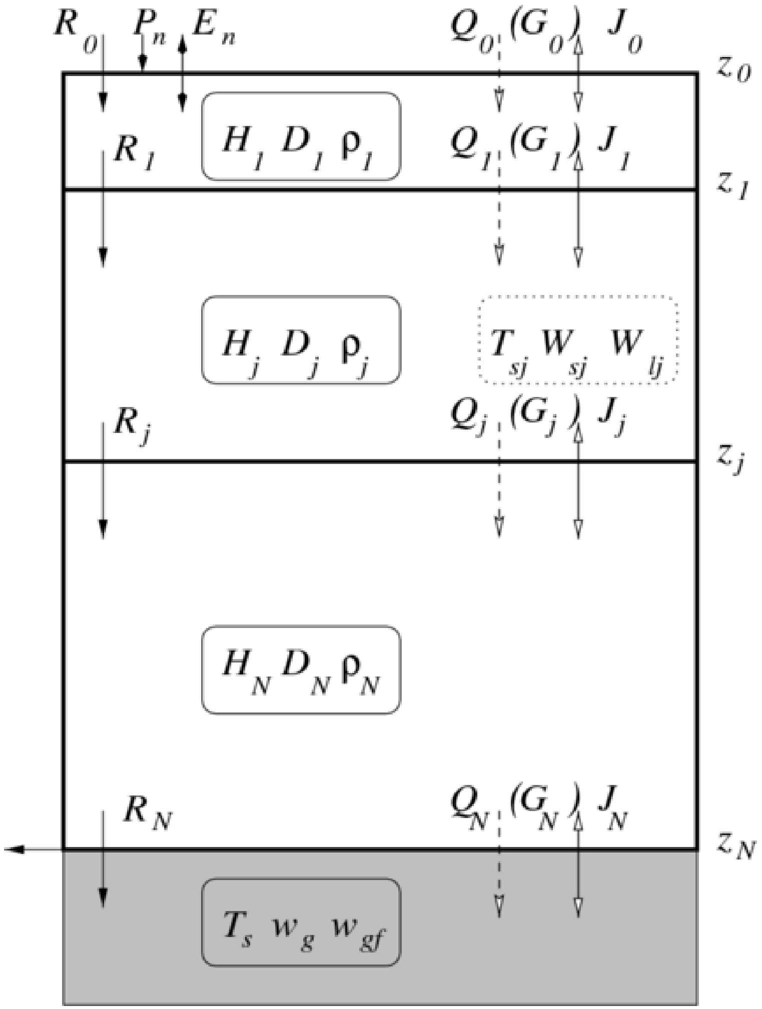
Time varying layer thicknesses

Total snowpack mass and energy conserved as grid changes in *t*



Explicit Diffusion and Cold Season Processes

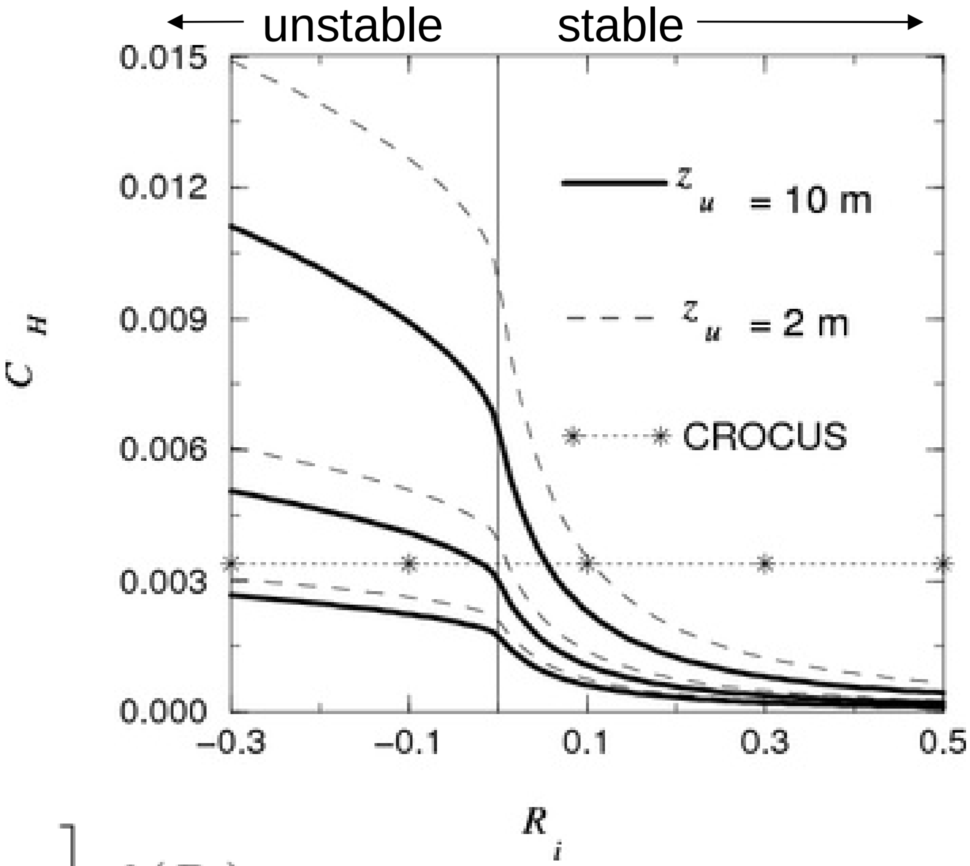
Grid and numerical setup essentially the same as for the soil heat diffusion Equation (DIF)



Explicit Diffusion and Cold Season Processes

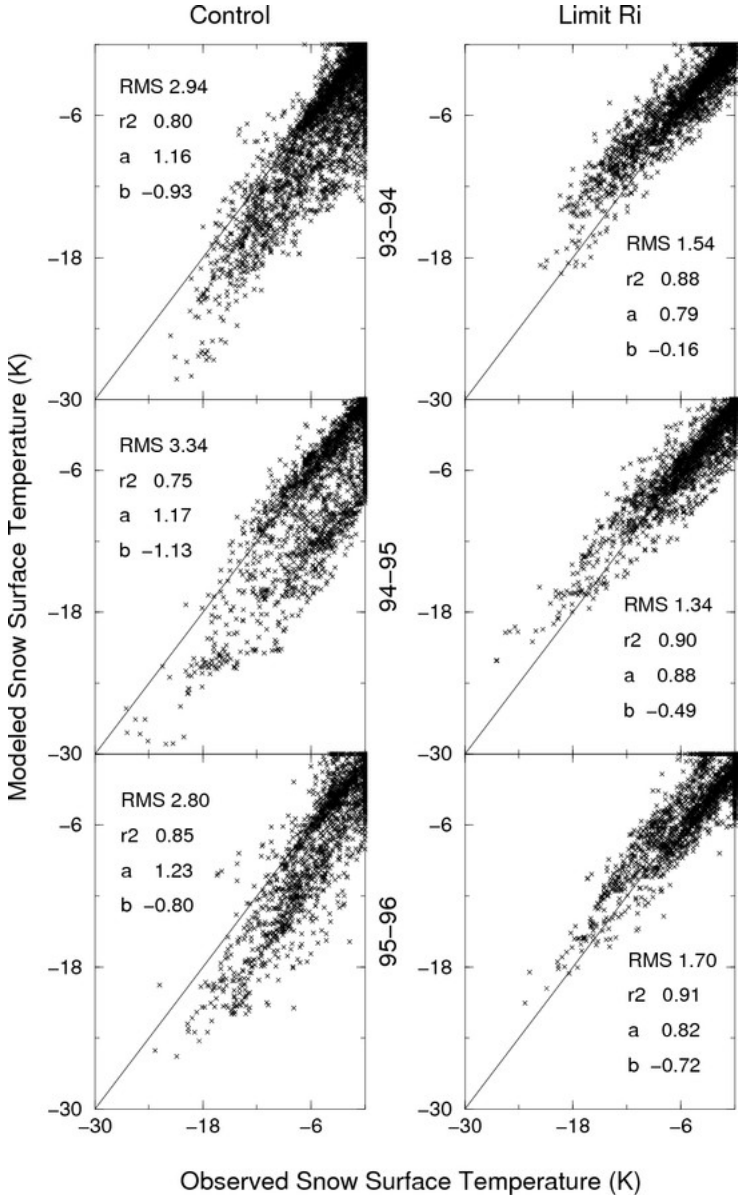
Richardson number limit options (CSNOWRES=RIL) for snow 3-L

- during very stable conditions, decoupling from the atmosphere can lead to very cold surface snow temperatures. Fix from ARPEGE....



$$C_H = \left[\frac{k^2}{\ln\left(z_u/z_{0t}\right)\ln\left(z_a/z_{0t}\right)}\right] f\left(R_i\right)$$

Explicit Diffusion and Cold Season Processes



Example using RIL:

Impact of Using RIL option (with Richmax=0.20) at Col de Porte for 3 years. Good improvement...also impacts melting.

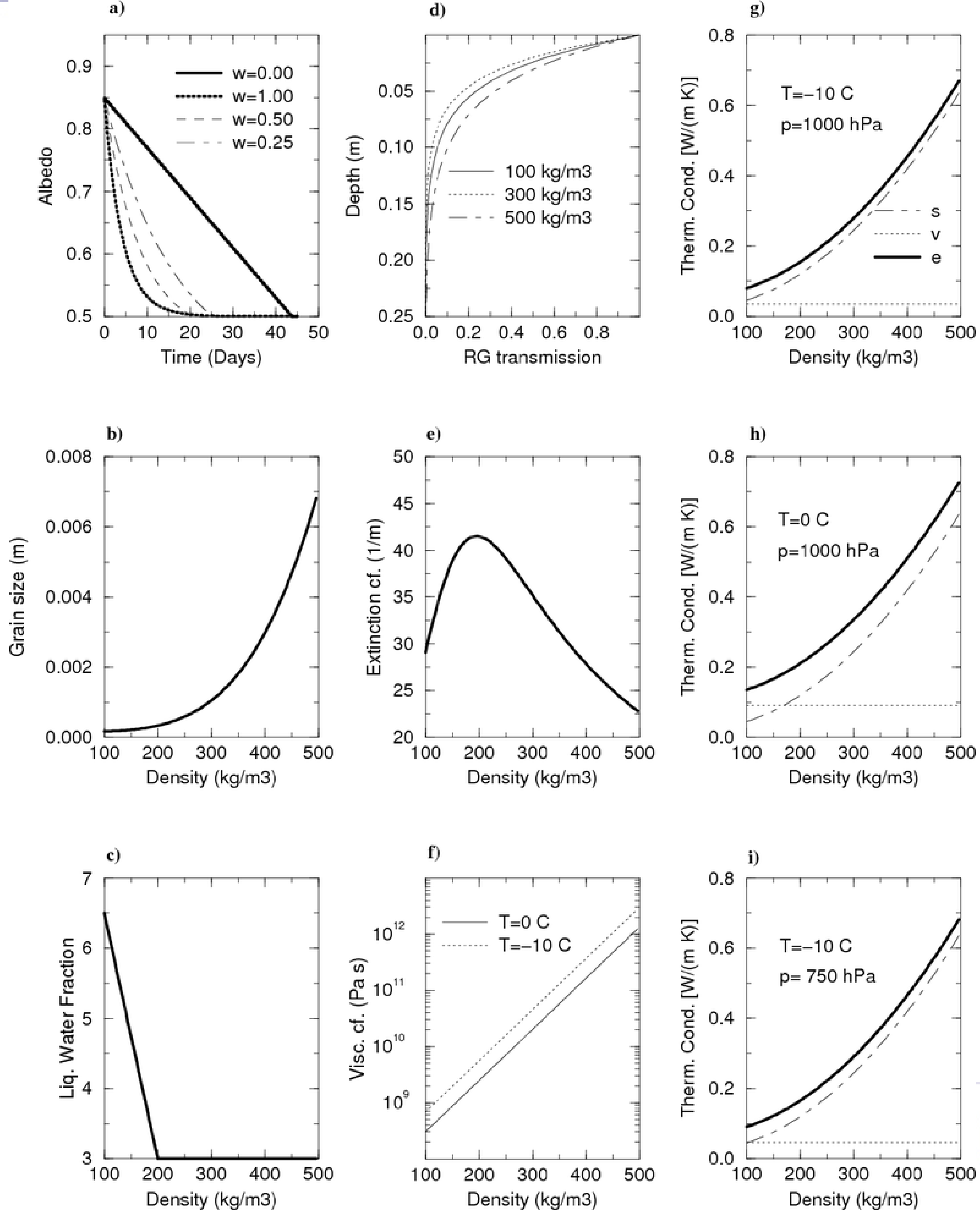
Explicit Diffusion and Cold Season Processes

Phase changes and liquid water budget:
- relatively simple (“tipping bucket” hydrology)
- phase changes don't change *H*, but partitioning between *T* and W_l (unless runoff/mass loss)

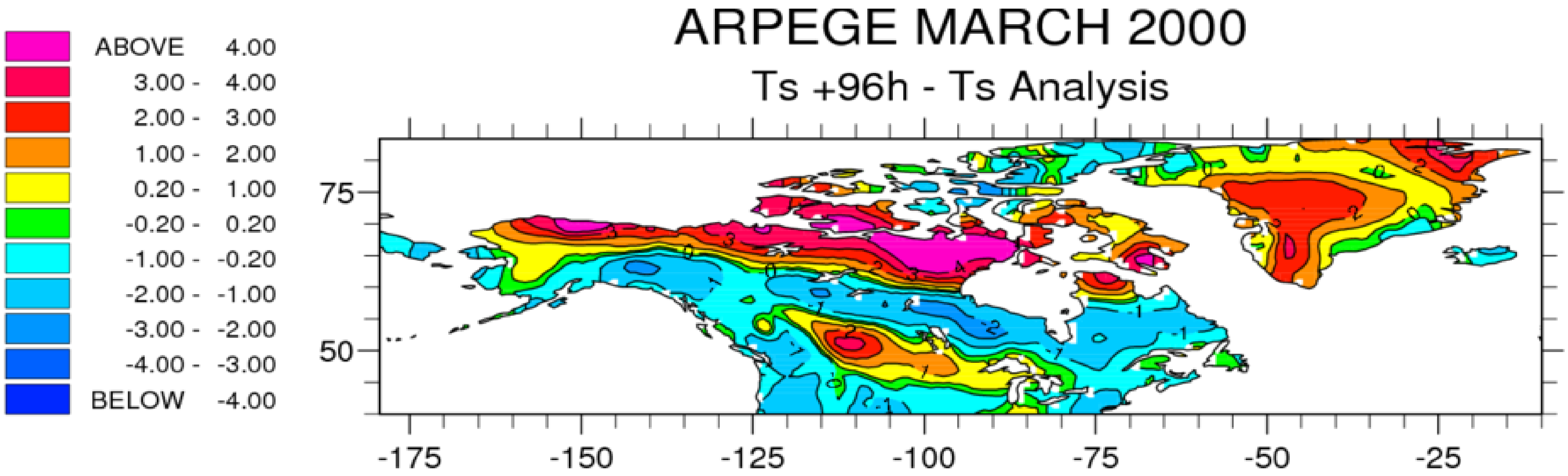
$$
\begin{aligned}
F_{sm\,i} &= \min\left[c_{s\,i}\,D_{s\,i}\,\left(T_{s\,i} - T_f\right),\; L_f\left(W_{s\,i} - W_{l\,i}\right)\right]/\Delta t \\
F_{sf\,i} &= \min\left[c_{s\,i}\,D_{s\,i}\,\left(T_f - T_{s\,i}\right),\; L_f W_{l\,i}\right]/\Delta t \;\; . \\
F_{s\,i} &= F_{sm\,i} - F_{sf\,i}
\end{aligned}
$$

$$
\frac{\partial W_{l\,i}}{\partial t} = R_{l\,i-1} - R_{l\,i} + F_{s\,i}/L_f \qquad \left(W_{l\,i} \le W_{l\,i\,\max}\right)
$$

3-L physics summary



Explicit Diffusion and Cold Season Processes



Impact of new albedo, snow fraction

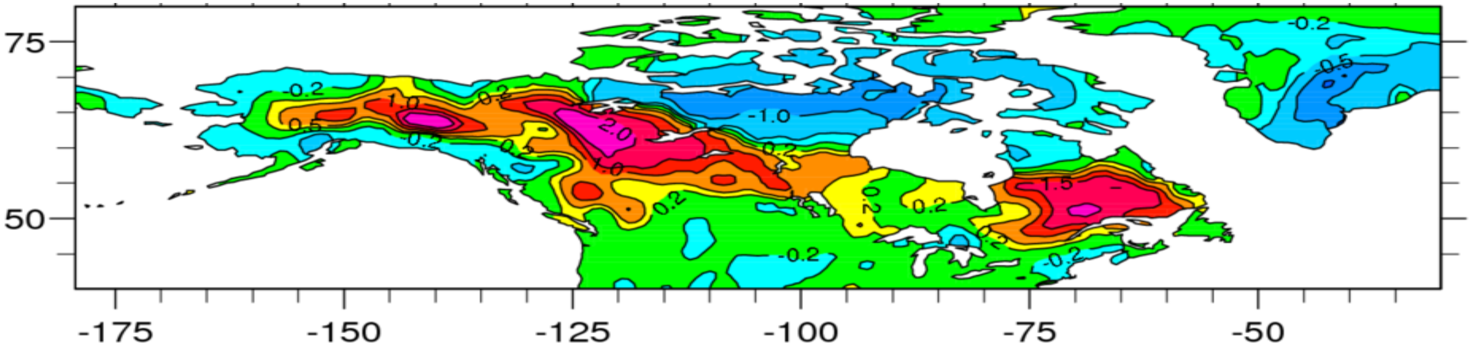
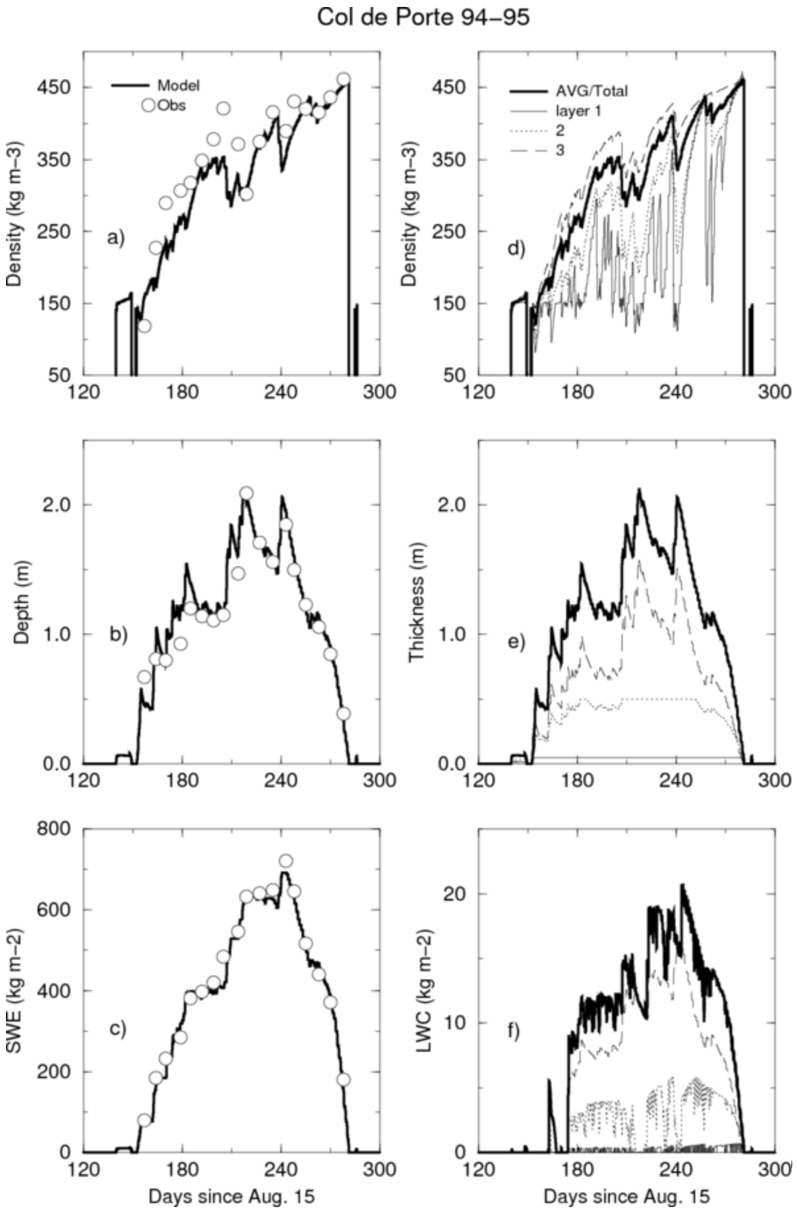


Figure 5: Impact of the new scheme on the T_{2m} 96h forecast (avraged on the 15 runs).

From E. Bazile, GMAP

Explicit Diffusion and Cold Season Processes



ISBA-ES

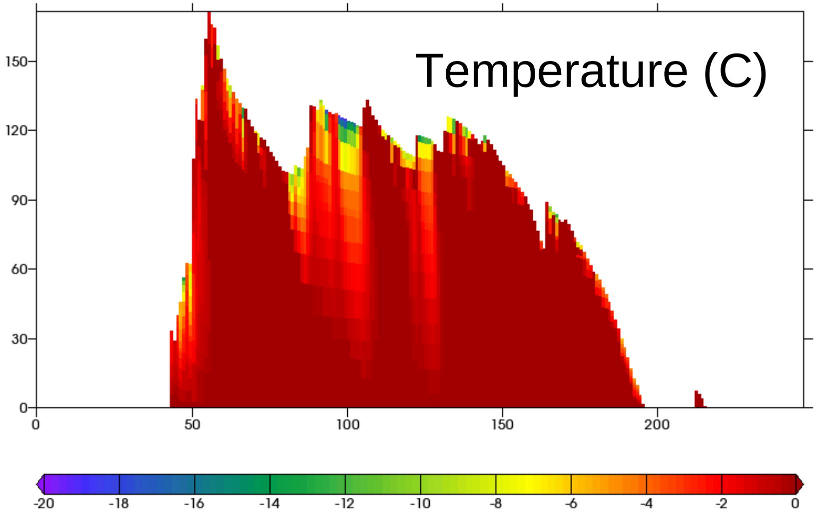
Off-line simulation for Col de Porte (1994-95)

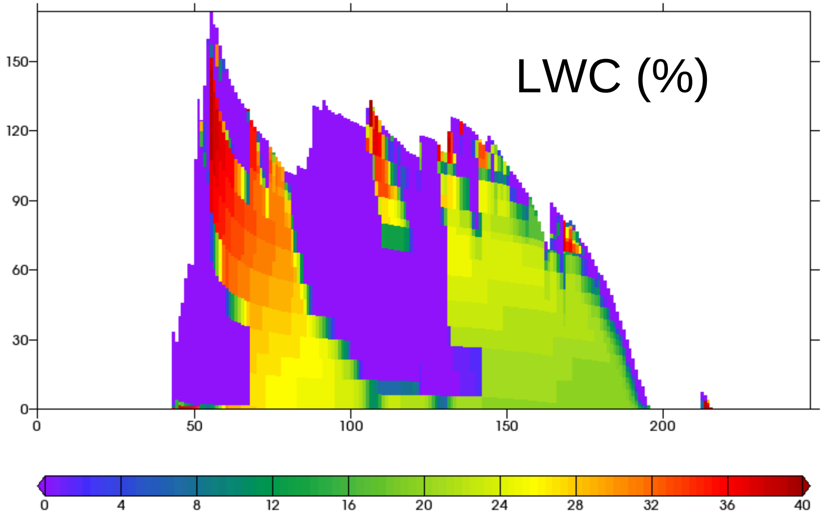
Observed SWE, Depth

Using default 3L configuration

ulouse

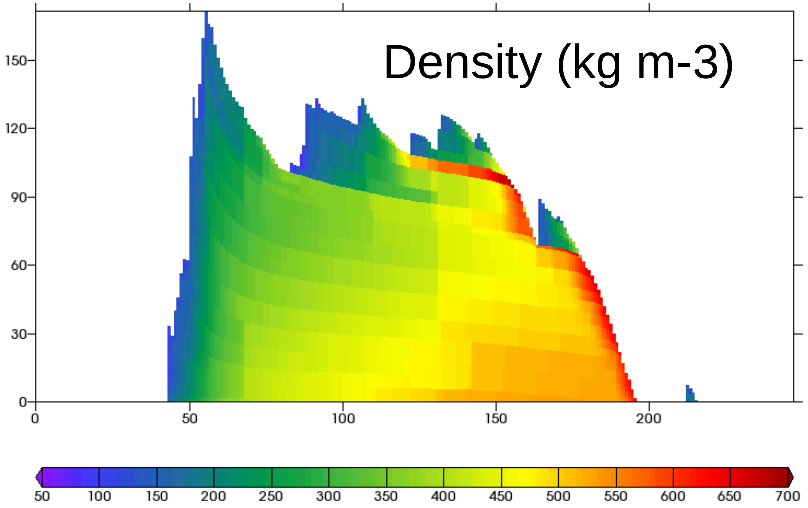
Explicit Diffusion and Cold Season Processes





Profile – Simulations for Col de Porte

- Annual cycle
- by Eric Brun, using ISBA-ES with 10 layers (addtion by V. Vionnet)



Explicit Diffusion and Cold Season Processes

Contact:

Aaron Boone, Eric Martin, Patrick LeMoigne

Eric Brun, Vincent Vionnet, Eric Bazile, Hervé Douville (snow),

Bertrand Decharme (soil, hydrology)

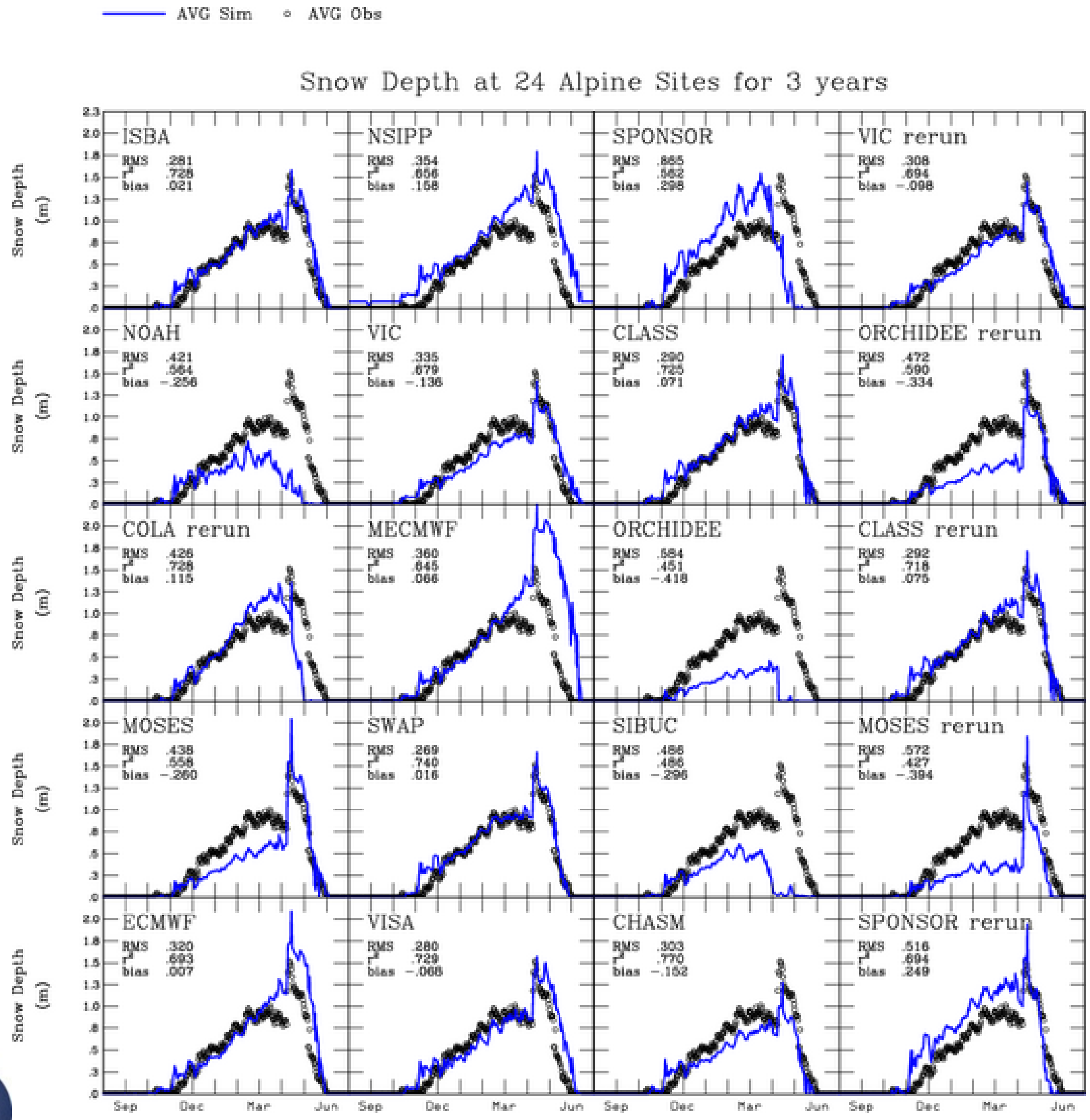
GAME-CNRM Météo-France

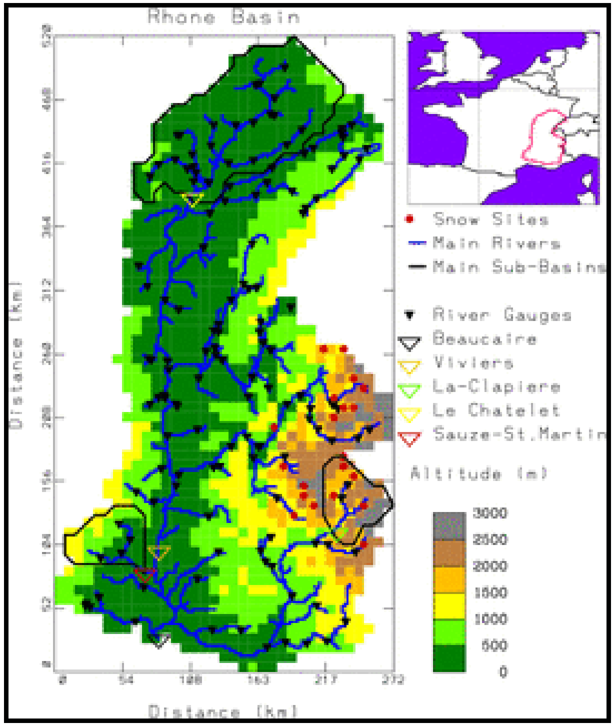
GAME-CNRM

Explicit Diffusion and Cold Season Processes

extra..........................

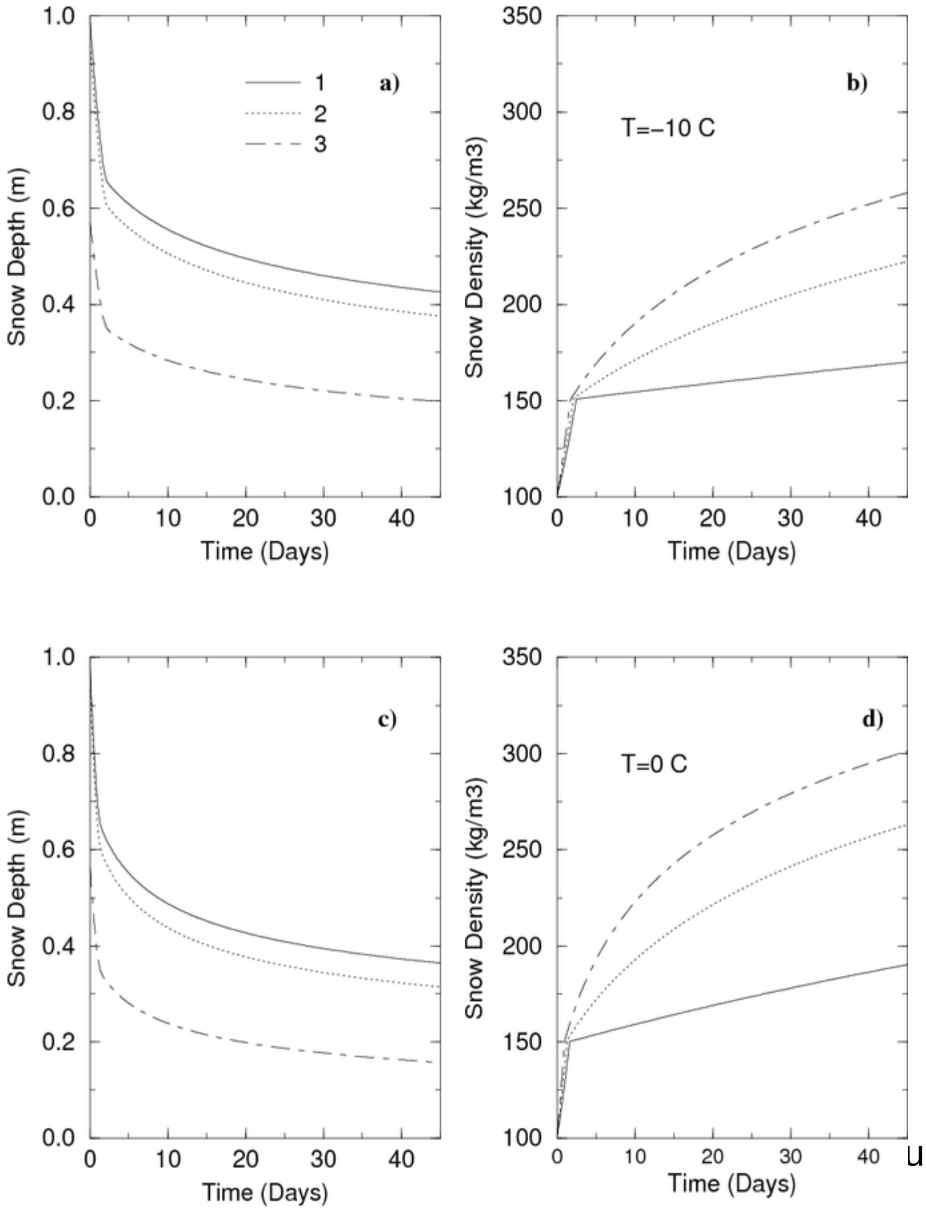
Explicit Diffusion and Cold Season Processes





Average snow Depth for 24 sites in the Alps from the Rhone-AGG Exp.

Explicit Diffusion and Cold Season Processes



Compaction/settling in snow 3-L:
- function of temperature, density
- overlying weight of snow

Initialize with fresh snow density and 1m depth for 2 different constant T profiles...

use