SURFEX Snow Schemes

Aaron Boone

Contributions from B. Decharme, H. Douville, E. Bazile, E. Brun, E. Martin, P. Lemoigne…..

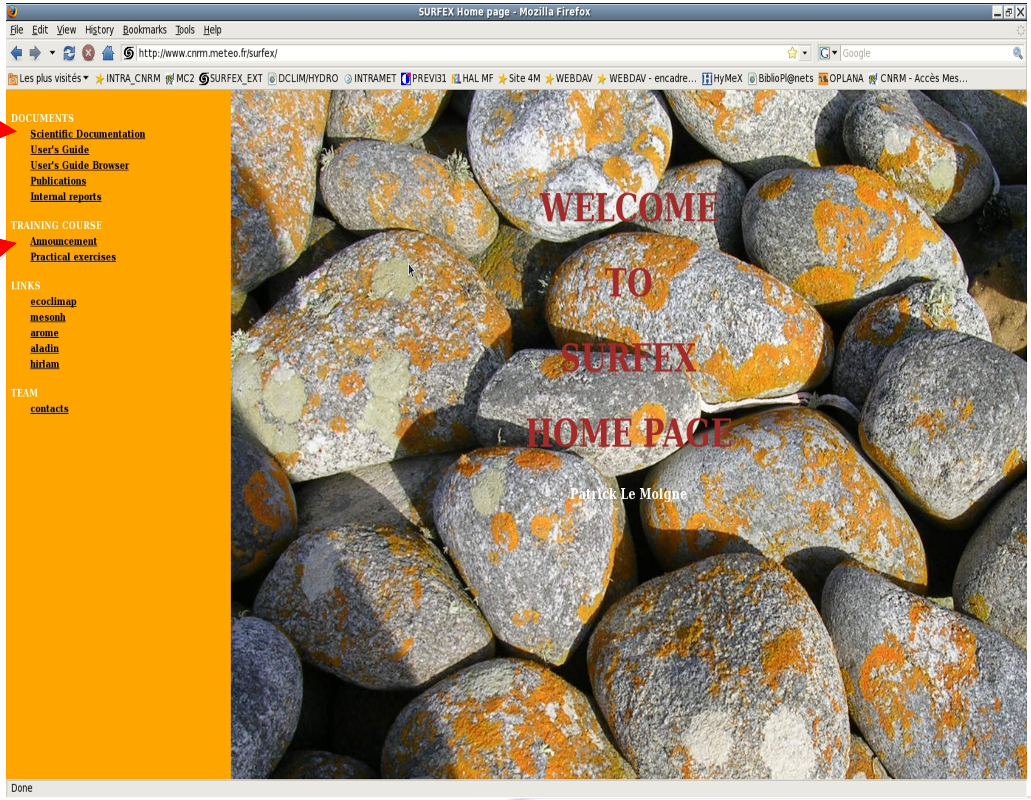
CNRS and Météo-France, Toulouse

Scientific documentation

User's guide

Announcements

www.cnrm.meteo.fr/surfex/



SURFEX Snow Schemes

SURFEX is a « **surf**ace **ex**ternalisée » ➔ Externalised Surface

SURFEX is a surface code as autonomous as possible, which can be run in a coupled mode with a meteorological model, or in a stand alone mode

SURFEX is designed as a modular scheme that can incorporate various parameterisations

SURFEX is expected be used in various applications, through existing and future collaborations on operational numerical weather predictions, climate research (next IPCC)… and improve for the benefit of all.

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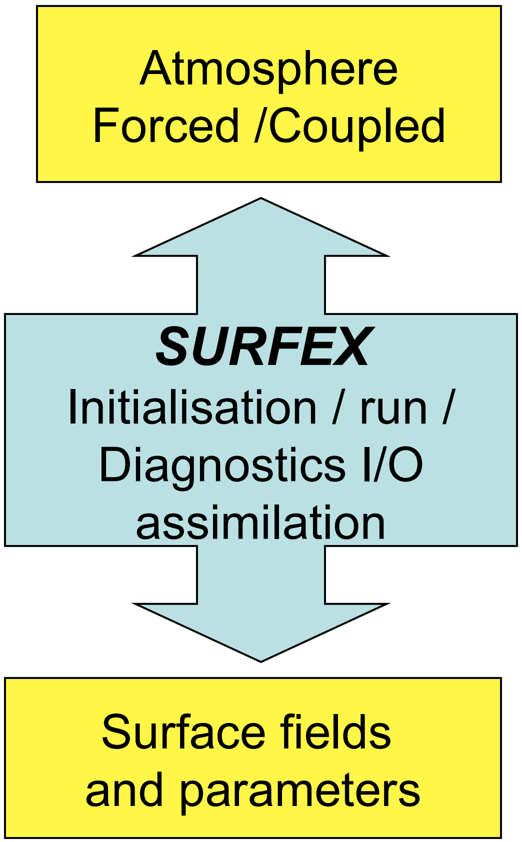
Why do we need externalised surface codes ?



- The aim of a surface code is to simulate the fluxes between the surface and the atmosphere : energy, water, carbon, dust, snow, chemical species…
- The surface code needs to simulate **processes** « below » or « inside » the surface to provide the **fluxes**.
- Surface codes are improved and validated offline, many works on surface processes are done by people not belonging to the meteorological or climatological communities.
- The use of the **same code** for coupled and offline application is mandatory in order to ensure the coherency between the two applications.
- Need to **externalise** the surface code of the atmospheric model. I.e. clearly separate them from other part of the code in order to run them in stand alone mode

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Sea and oceans :
- Prescribed SST, Charnock formula
- Mondon and Redelsperger
- ECUME (multicampaign parametrisation)
- 1D ocean model

Lakes :
- Prescribed surface temperatures, Charnock formula
- FLake

Soil/Vegetation/Snow : ISBA
(Interaction Soil Biosphere Atmosphere)

Town : TEB (Town Energy Balance)
-Canyon Approach
-Detailed radiative scheme
-Heat storage in buildings

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- The surface is divided into 4 main **Tiles**, which are treated by different models

Sea/Oceans	Lakes
Nature (bare soil/ vegetation)	Towns

- The tile **Nature** is divided into 12 **patches** or **natural functional types**

NO no vegetation	C3 (C3 crops)
ROCK (bare rock)	C4 (C4 crops)
SNOW (snow and ice)	IRR (irrigated crops)
TREE (deciduous broadleaved forest)	GRAS (temperate /C3 grassland)
CONI (evergreen needleleaved forest)	TROG (tropical /C4 grassland)
EVER (evergreen broadleaved forest)	PARK (wetlands)

- **Fluxes** from all **(1-12)** tiles **aggregated** to a single land surface flux ➔

* Snow can occur in each patch

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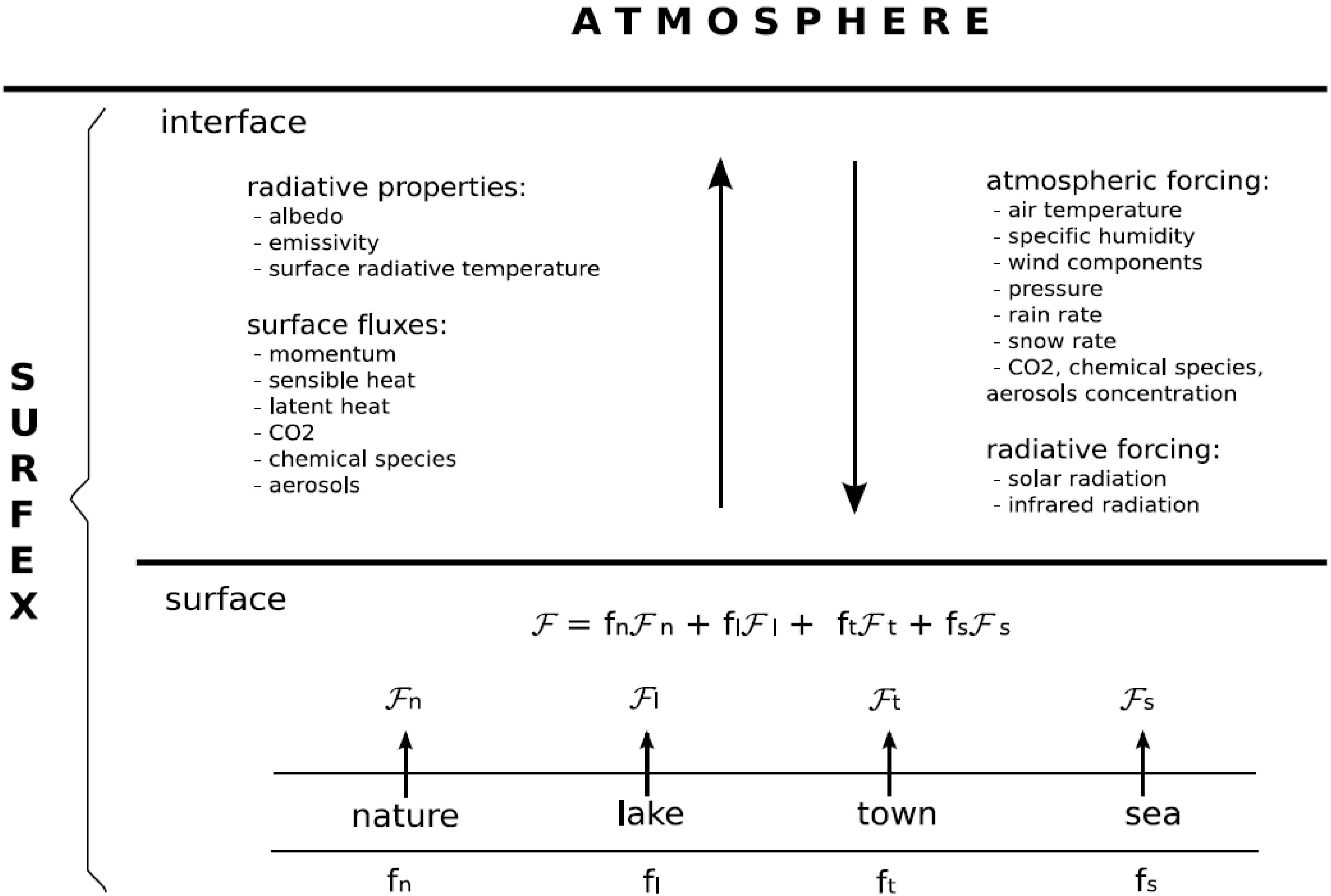

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Cold Season Processes (used with CSOIL=2-L, 3-L, DIF)

A) Soil Phase changes: CSOILFRZ=

i) Phase changes based on water content (DEF)

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

C) Soil heat Transfer (CSOIL=DIF)

Soil Thermal conductivity includes ice explicitly

CSCOND=PL98 (default NP89)

B) Snowpack: CSNOW=

i) Single-layer bulk snow (EBA)

ii) Composite snow (DEF)

iii) Explicit Snow (3-L)

- DEF or RIL Rich. Number limit

iv) Explicit Snow – CROCUS (under development!)

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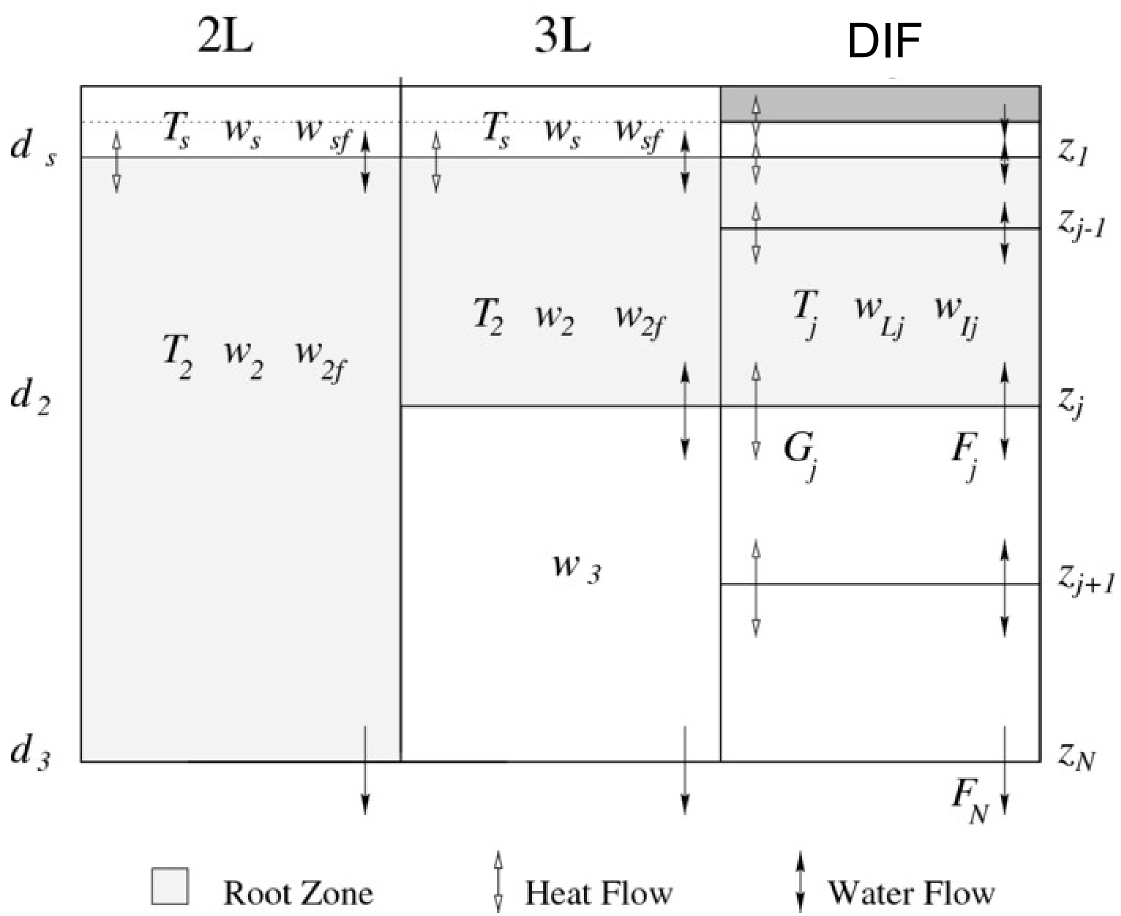
Soil Scheme Options



Comparison: 2 force restore soil options verses DIFusion grid (Richards Eq, Heat Diffusion)

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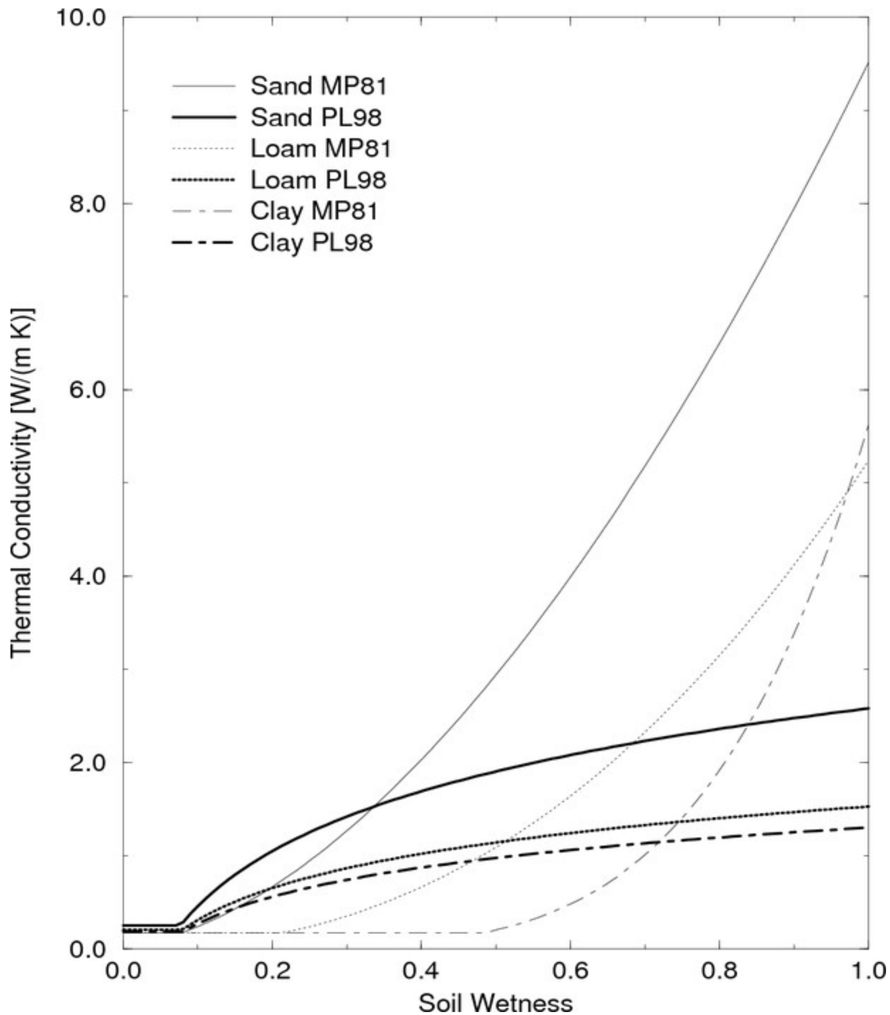
Soil Thermal conductivity: CSCOND
NP89: based on McCumber and Pielke (used implicitly in FR option)
- no explicit accounting for soil ice

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

- ice thermal conductivity ➔ 2.22 (W m-1K-1)



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Phase Changes in the Soil: CSOILFRZ=DEF option

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

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

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

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

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

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

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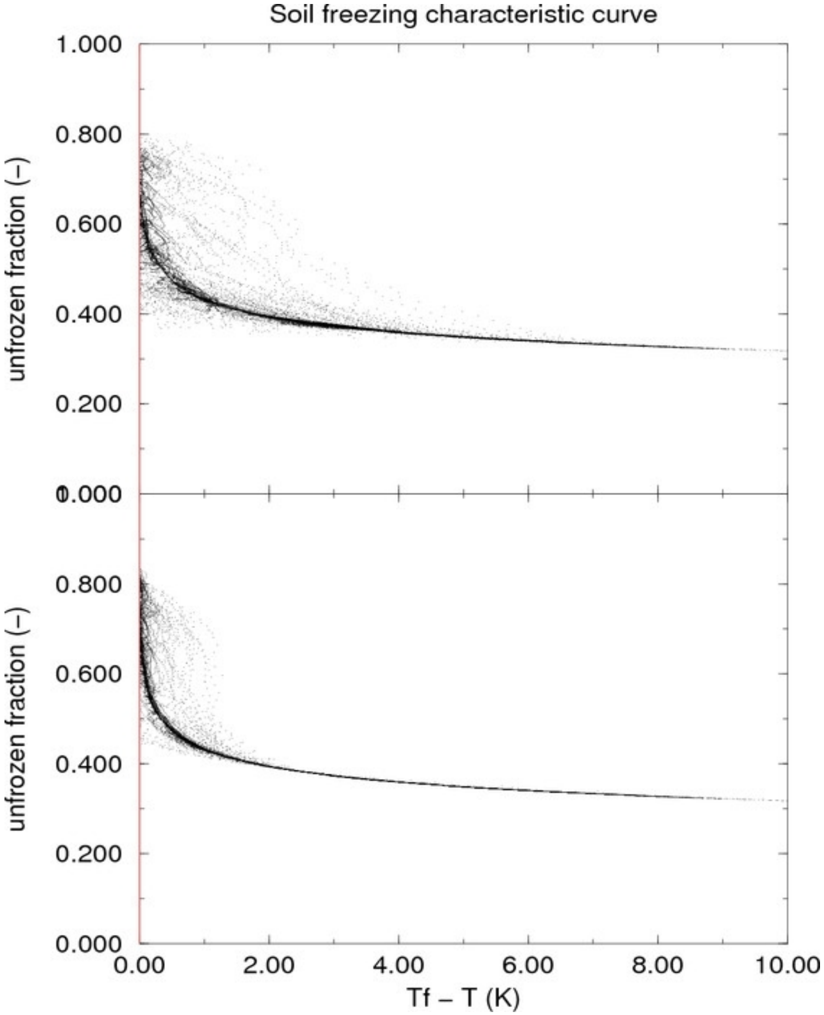
From Gibbs free energy concept $$\psi^* = \frac{L_f\,(T - T_f)}{g\,T}$$

And Clapp and Hornberger, we get:

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

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



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

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Snow scheme options: CSNOW

EBA - Bazile composite scheme, 3 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

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

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DEF - Composite snow scheme
EBA - Composite (density only used to compute diagnostics)

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

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

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

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

Comoposite=
Single soil-vegetation-snow energy budget

More details on differences➔ talk by E. Bazile

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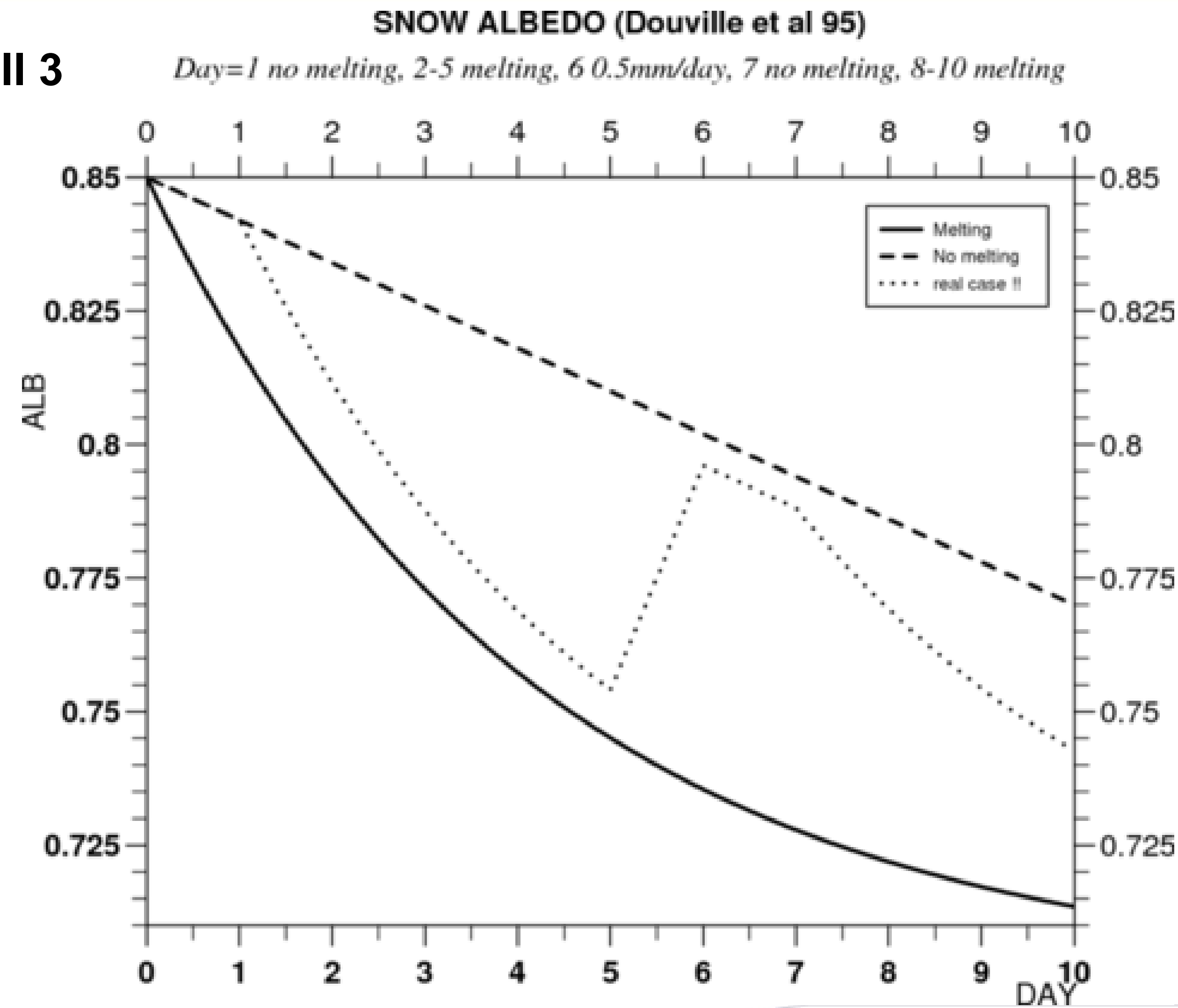
Albedo scheme **in all 3 model** options



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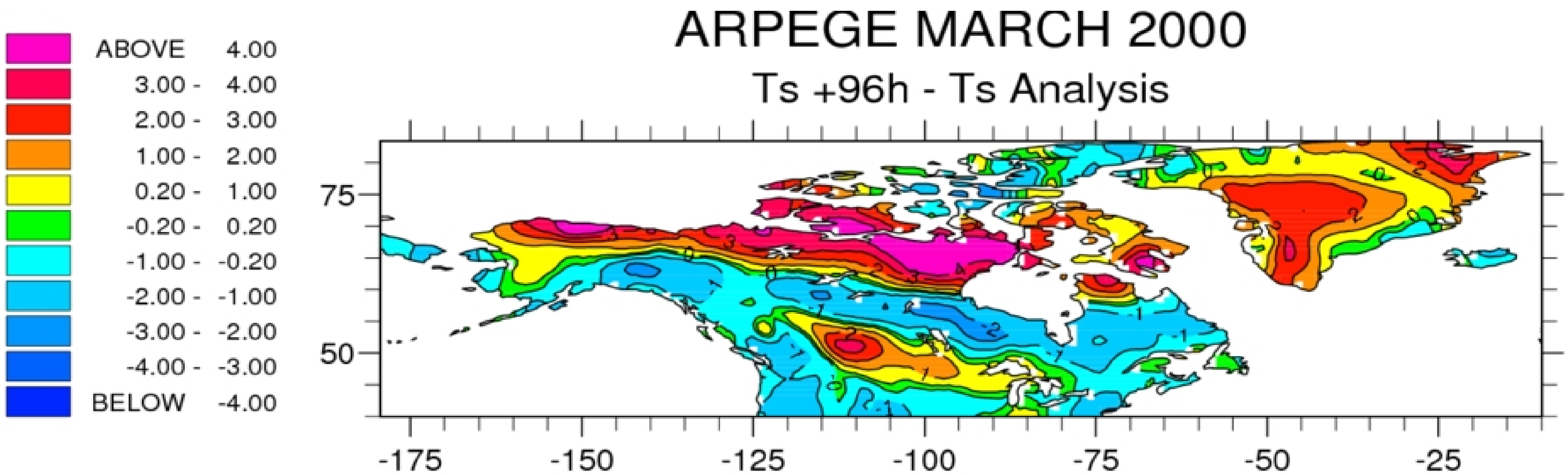

Impact of new albedo, snow fraction

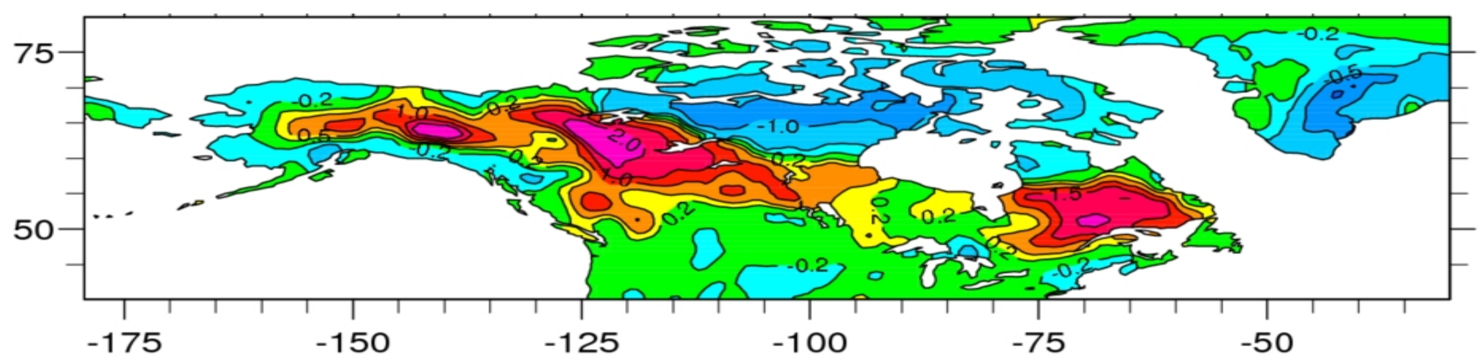

Figure 5: Impact of the new scheme on the T_{2m} 96h forecast (avraged on the 15 runs).

From E. Bazile, GMAP

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Washington DC, Feb 2010

SURFEX Snow Schemes

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

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

veg → $$p_{nv} = h_n / (h_n + 5 z_0)$$

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

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

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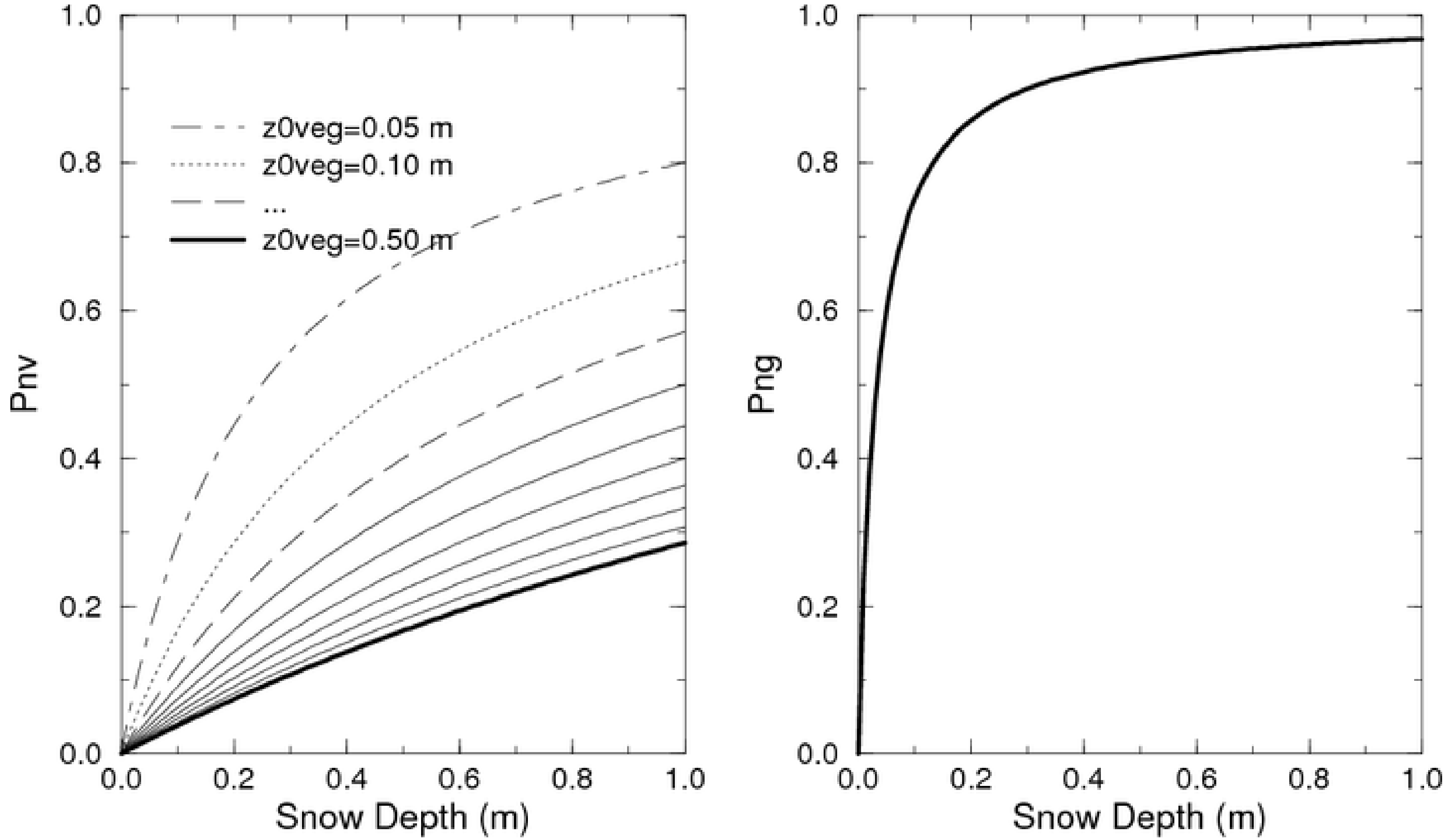
Basic ideas: cover bare-ground faster...and taller vegetation with lower pnv



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3-L: ISBA-ES is more detailed:

- an N-layer scheme (default 3),4 prognostic variables
- explicit compaction (and melt densification)
- radiative transfer
- explicit energy budget: prognostic vars = albedo, density, SWE and ***H***
- liquid water content (using enthalpy concept)

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

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

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

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

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3-L - Explicit snow scheme: 4 prognostic variables (N-layers, default=3, have used 10…)

***Seperate Explicit Snow Energy Budget**: Snow scheme ONLY called where snow is falling or where is exists already

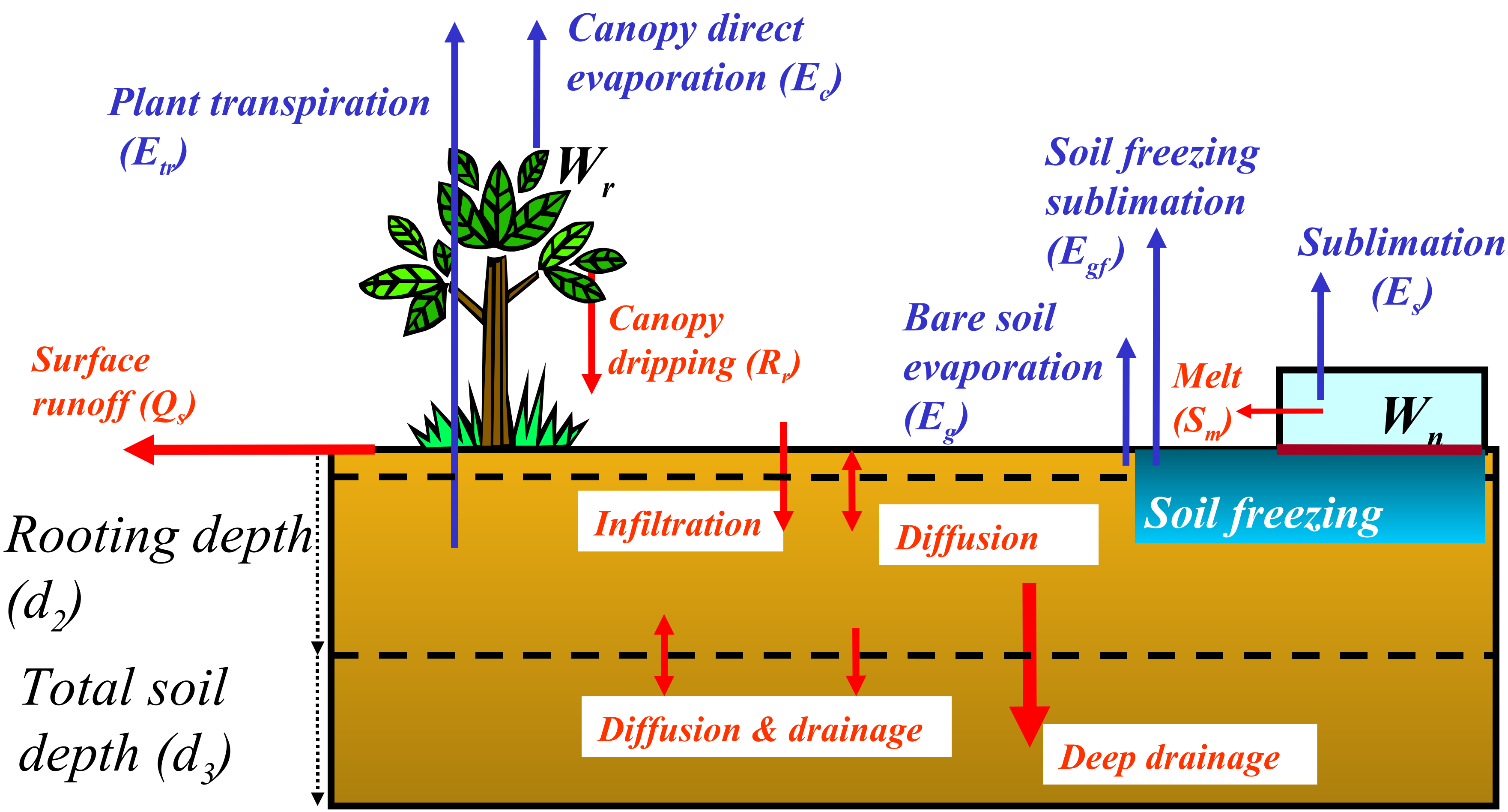
$$\frac{\partial W_s}{\partial t} = (P_n + P_{rn} - R_{l\,N} - E_n)$$

$$\frac{1}{\rho_{s\,i}}\frac{\partial \rho_{s\,i}}{\partial t} = \frac{\sigma_{s\,i}}{\eta_{s\,i}\left(T_{s\,i}, \rho_{s\,i}\right)} + a_{sc}\exp\left[-b_{sc}\left(T_f - T_{s\,i}\right) - c_{sc}\max\left(0,\ \rho_{s\,i} - \rho_{sc}\right)\right]$$

$$H\left[\begin{array}{l} c_{s\,i} D_{s\,i}\dfrac{\partial T_{s\,i}}{\partial t} = G_{s\,i-1} - G_{s\,i} - F_{s\,i} \\ \dfrac{\partial W_{l\,i}}{\partial t} = R_{l\,i-1} - R_{l\,i} + F_{s\,i}/L_f \qquad (W_{l\,i} \le W_{l\,i\,\max}) \end{array}\right.$$

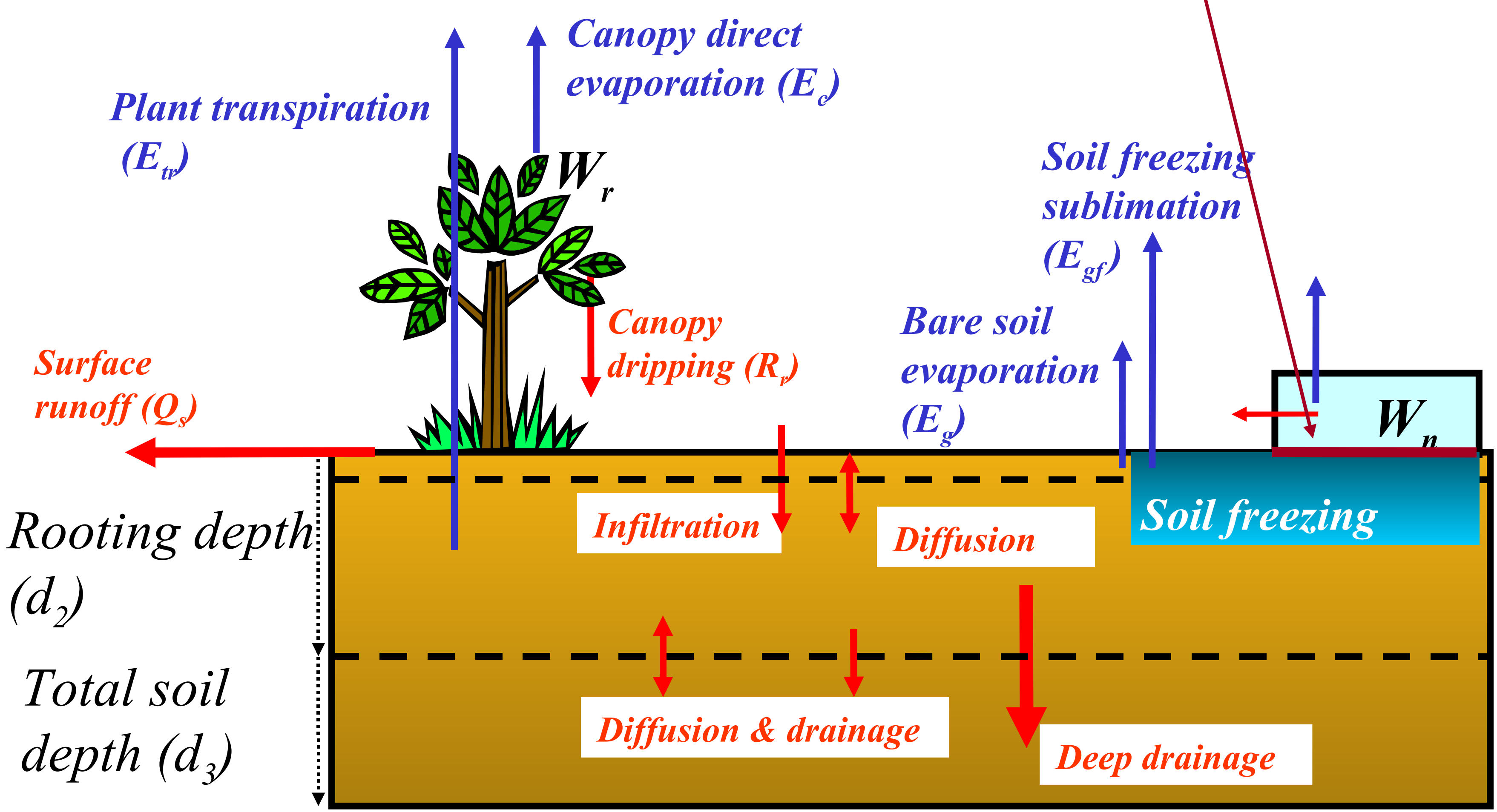
Plus the same albedo Eq

$$
\begin{aligned}
\frac{1}{C_T}\frac{\partial T_s}{\partial t} = & (1-p_n)\left[R_g\,(1-\alpha)+\epsilon\left(R_{at}-\sigma {T_s}^4\right)-H-LE\right] \\
& + p_n\left[J_{s\,N}+Q_{s\,N}+c_w\,R_{l\,N}\,(T_f-T_s)\right] \\
& - \frac{2\pi}{\tau C_T}(T_s-T_2)+L_f\,F_{sw}
\end{aligned}
$$



$$\frac{1}{C_T}\frac{\partial T_s}{\partial t} = (1-p_n)\left[R_g\,(1-\alpha)+\epsilon\left(R_{at}-\sigma {T_s}^4\right)-H-LE\right] + p_n\left[J_{s\,N}+Q_{s\,N}+c_w\,R_{l\,N}\,(T_f-T_s)\right] - \frac{2\pi}{\tau C_T}(T_s-T_2)+L_f\,F_{sw}$$

Lower snowpack boundary condition



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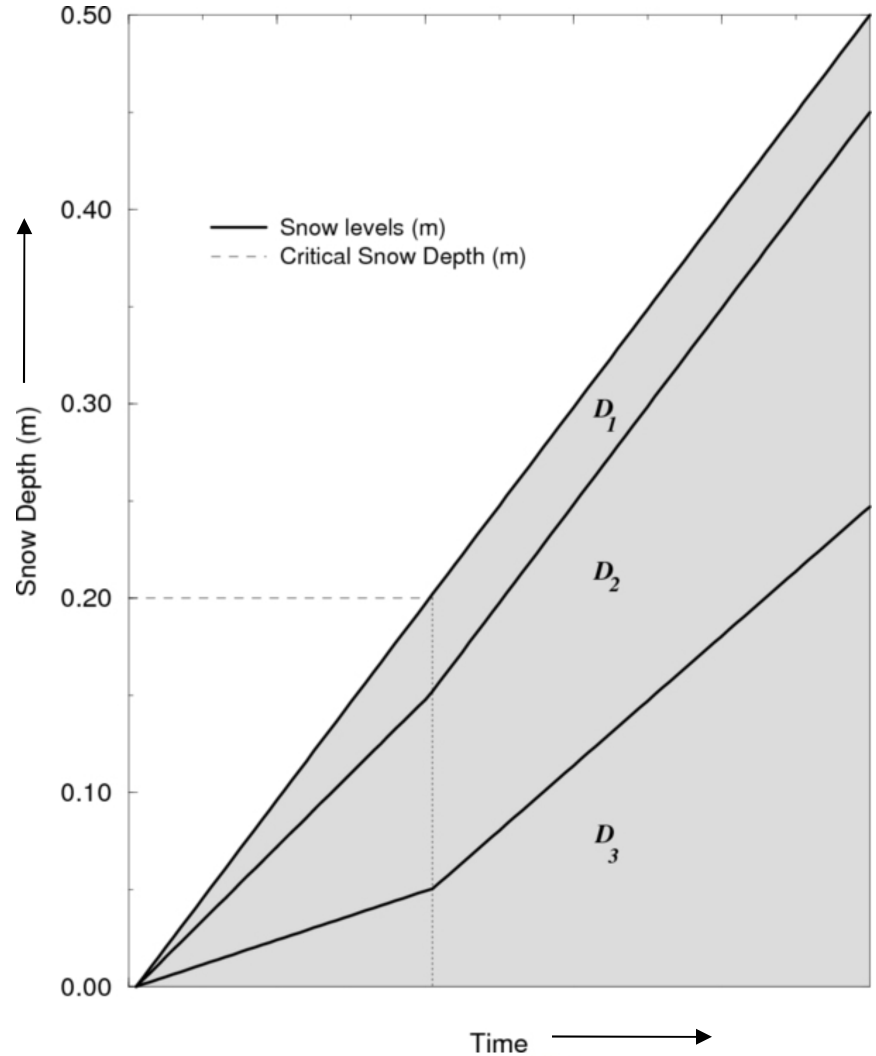
Time varying layer thicknesses

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



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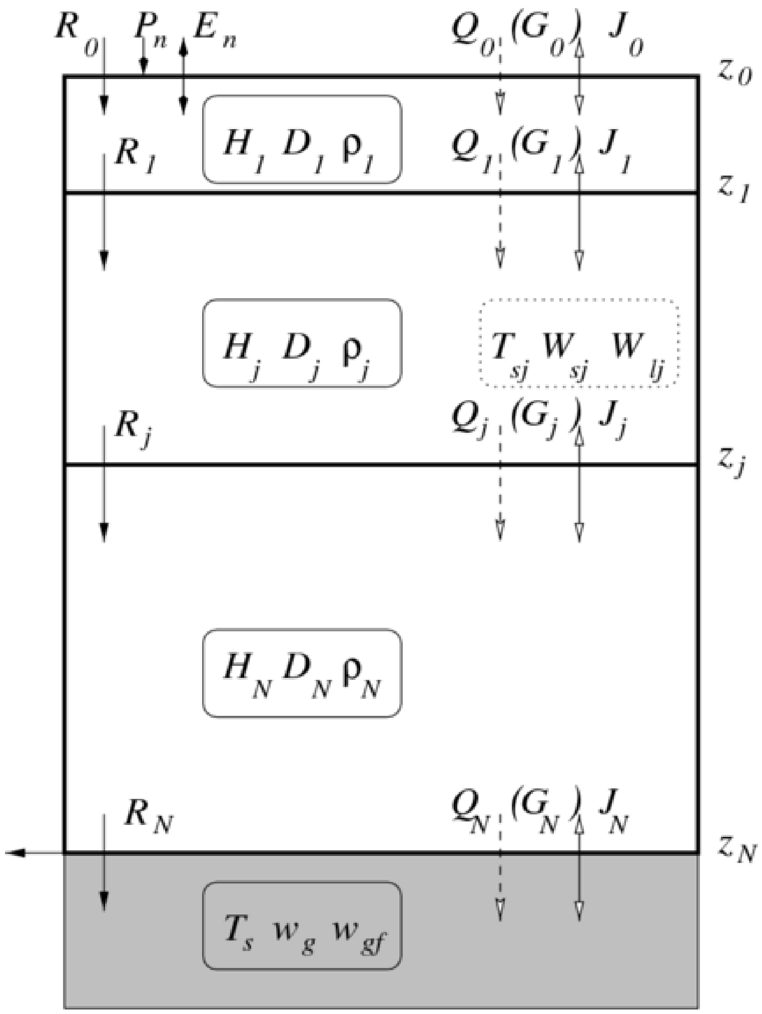
Grid and numerical setup essentially the same as for the soil heat diffusion Equation (DIF)



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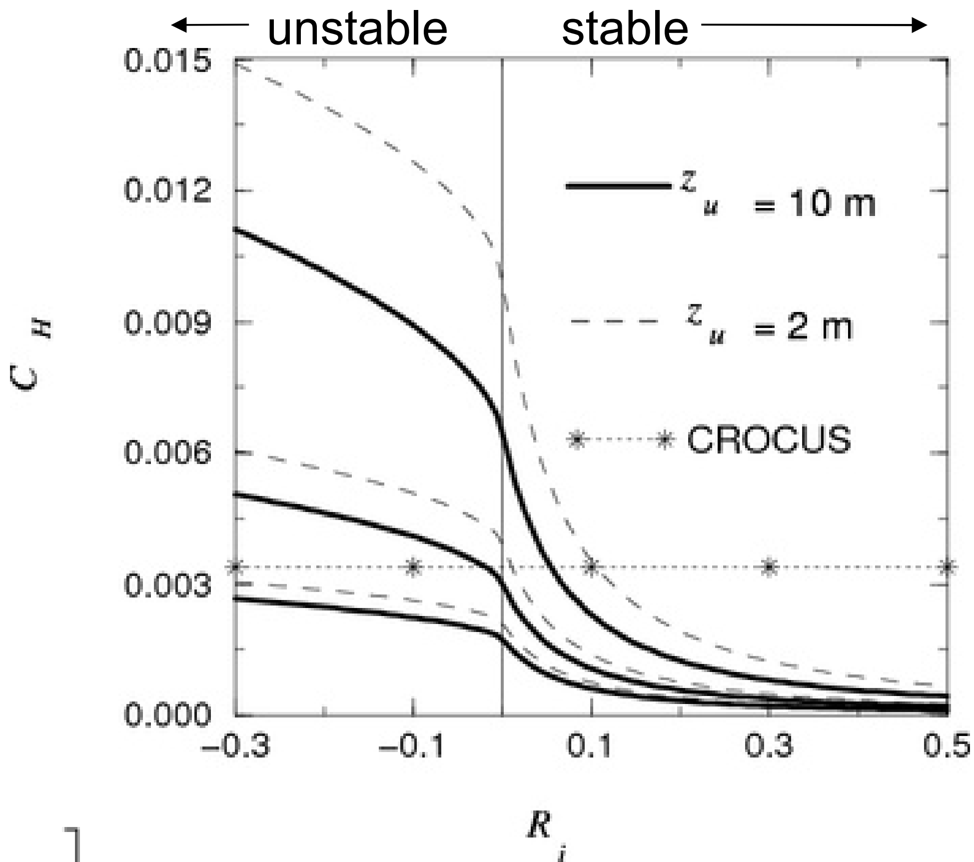
Richardson number limit options (CSNOWRES=RIL) for snow 3-L

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



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

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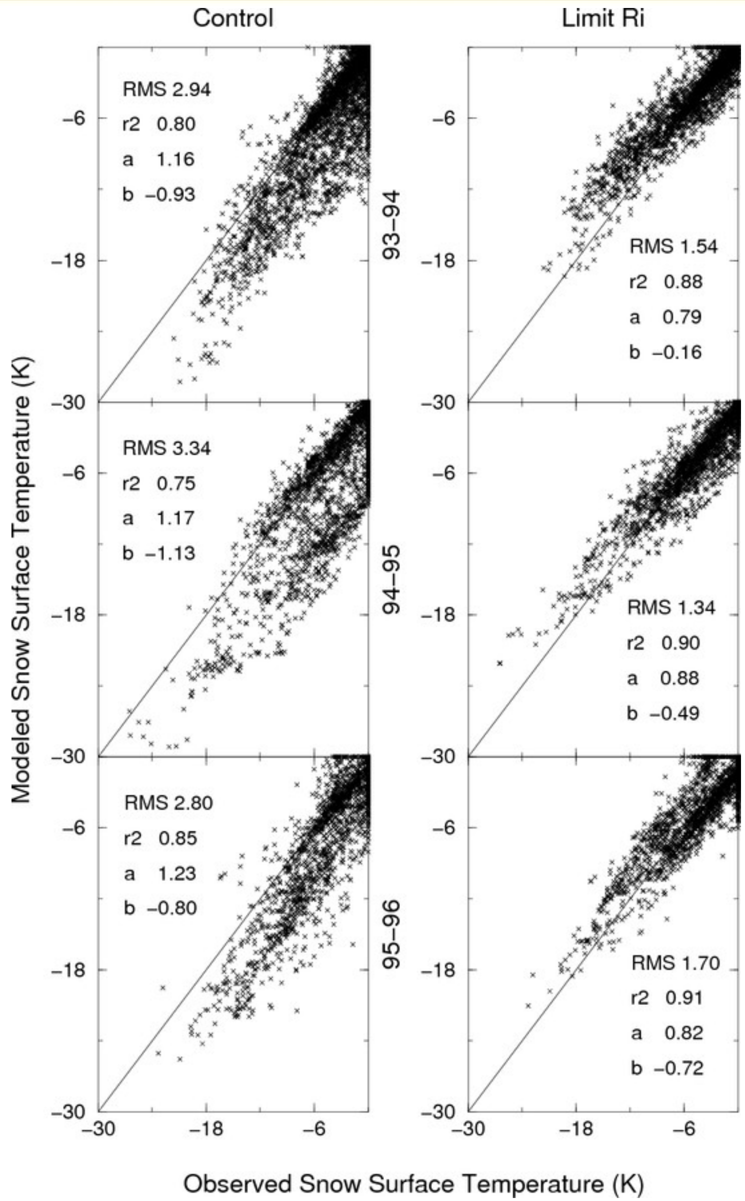
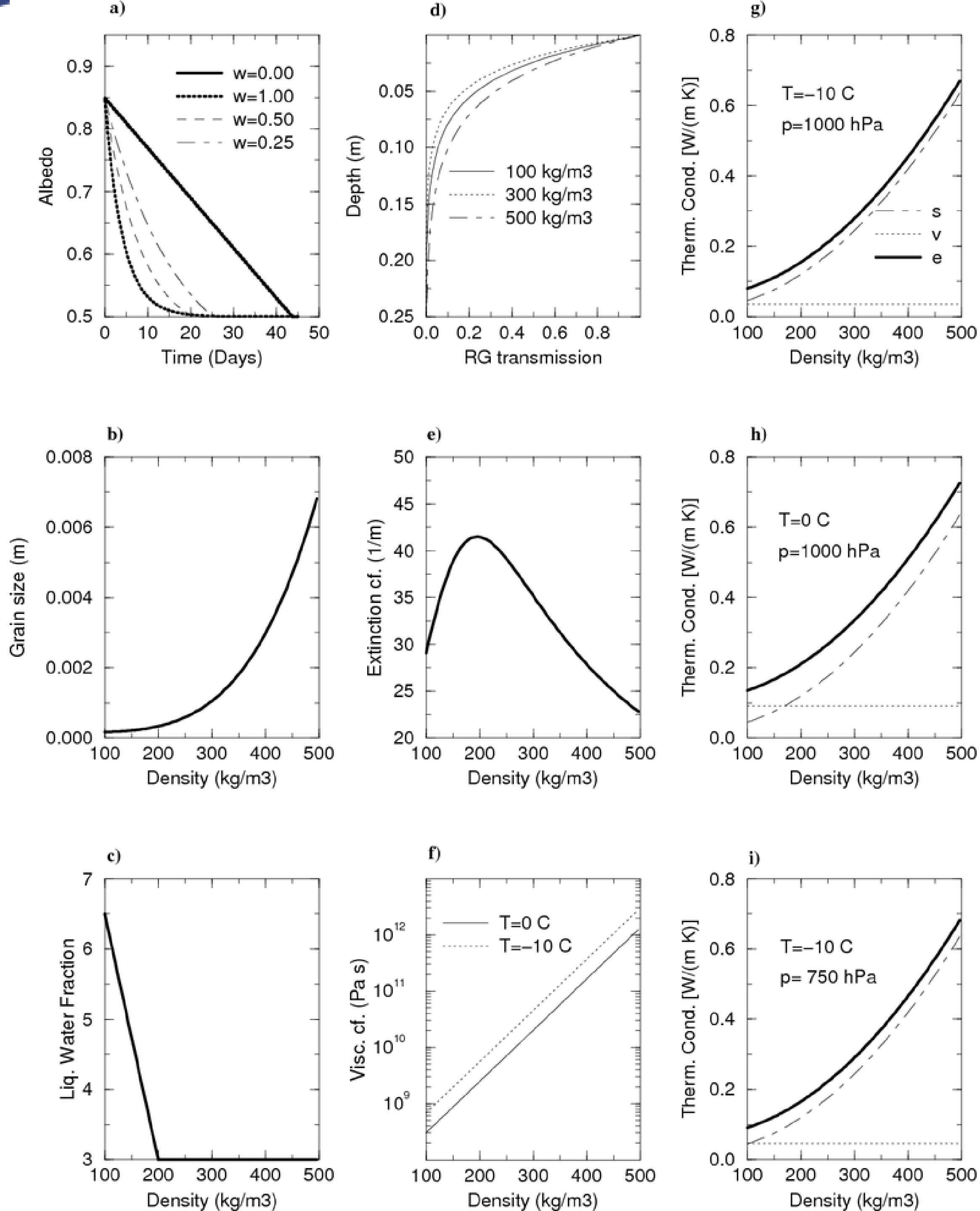


Example using RIL:

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

cnrs

METEO FRANCE
Toujours un temps d'avance



3-L physics summary

Alot based on Anderson (1976) and CROCUS

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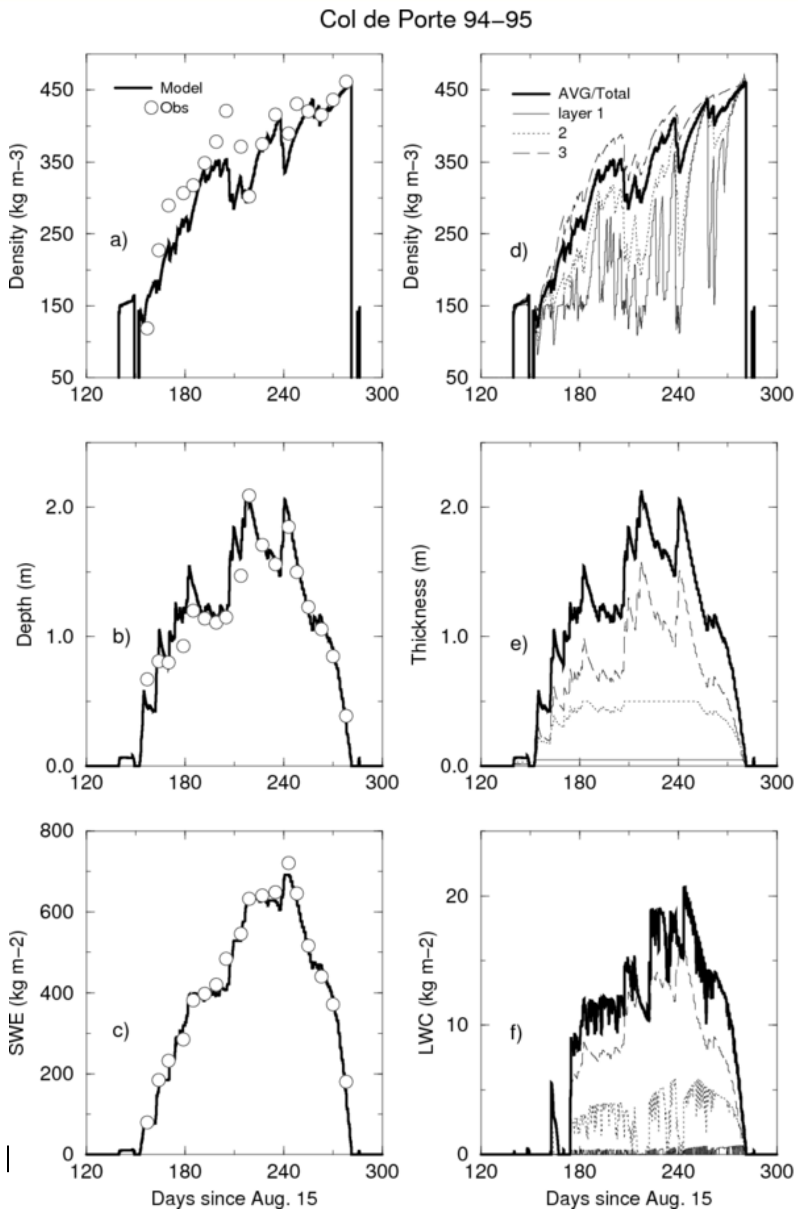

ISBA-ES

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

Observed SWE, Depth

Using default 3L configuration

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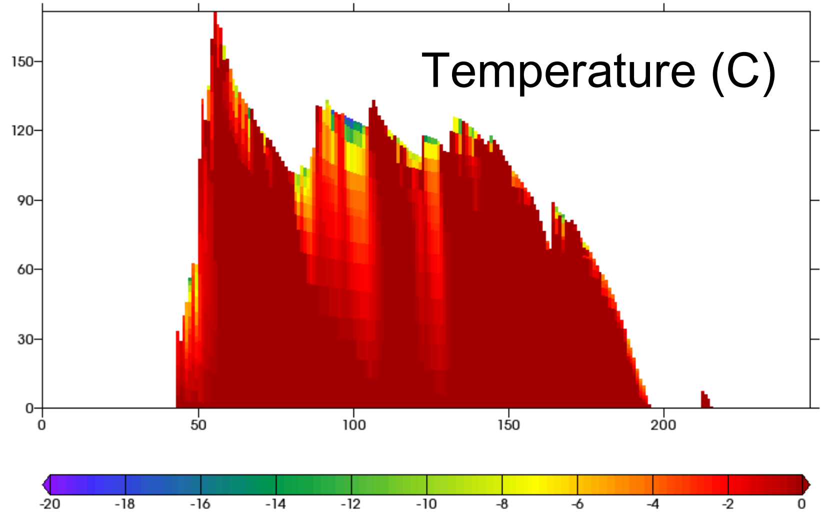
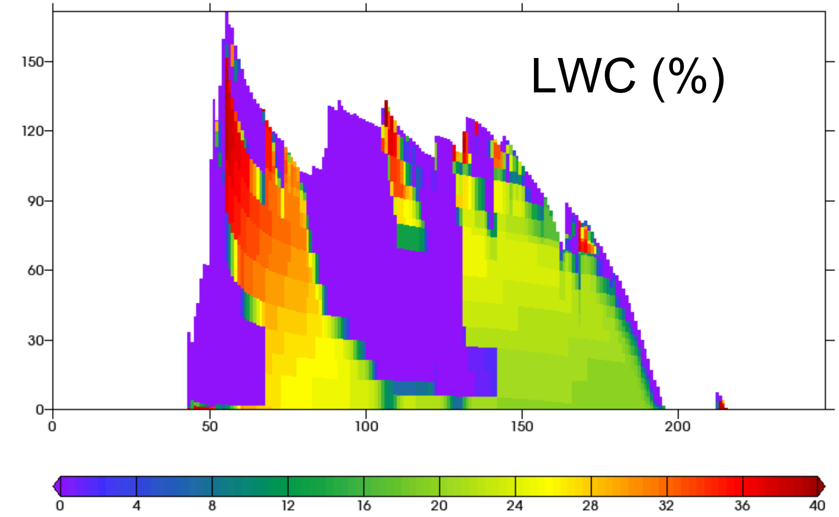
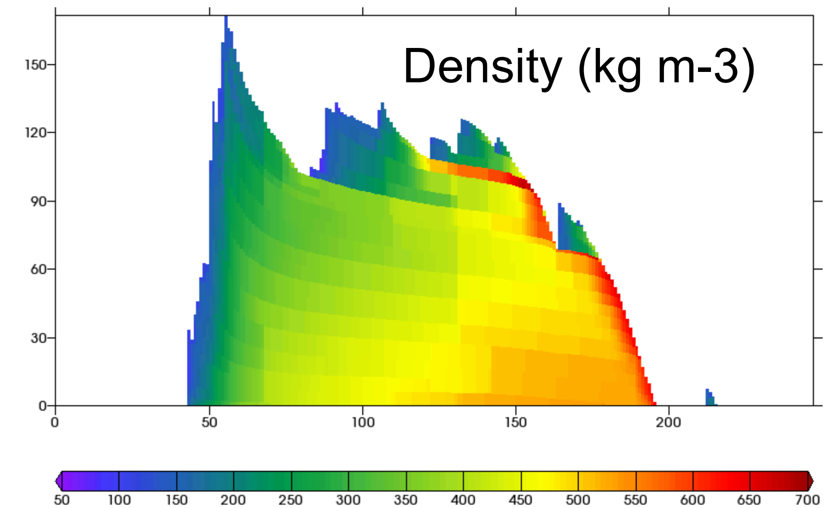




Profile – Simulations for Col de Porte

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



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Global Scale Simulation from 1986-2006 (ISBA-Offline, D95)

Forcing input: Princeton Forcing

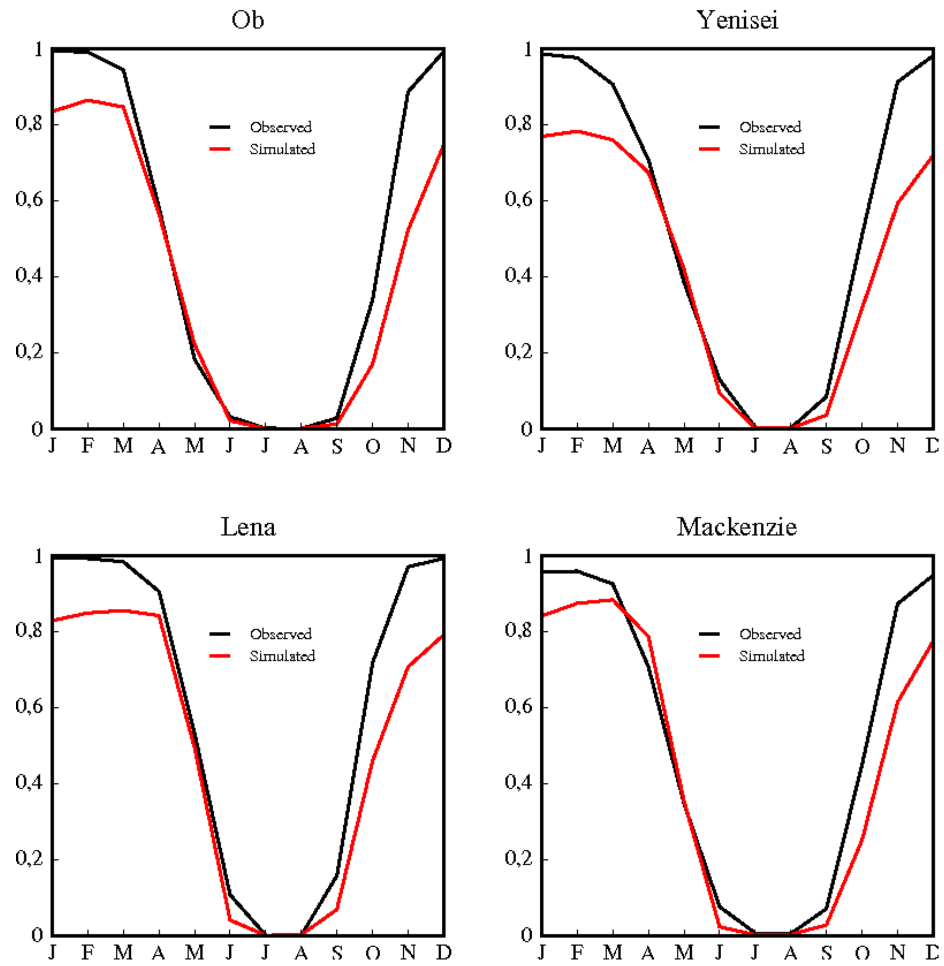
•Based on NCAR-NCEP reanalysis

•Precip: gridded obs+TRMM…

•hybridized ➔ monthly precip totals match GPCC-V4)

Evaluation:

•NSIDC ➔ Satellite based, 1x1 degree product



From Alkama et al., 2010

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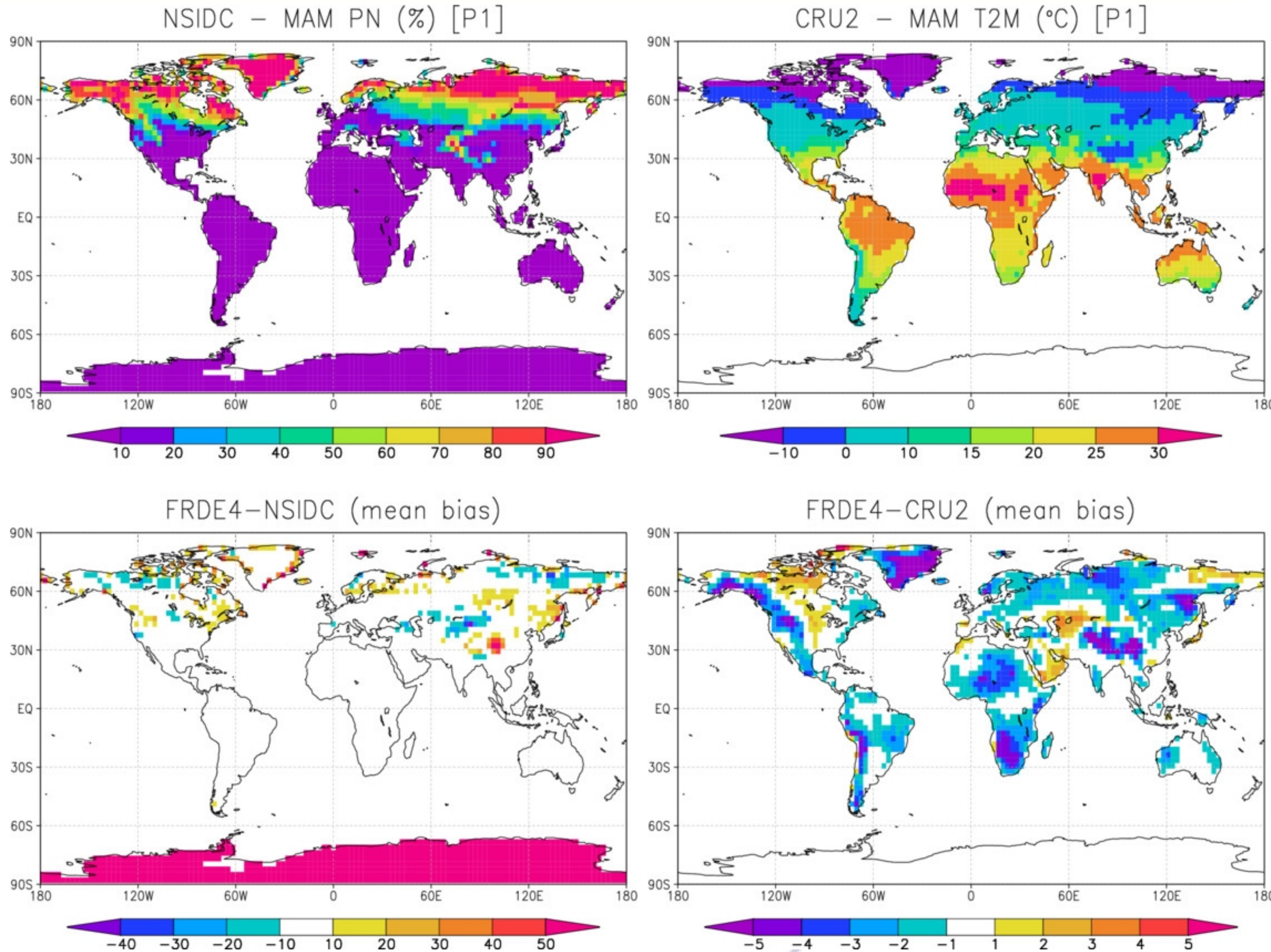
Coupled GCM snow simulation

ARPEGE-Clim using Forced SSTs (Stéphane Sénési)

Climatological bias (1970-1999) of simulated snow (D95) cover (vs NSIDC) and T2M (vs CRU)



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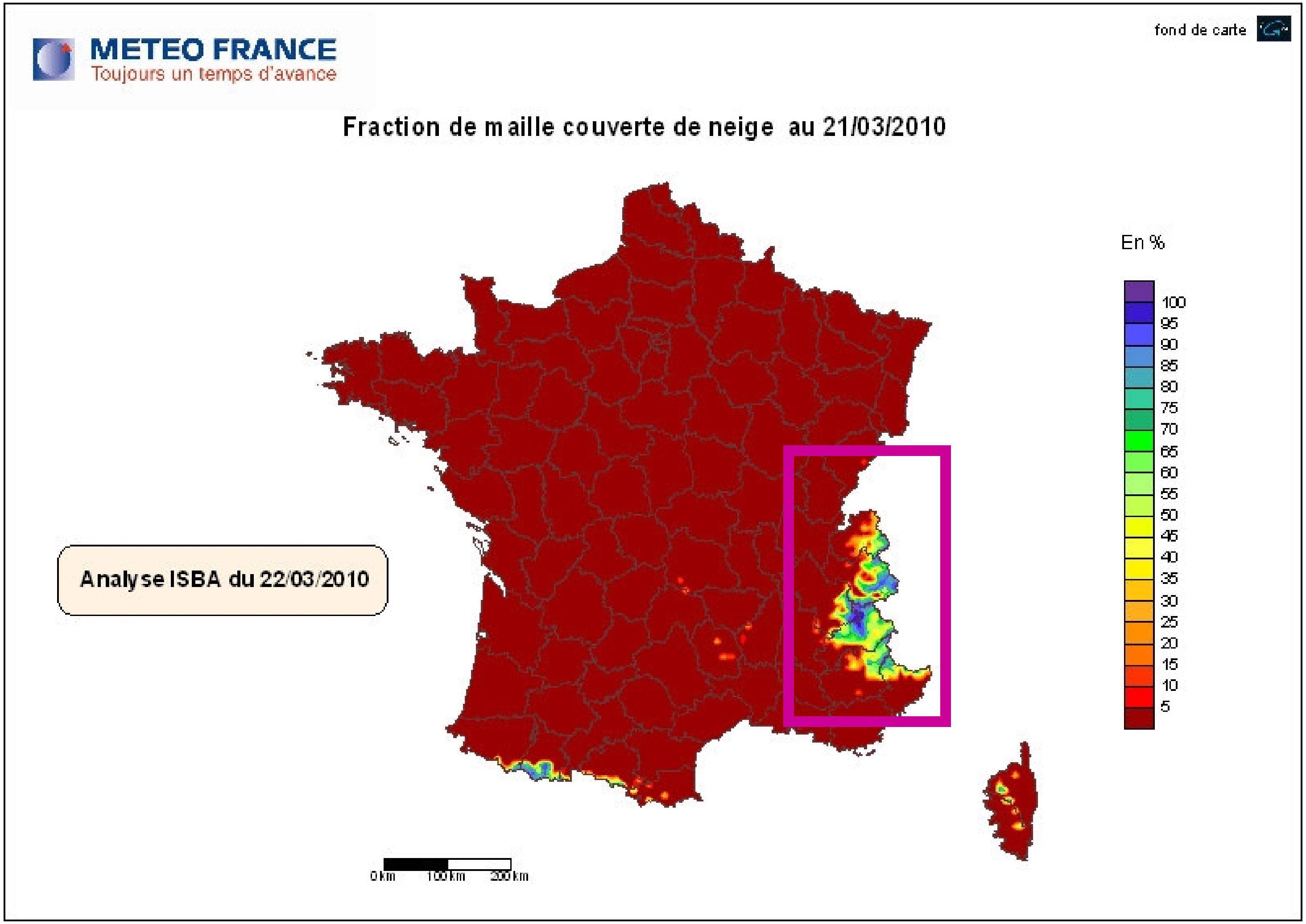
Operational **SIM**

SAFRAN

ISBA

MODCOU

8 km res



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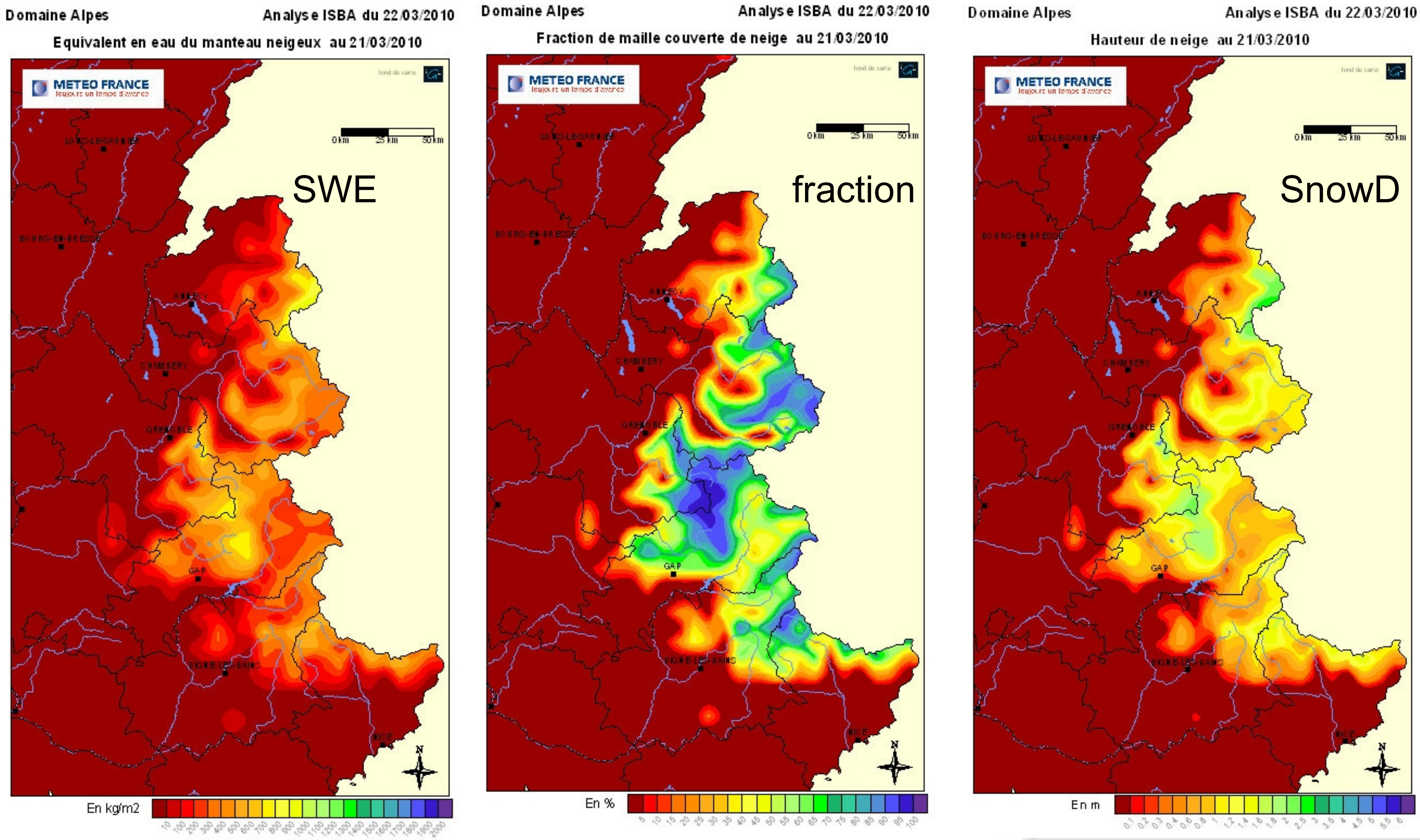

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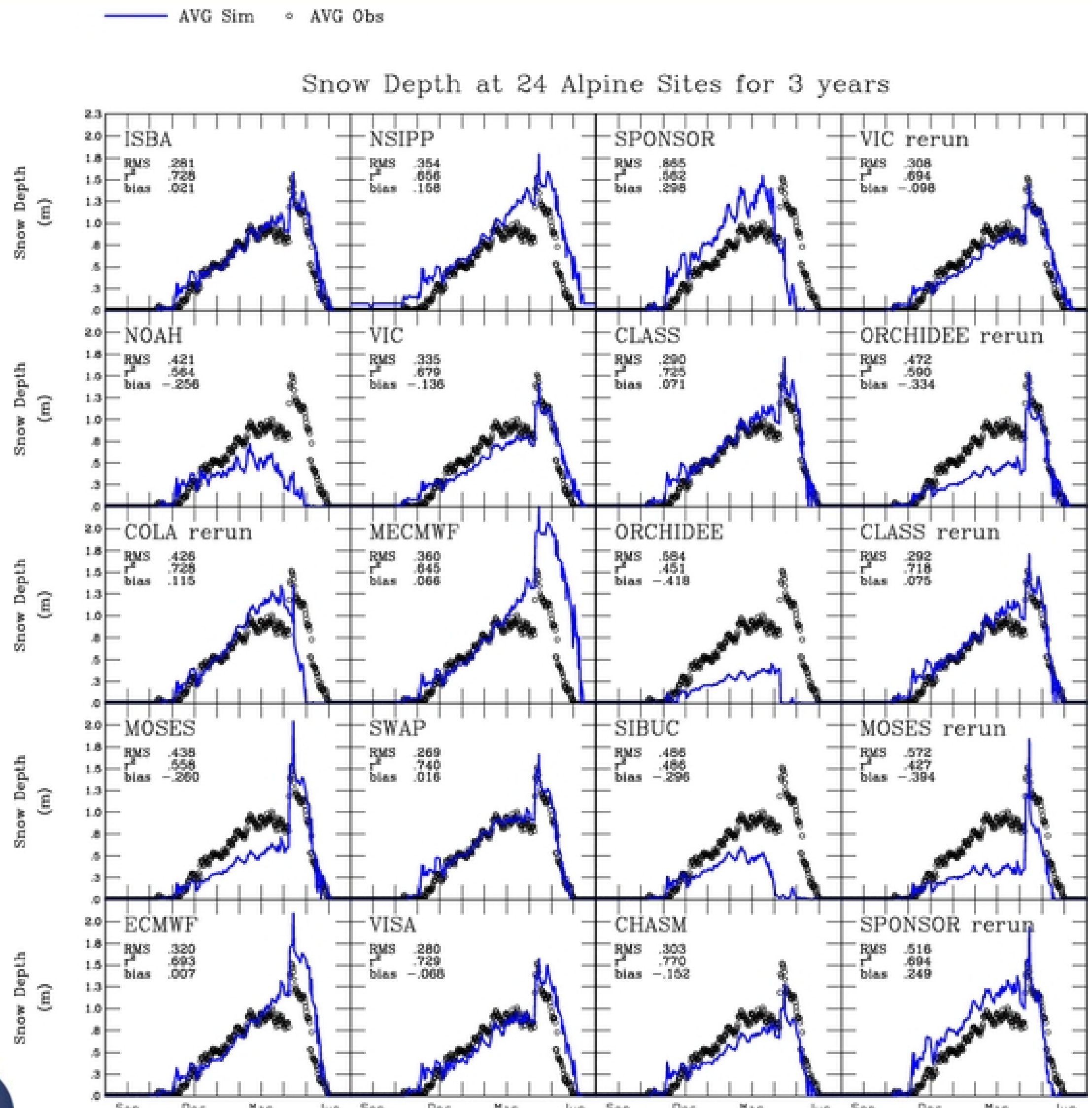

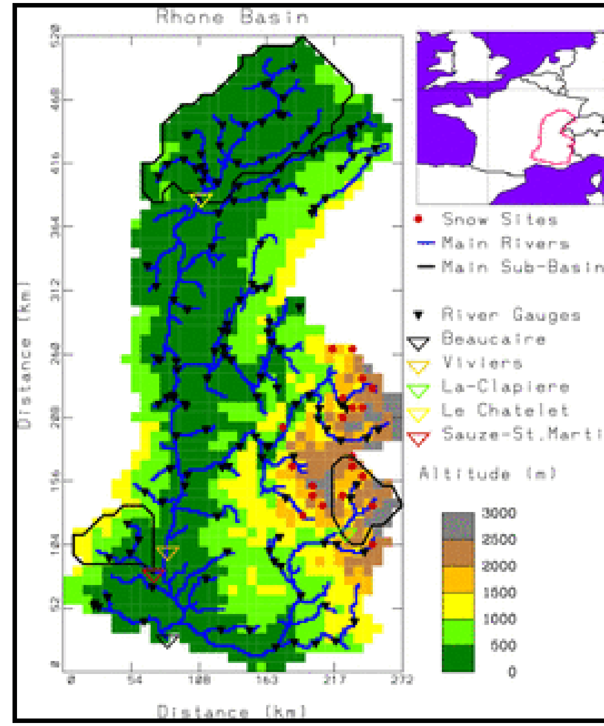

Average snow Depth for 24 sites in the Alps from the Rhone-AGG Exp.

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Summary

- 3 different models (approches currently available)

-_All can be used in offline mode currently, or with explicit fluxes (MesoNH or AROME)

- Ongoing evaluation/validation/development (NWP, GCM, Global or Regional Offline, hydrological, local scale….) Contributions?

Perspectives

- CROCUS in SURFEX (for detailed snow process studies), using code (when possible) and methodology of ISBA-ES

- Implicit coupling (ISBA-ES, then CORCUS)

- Still need work on sub-grid parameterizations !!!

- Explicit vegetation Canopy (See Gollvik talk) ➔

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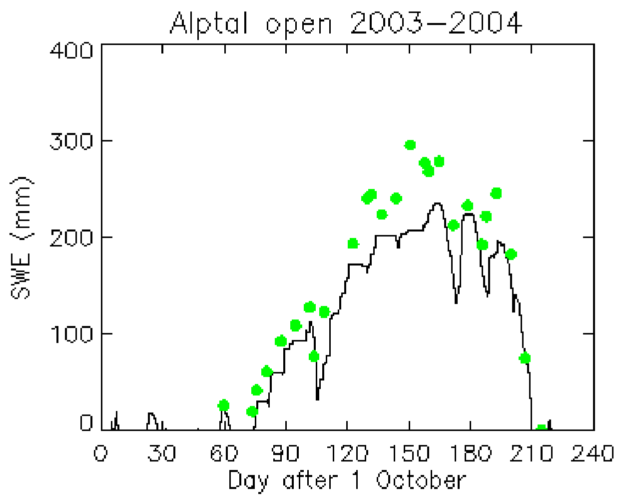
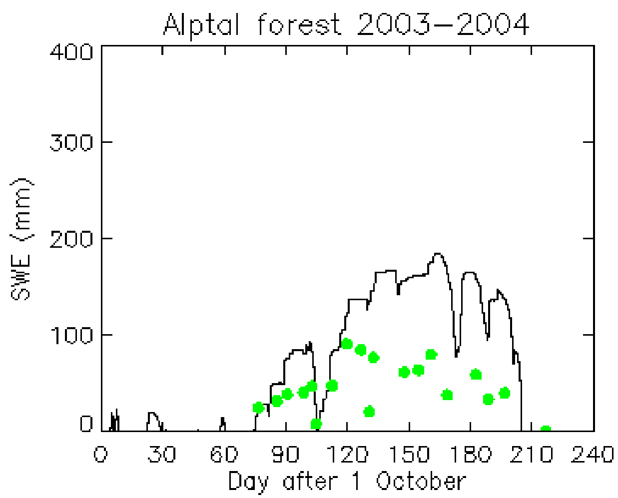
SNOWMIP2

R. Essery (in this very room!)
N. Rutteri and *many* colleagues!





ISBA-ES, 3layers

• Problem with representation of canopy interactions (lack thereof)

New Canopy➔ with Samuelsson, Gollvik, Lemoigne, Martin et al.

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

Bertrand Decharme (soil, hydrology)

SURFEX:

Eric Martin, Patrick LeMoigne, Stephanie Faroux

GAME-CNRM Météo-France

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