ISBA
(Interactions between the Surface Biosphere Atmosphere)

The model for **natural continental surfaces**

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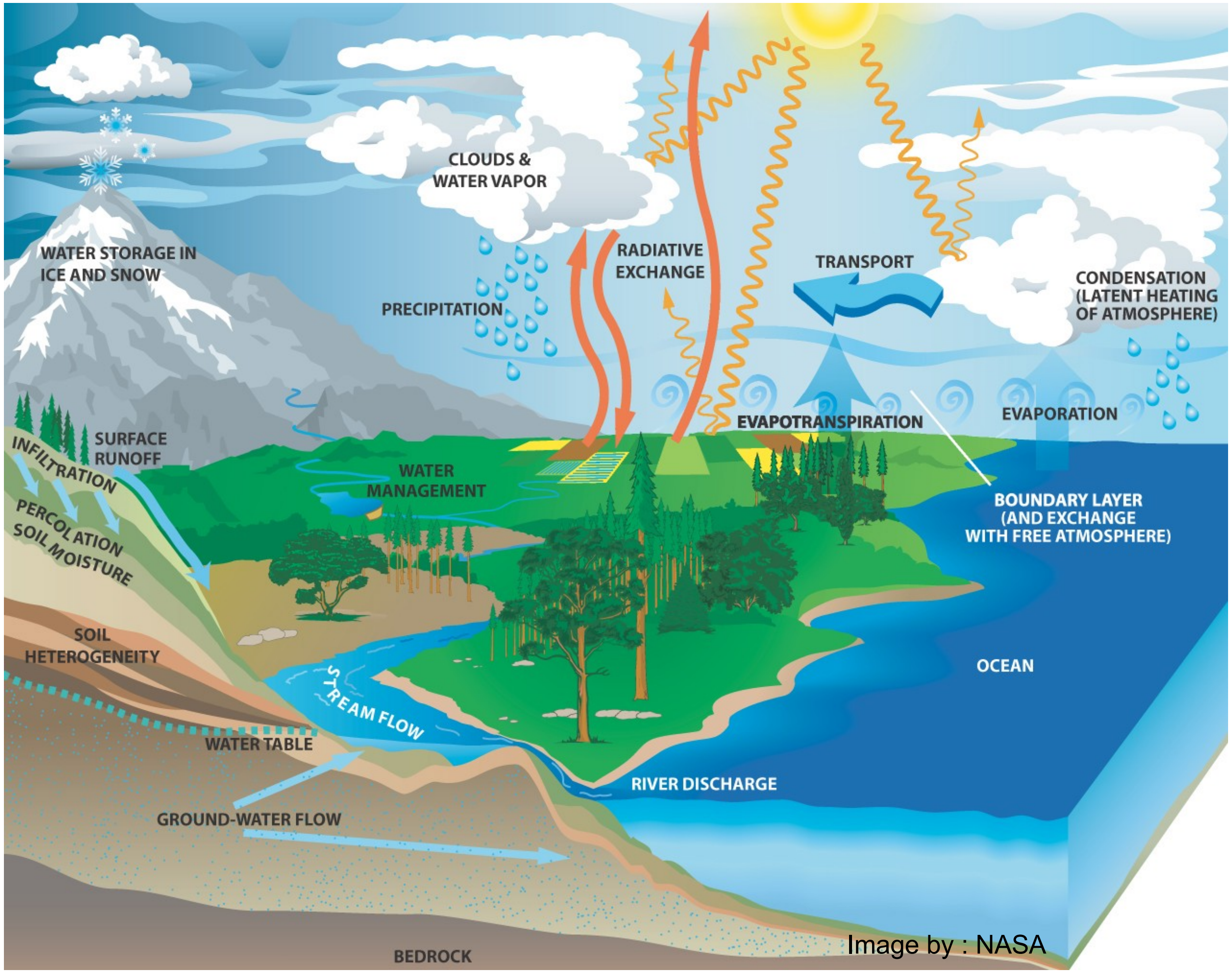
Land Surface Model (LSM) ISBA



- Numerical Weather Prediction (operational...)
- Climate
- Real-time Hydrometeorological Monitoring
- Avalanche Prediction
- Research (water resource monitoring, improved understanding, climate change impact studies...)

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Model of the « nature » part of SURFEX

Exchanges of energy, water, carbon, momentum (also aerosols/dust, snow) with the atmosphere and water mass exchanges with hydrology

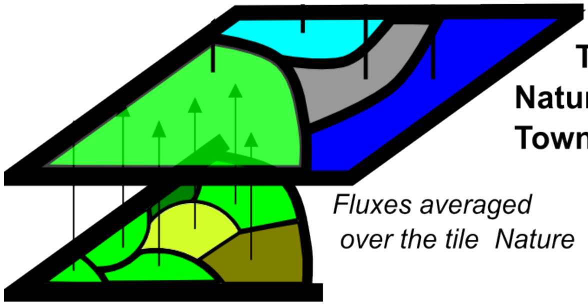
Work with the « mean » properties of the mesh (aggregation rules, or on a ma number of patches [1 to 12 (19), according to the user's choice]. In the cas of patches, each is independent (no lateral transfers).

<u>Input parameters</u>

- characterize type of sfc

<u>Physics :</u>

- Force restore model : energy and water
- Multilayer soil model « diffusion »
- Bulk or Multilayer Snow
- Photosynthesis and carbon cycle



Introduction : main parameters

Primary parameters **Secondary parameters**

Soil

Soil Organic Carbon (SOC)

Clay fraction (X_{clay})

Sand fraction (Y_{sand})

- Soil thermal and hydrological parameters [e.g. Saturation/porosity (Wsat)….etc.]
- Field capacity (W_{fc})
- Wilting point (W_{wilt})

Vegetation

Type of cover

- Stomatal/Canopy resistance [e.g. Minimal surface resistance (R_{smin}), …etc.]
- Leaf area index (LAI)
- Roughness lengths for momentum and heat z_0 and z_{0h}
- Fraction of vegetation (veg)

Both

- Soil depth (d_i) i =1,2,...
- Albedo (α)
- Emissivity(β)

* potentially evolving in time

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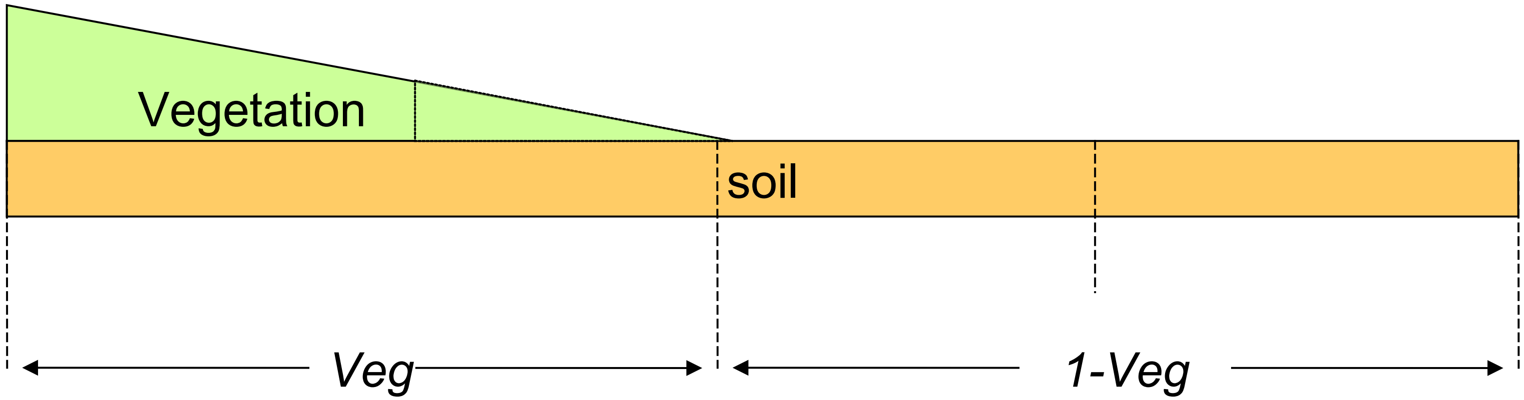
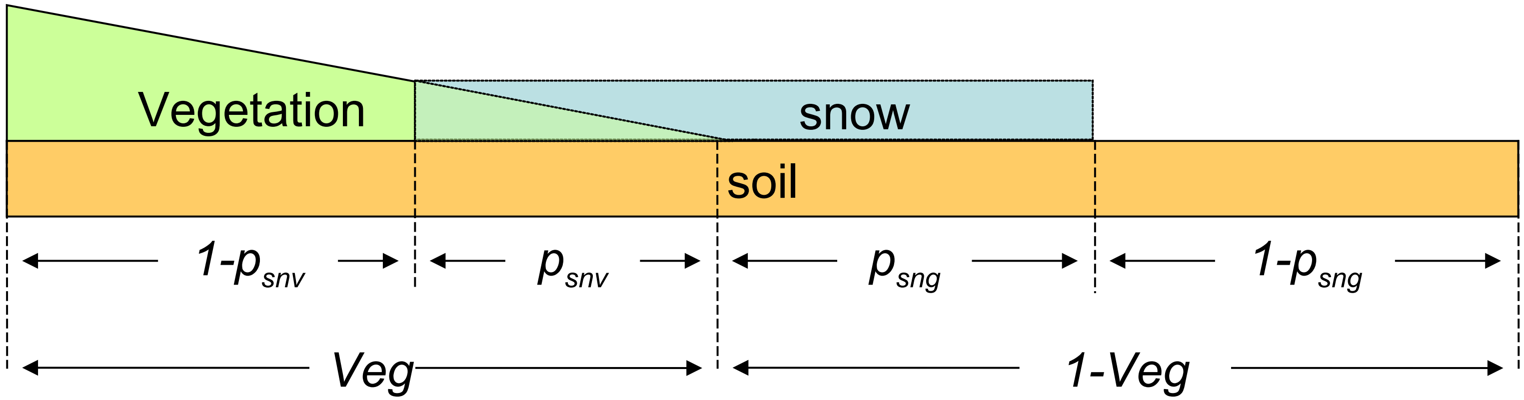
Description of the surface : fraction of vegetation and snow per patch



Description of the surface : fraction of vegetation and snow per patch



Snow fraction : $p_{sn} = p_{snv} + p_{sng}$

Albedo : $\alpha_{total} = (1-p_{snv})\,\alpha_{veg} + p_{sn}\,\alpha_{snow} + (1-p_{sng})\,\alpha_{soil}$

Emissivity : $\varepsilon_{total} = (1-p_{snv})\,\varepsilon_{veg} + p_{sn}\,\varepsilon_{snow} + (1-p_{sng})\,\varepsilon_{soil}$

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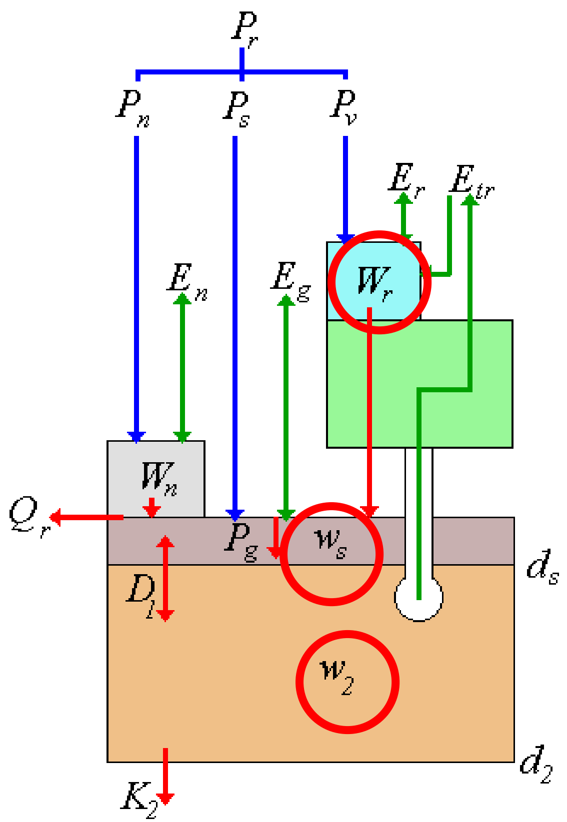
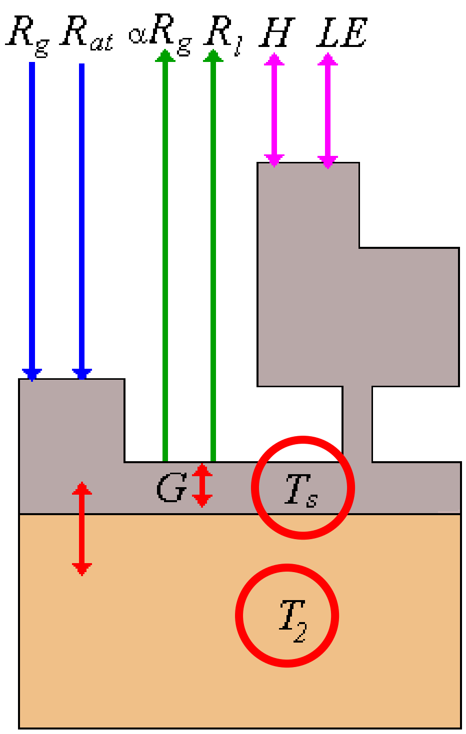
ISBA : soil description

Option Namelist : CISBA	Temperature profile	Hydrology profile
2-L	Ts : surface temperature T2 : deep temperature	- Surface layer (~1cm) - Root zone
3-L		- Surface layer (~1cm) - Root zone - Sub-root zone
DIF	N temperature	N soil layers (default = 14 layers) - Root zone depends on vegetation - Richard's equation for water - Heat diffusion for T_g

ISBA : the basic FR version : CISBA=2-L





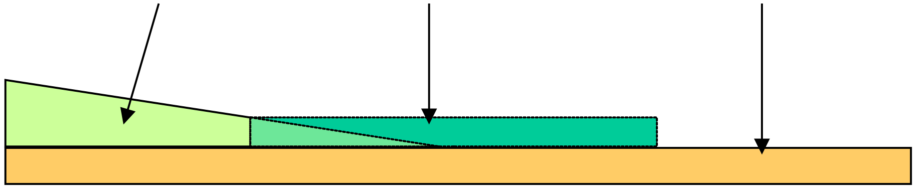
5 prognostic variables **(except snow) :** *T_s, T_2, W_r, w_g, w_2*

Surface energy budget : temperature

$$\frac{\partial T_s}{\partial t} = C_T\left(R_n - H - LE\right) - \frac{2\pi}{\tau}\left(T_s - T_2\right)$$

$$\frac{\partial T_2}{\partial t} = \frac{1}{\tau}\left(T_s - T_2\right)$$

Inertia coefficent : $C_T = 1 / \left[\frac{veg\left(1 - p_{snv}\right)}{C_v} + \frac{p_{sn}}{C_n} + \frac{\left(1 - veg\right)\left(1 - p_{sng}\right)}{C_g} \right]$



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Hydrological budget : evapotranspiration (snow-free part)

$$E = E_g + E_{veg} \longrightarrow E_{veg} = E_c + E_{ETR}$$

$$E_{veg} = \underbrace{veg\,(1-p_{nv})}_{\text{Snow free vegetation fraction}}\;\underbrace{\rho_a\, C_H\, V_a\, h_v\, [q_{sat}(T_s) - q_a]}_{\text{Surface – Atmosphere exchange}}$$

$$E_g = \underbrace{(1-veg)\,(1-p_{ng})}_{\text{Snow and vegetation free fraction}}\;\underbrace{\rho_a\, C_H\, V_a\, [\alpha\, q_{sat}(T_s) - q_a]}_{\text{Surface – Atmosphere exchange}}$$

Hydrological budget : evapotranspiration

Baresoil component:

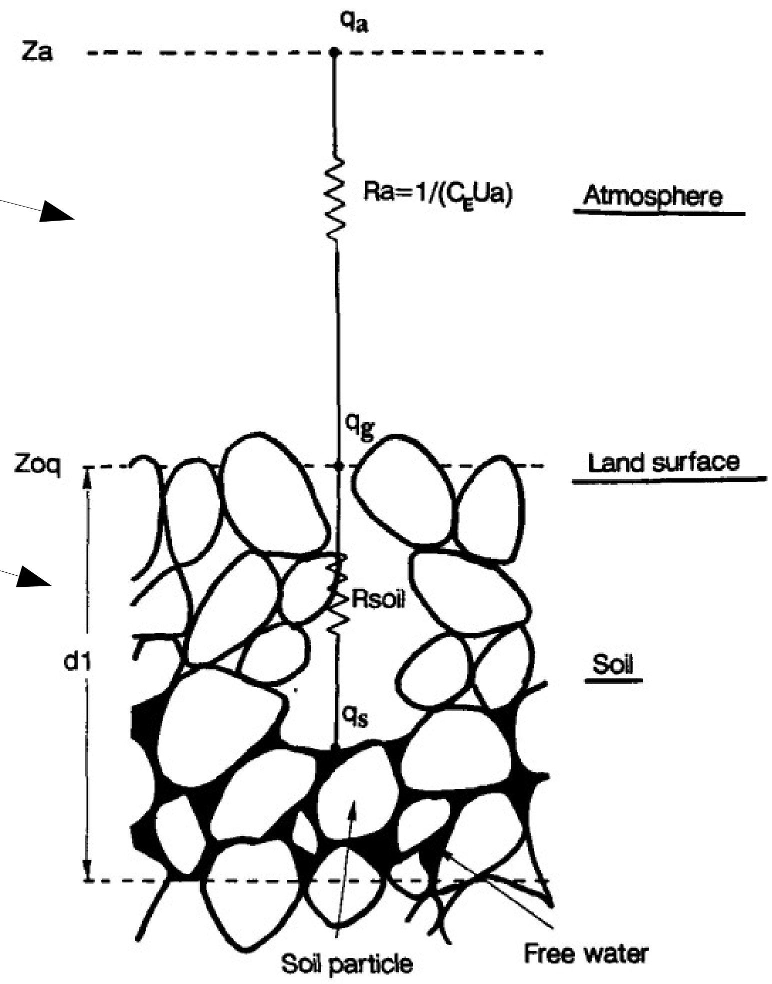
$$E_g = \frac{\rho_a}{R_a}\left[\alpha\, q_{sat}\,(T_s)\ -\ q_a\right]$$

q_g

$$R_a = \frac{1}{C_H\, V_a}$$

$\alpha \rightarrow$ depends on moisture in uppermost soil layer….

Kondo et al., 1990



Hydrological budget : evapotranspiration

Evapotranspiration from vegetation :

$$E_{veg} = veg\left(1 - p_{nv}\right)\rho_a C_H V_a h_v \left[q_{sat}\left(T_s\right) - q_a\right]$$

Snow free vegetation fraction

Surface – Atmosphere exchange

Haltead coef

$$h_v = \delta + \left(1 - \delta\right) R_a / \left(R_a + R_s\right) \quad with \quad R_a = \frac{1}{C_H V_a}$$

$$E_{veg} = E_c + E_{tr}$$

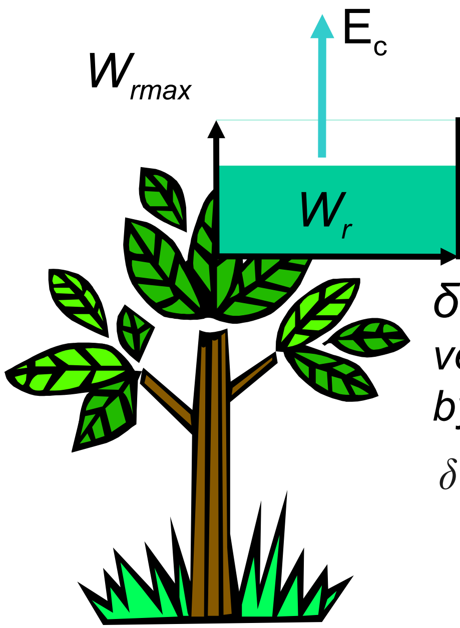
$$E_c = veg\ (1 - p_{nv})\ \rho_a \left(\frac{\delta}{R_a}\right) \left[q_{sat}\left(T_s\right) - q_a\right]$$

Evaporation (water on veg)

$$E_{tr} = veg\ (1 - p_{nv})\ \rho_a \left(\frac{1 - \delta}{R_a + R_s}\right) \left[q_{sat}\left(T_s\right) - q_a\right]$$

Transpiration

Surface hydrologic budget : interception reservoir

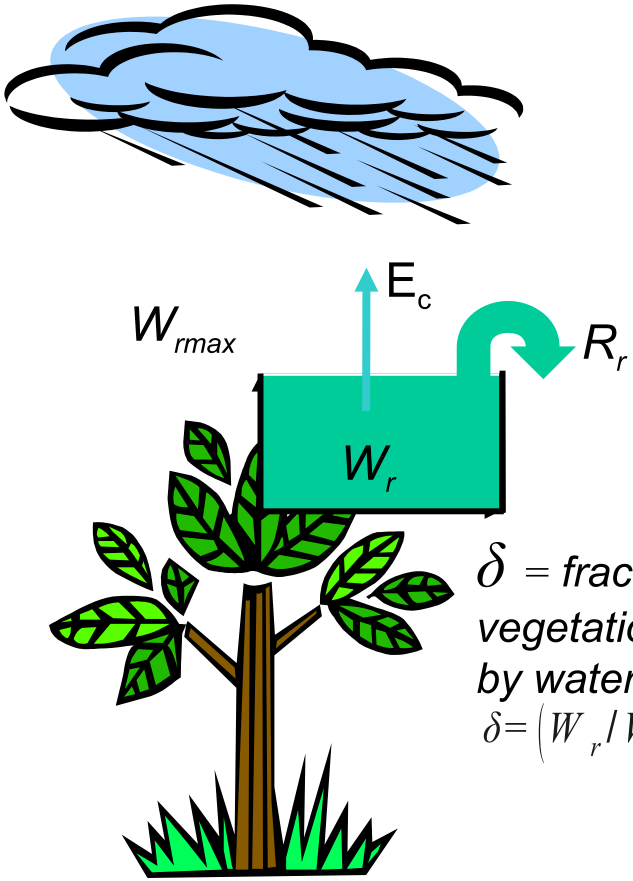


δ = fraction of vegetation covered by water

$$\delta = \left(W_r / W_{r\max} \right)^{2/3}$$

Deardorff, 1978.

Surface hydrologic budget : interception reservoir



δ = *fraction of vegetation covered by water*

$\delta = \left(W_r / W_{r\max}\right)^{2/3}$

$$\frac{\partial W_r}{\partial t} = \left(1 - p_{nv}\right) vegP - E_c - R_r$$

$$R_r = \max\left(0, \frac{W_r - W_{r\max}}{\Delta t}\right)$$

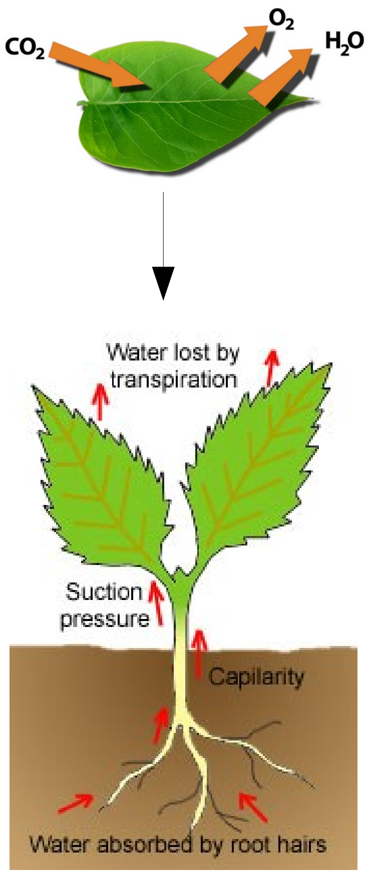
$$W_{r\max} = 0.2\, vegLAI$$

Deardorff, 1978.

Hydrological budget : evapotranspiration

Transpiration:

$$E_{tr} = \rho_a (1-\delta) \frac{[q_{sat}(T_s) - q_a]}{R_a + R_s}$$



Simple (Jarvis) option : NO explicit photosynthesis

$$R_s = \frac{R_{s\,min}}{LAI} \frac{F_a}{F_2} \quad with \quad \begin{cases} F_a = \text{Atmospheric constrains (SW, } T_a\text{, } Q_a\text{)} \\ F_2 = max\left[0, min\left(1, \frac{w_{root} - w_{wilt}}{w_{fc} - w_{wilt}}\right)\right] \end{cases}$$

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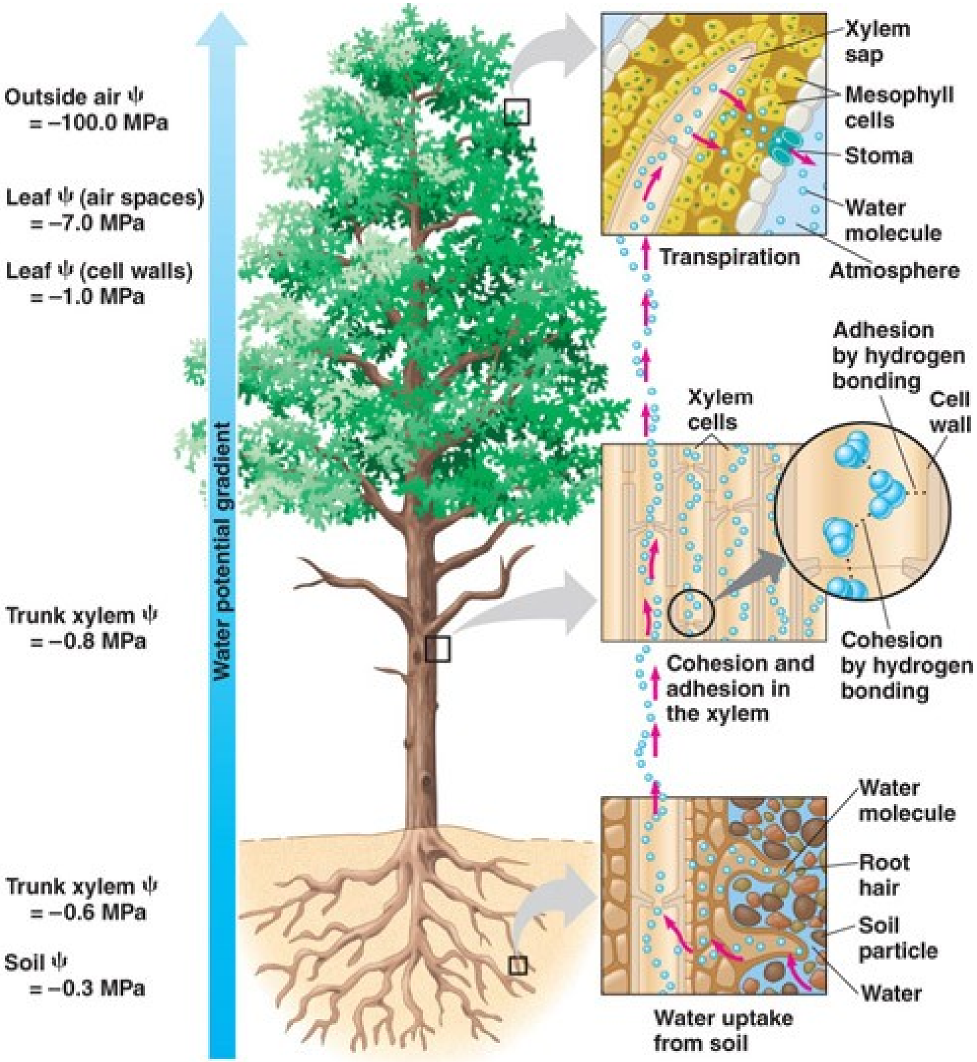
Hydrological budget : evapotranspiration

Transpiration:

$$E_{tr} = \rho_a (1-\delta) \frac{[q_{sat}(T_s) - q_a]}{R_a + R_s}$$

In reality:
Canopy resistance includes many processes: soil water extraction (root resistance, profile/depth, stress), photosynthesis (vapor pressure deficit, light/shading, CO_2 concentration, T, base resistance…)
→ **ISBA-Ags options**



Hydrology : transfers in the soil (FR)

$$\frac{\partial w_1}{\partial t} = \frac{C_1}{\rho_w d_1}\left[I_r - E_g\right] - D_1 \qquad w_{min} \leq w_1 \leq w_{sat}$$

$$\frac{\partial w_2}{\partial t} = \frac{1}{\rho_w d_2}\left(I_r - E_g - E_{tr}\right) - K_2 \qquad w_{min} \leq w_2 \leq w_{sat}$$

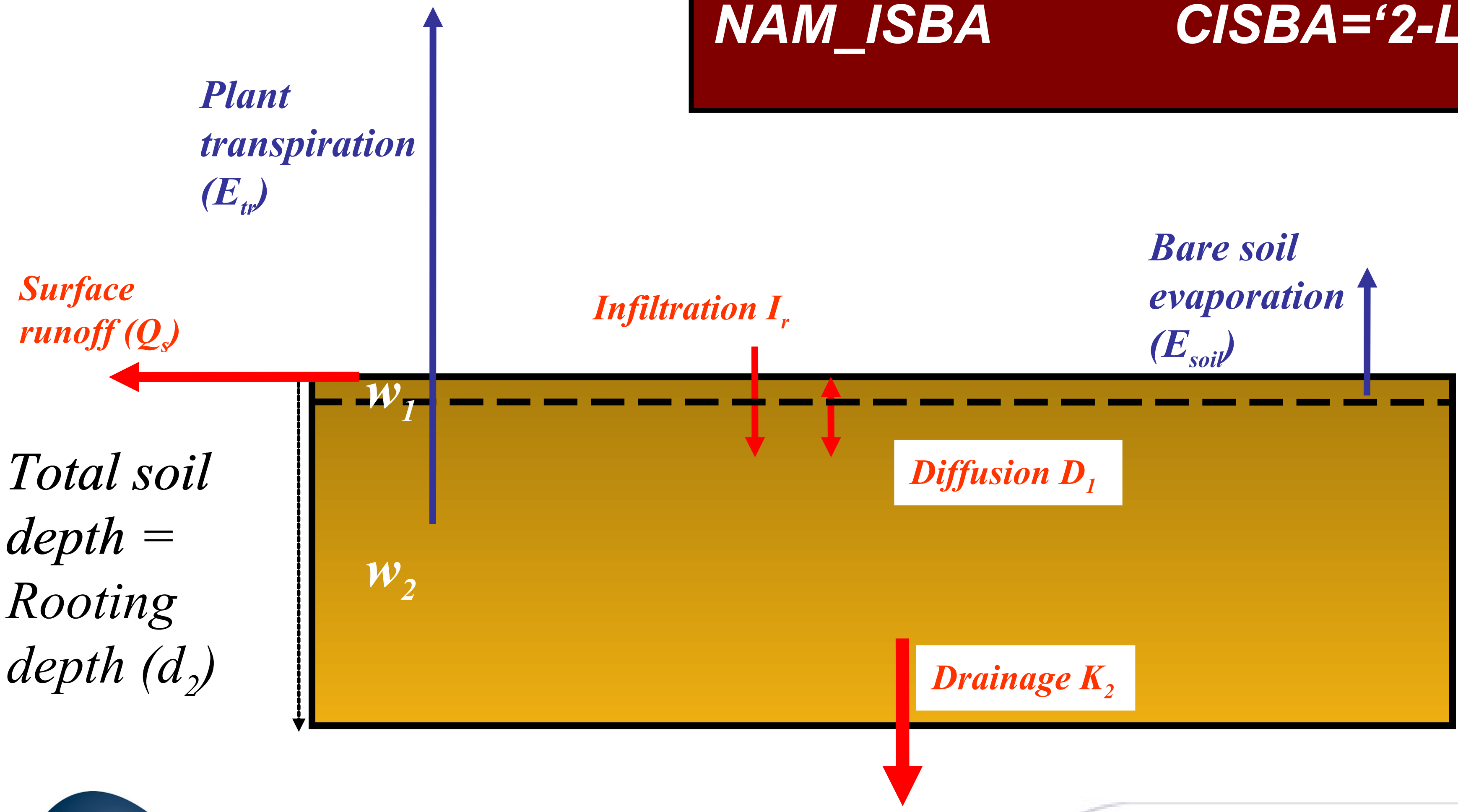
w_2 : total water content, w_1 : fraction of w_2 near the surface (superficial)

Infiltration : $I_r = (1 - veg)P + R_r + S_m - Q_s$

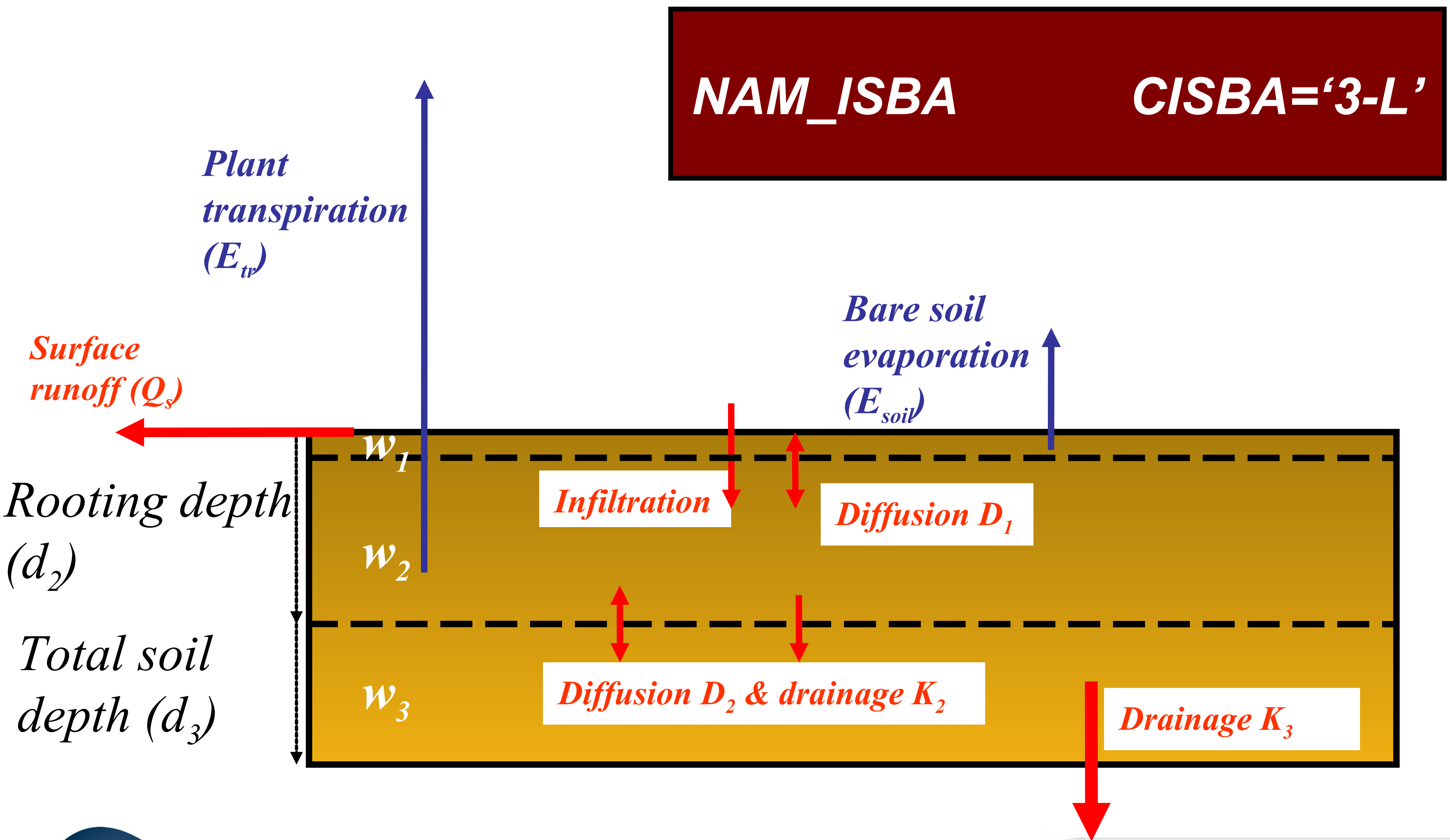
Surface runoff : $Q_s = \frac{d_2 \rho_w}{\Delta t}\max\left(0, w_2 - w_{sat}\right)$

Water Budget : Soil moisture

NAM_ISBA CISBA='2-L'



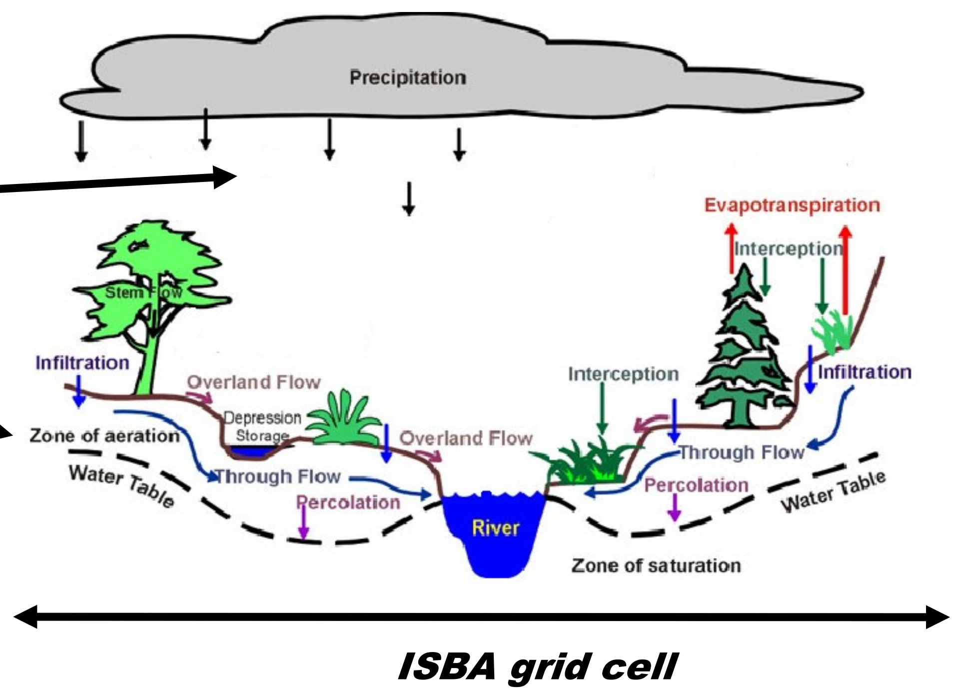
Water Budget : Soil moisture



Hydrologic specific options

Spatial variability of hydrologic processes :

- *Precipitation*
- *Topography*
- *Soil properties*
- *Vegetation (Tiles)*



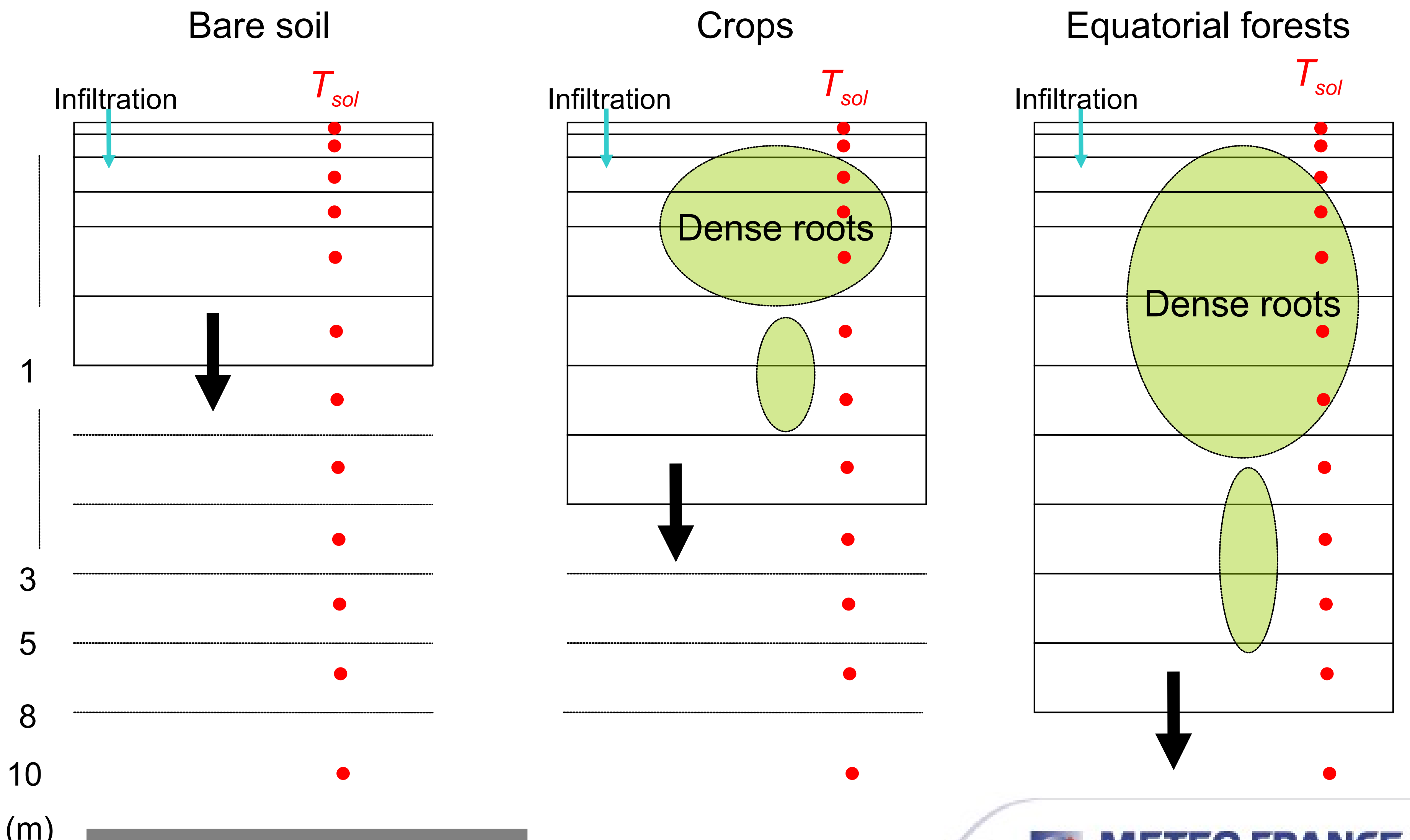
Exponential profile of k_{sat} with soil depth

NAM_ISBA	***NPATCH=12***
NAM_ISBA_SGH	***CRAIN ='SGH'*** ***CHORT='SGH'*** ***CRUNOFF='DT92' or 'SGH'*** ***CKSAT='SGH'***

Vegetation (Tiles)

Others

Soil heat and mass transfer → Default configuration for ISBA-DF (14L)



Source : B. Decharme, CNRM

Model « Diffusion » N layers CISBA=DIF

Energy

$$c\frac{\partial T}{\partial t} = \frac{\partial}{\partial z}\left(\lambda \frac{\partial T}{\partial z}\right) + L_f \Phi$$

Downgradient heat flux

Mass (liquid)

$$\frac{\partial w_l}{\partial t} = -\frac{\partial}{\partial z}\left[k\left(\frac{\partial \psi}{\partial z} + 1\right)\right] - \frac{\Phi}{\rho_i} - \frac{S_E}{\rho_l}$$

Mixed form Richards Eq (heterogeneous soil profile)

Mass (solid)

$$\frac{\partial w_i}{\partial t} = \frac{\Phi}{\rho_i}$$

Only phase changes

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Model « Diffusion » N layers CISBA=DIF

Energy

$$c\frac{\partial T}{\partial t} = \frac{\partial}{\partial z}\left(\lambda \frac{\partial T}{\partial z}\right) + L_f \Phi$$

Diffusion

Phase change (liquid - solide)

Mass (liquid)

$$\frac{\partial w_l}{\partial t} = -\frac{\partial}{\partial z}\left[k\left(\frac{\partial \psi}{\partial z} + 1\right)\right] - \frac{\Phi}{\rho_i} - \frac{S_E}{\rho_l}$$

Mass (solid)

$$\frac{\partial w_i}{\partial t} = \frac{\Phi}{\rho_i}$$

Model « Diffusion » N layers
CISBA=DIF

Energy

$$c\frac{\partial T}{\partial t} = \frac{\partial}{\partial z}\left(\lambda\frac{\partial T}{\partial z}\right) + L_f\Phi$$

Mass (liquid)

$$\frac{\partial w_l}{\partial t} = -\frac{\partial}{\partial z}\left[k\left(\frac{\partial \psi}{\partial z} + 1\right)\right] - \frac{\Phi}{\rho_i} - \frac{S_E}{\rho_l}$$

Diffusion ↕

Drainage (gravity) ↓

Evapotranspiration loss

Mass (solid)

$$\frac{\partial w_i}{\partial t} = \frac{\Phi}{\rho_i}$$

Model « Diffusion » N layers CISBA=DIF

Energy

$$c\frac{\partial T}{\partial t} = \frac{\partial}{\partial z}\left(\lambda \frac{\partial T}{\partial z}\right) + L_f \Phi$$

Phase change (liquid - solide)

Mass (liquid)

$$\frac{\partial w_l}{\partial t} = -\frac{\partial}{\partial z}\left[k\left(\frac{\partial \psi}{\partial z} + 1\right)\right] - \frac{\Phi}{\rho_i} - \frac{S_E}{\rho_l}$$

Mass (solid)

$$\frac{\partial w_i}{\partial t} = \frac{\Phi}{\rho_i}$$

Ice is assumed to become part of the soild soil matrix

Model « Diffusion » N layers
CISBA=DIF : Boundary conditions

Energy

$$c\frac{\partial T}{\partial t} = \frac{\partial}{\partial z}\left(\lambda\frac{\partial T}{\partial z}\right) + L_f\Phi$$

↓

UPPER : Composite surface energy budget

$$G(z=0) = R_{net} - H - LE$$

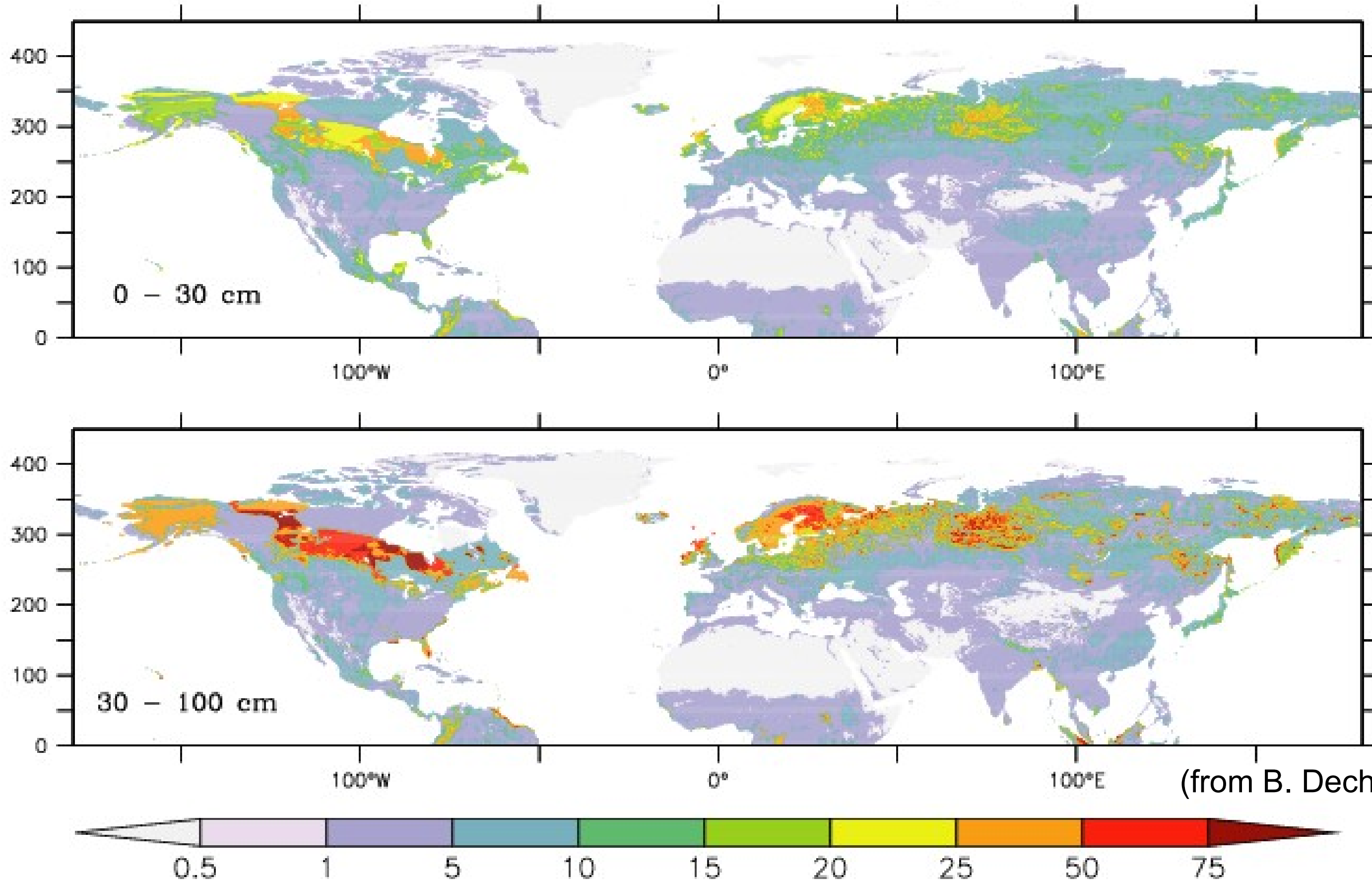
LOWER : flux=0 (depth depends on timescale)

Mass (liquid)

UPPER : Infiltration = Rainfall + snowmelt + canopy drip – surface runoff
LOWER : Drainage (gravitational → hydraulic conducitivty)

Soil physiographic Parameters

Issue : Many LSMs account for mineral soil hydrological and thermal properties while soil organic Carbon can have a big impact, notably at high latitudes :



(from B. Decharme)

Soil Organic Carbon (SOC) content ($kg.m^{-2}$) from HWSD database at 1km

Effects :

→ store more water

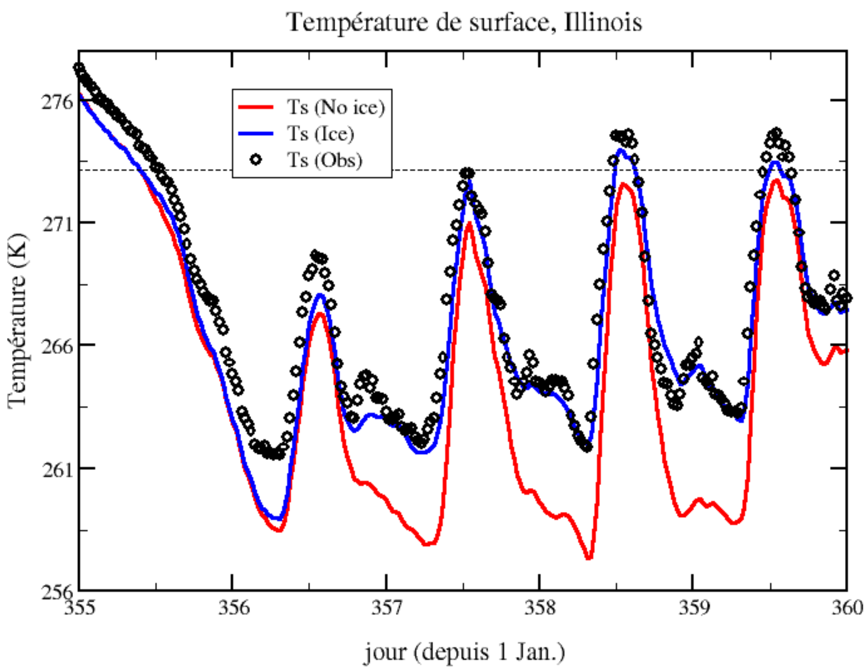
→ more insulating

YSOC_TOP
YSOC_SUB

ISBA-DIF : main options

Phase Changes in the soil :

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



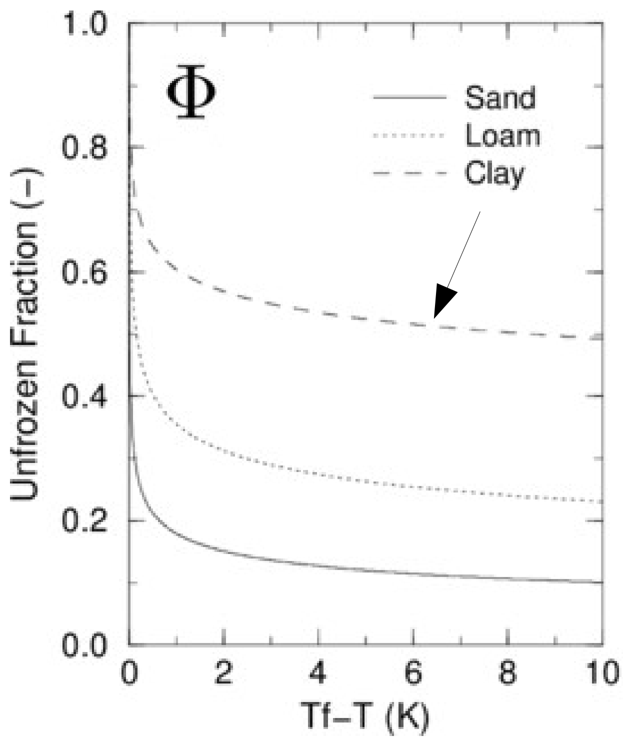
CSOILFRZ=LWT : As opposed to potentially freezing ALL liquid water, this method uses the freezing curve method. The maximum liquid water content for a given texture is a function of T...

- More *physical*...(closer to observations)
- Also avoids numerical problems since liquid water content stays above a minimum numerical threshold

ISBA-DIF : main options

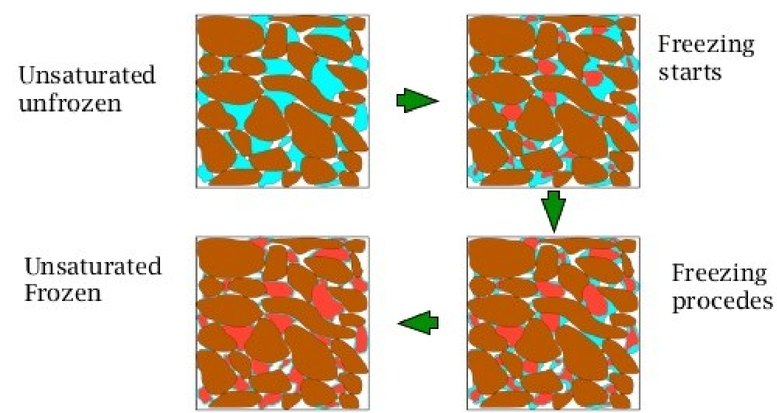
CSOILFRZ=LWT :

Gibbs-Free energy



Colder soil →

* liquide peut exister à des températures inférieures à 0C si la texture du sol est fine (e.g. argile)



The snow models of ISBA

EBA	1 reservoir, 2 prognostic variables (Wn, albédo) model : ARPEGE/PN, ALADIN/PN (Bazile)
D95 (default)	1 reservoir, 3 prognostic variables (Wn, albedo, density) (climate model, AROME, offline) (Douville, 1995)
3-L	ISBA-ES (explicit snow) multi-layer, 4 prognostic variables offline (chaîne SIM, …) and climate applications, 12 layers (Boone and Etchevers 2001 ; Decharme et al., 2016)
CRO	CROCUS/SURFEX : multilayer model based on ISBA-ES and the the snow model CROCUS (description of snow grains, incresed number of layers) (Brun et al., 1992, Vionnet et al., 2012)

Zoom on ISBA-ES (1/2)

- N layer- snow scheme (default : 12)
- snow settling (including compaction due to melting)
- SW Radiative transfer
- explicit surface energy budget : prognostic albedo, density, *SWE* and ***H*** (enthalpy)
- liquid water content (from *H*): tipping-bucket hydrology

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

H : 2 variables in 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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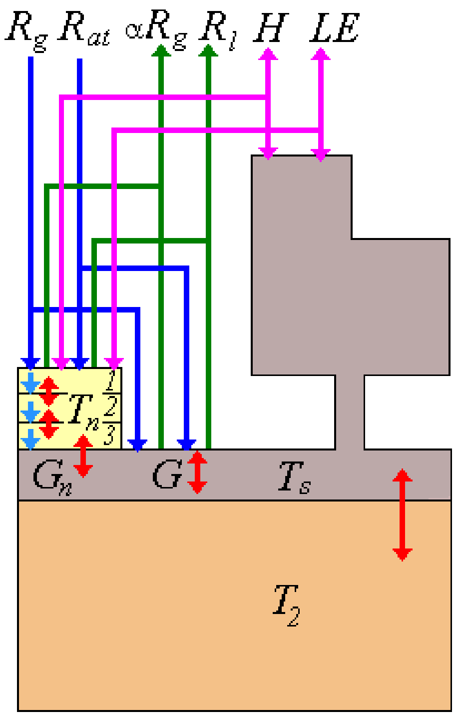
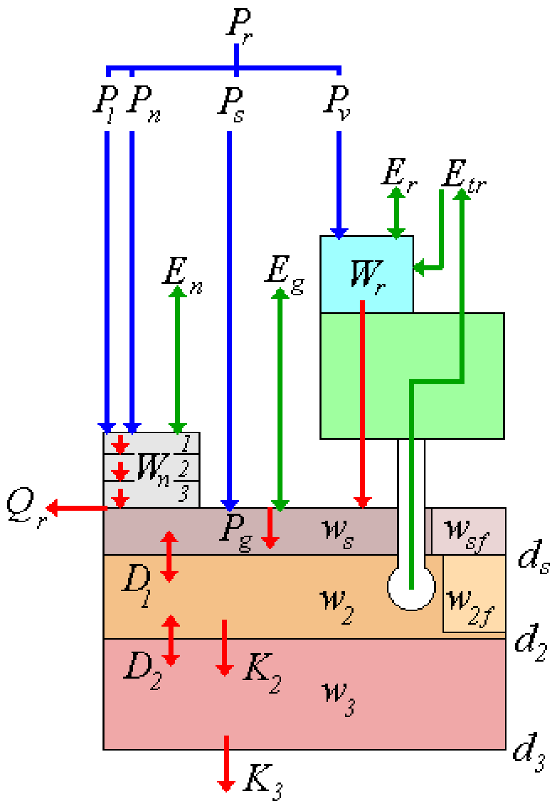
Zoom on ISBA-ES

The snow has a separate energy budget

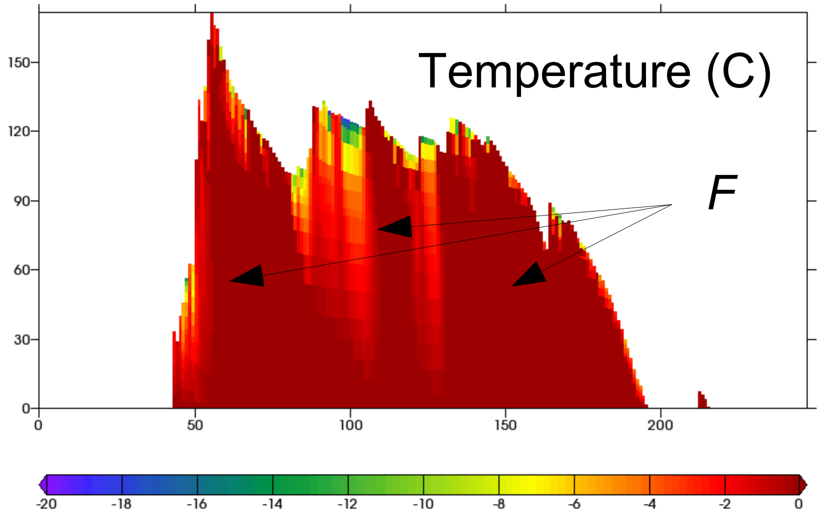
CSNOWRES=RIL to maintain turbulent exchanges under very stable conditions

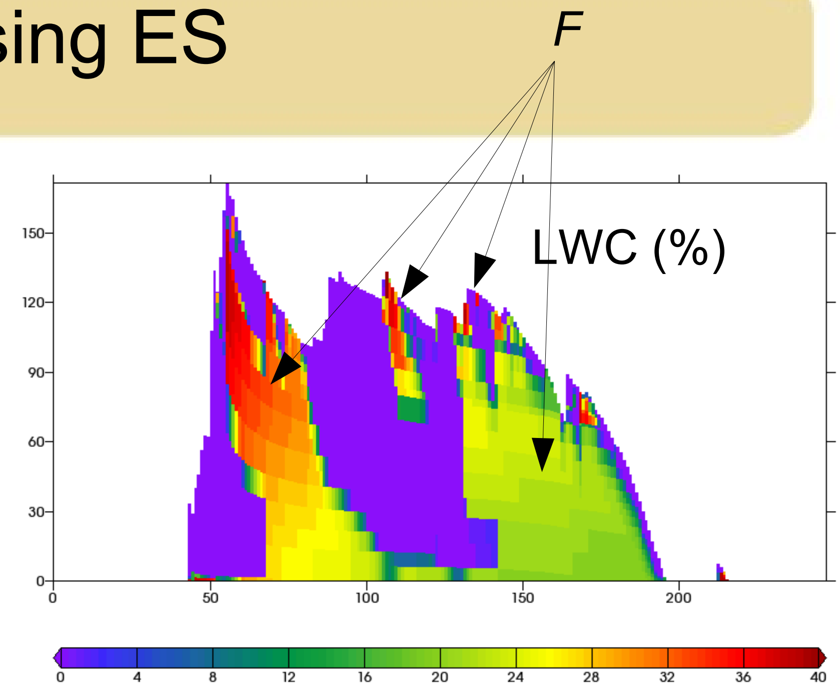
Development of a separate energy budget for snow/vegatation





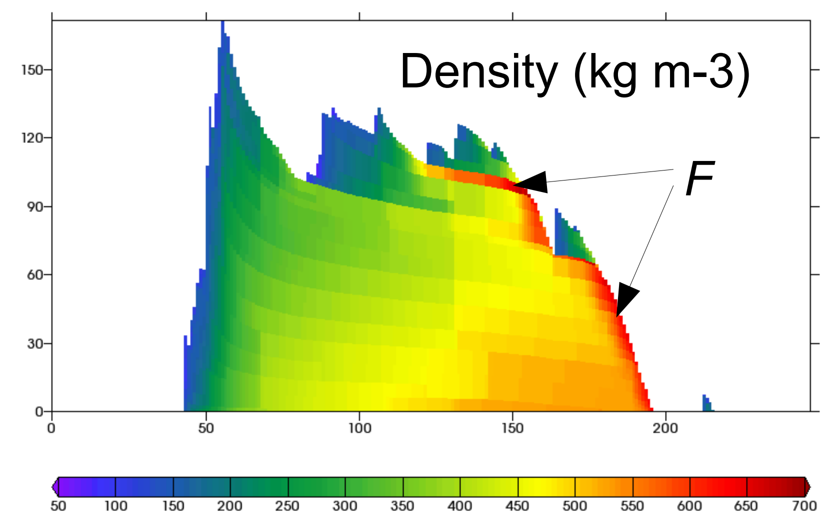
Snowpack : simulation using ES





Profile – Simulations for Col de Porte

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



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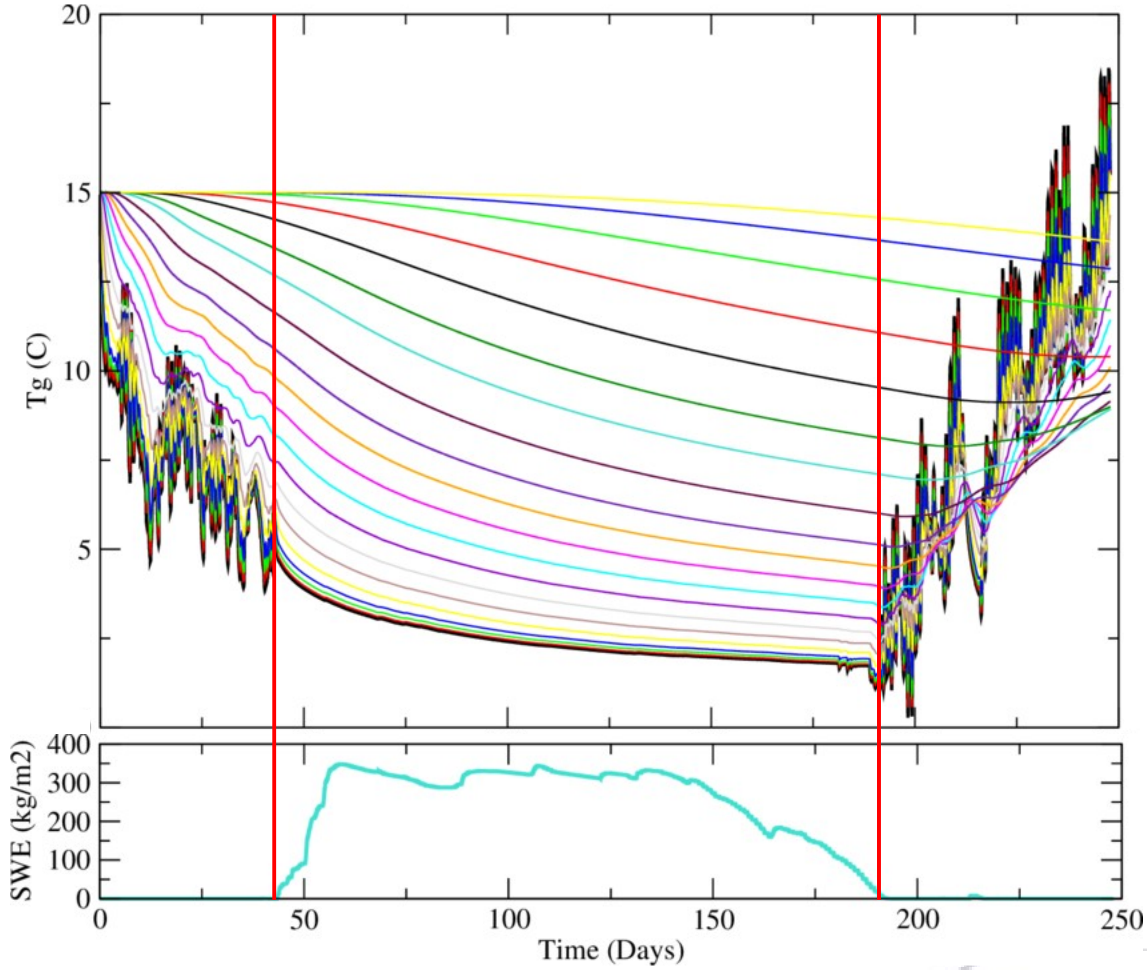
Conduction

Impact of snow thermal conductivity on the sub-surface soil T :



Carbon options (ISBA-A-gs, ISBA-CC)

Carbon fluxes:

→ Photosynthesis, ecosystem respiration, net exchanges with the ecosystem

Biomass (including LAI : leaf area index)

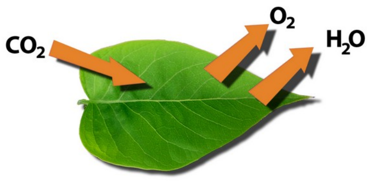
→ Evolution of the above-ground and below-ground biomass

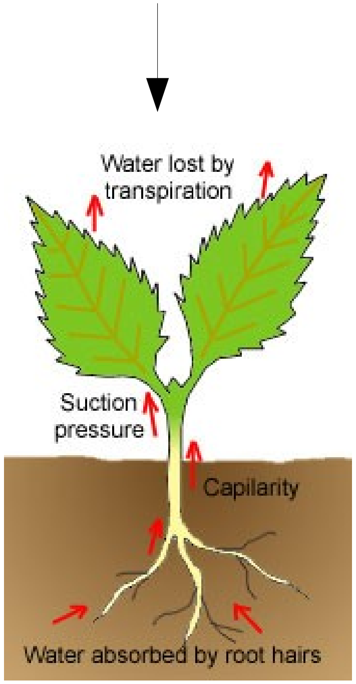
Carbon stock

→ Organic matter, mulch, wood

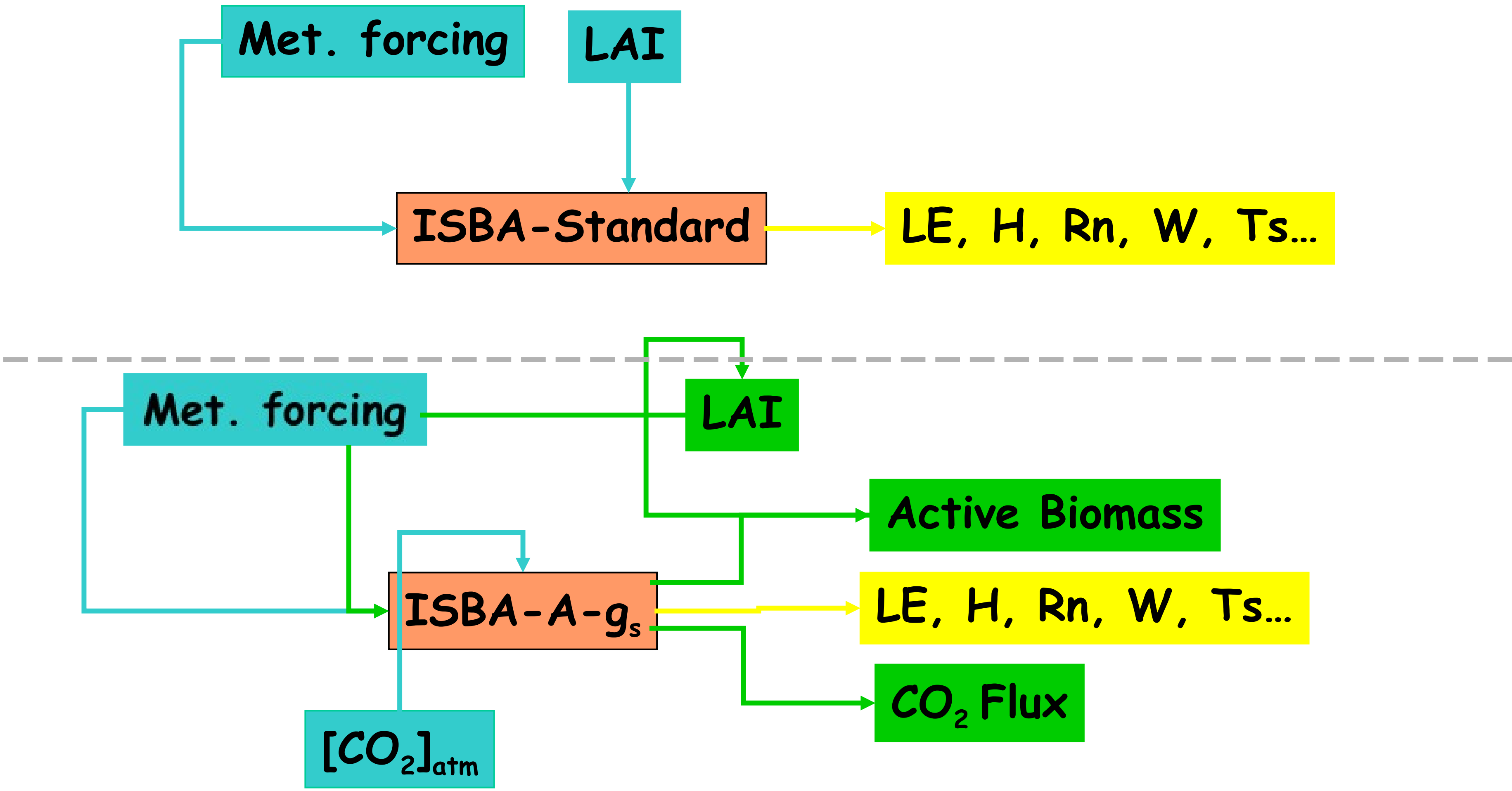
Better representation of plant behaviours (C3 vs C4), LAI consistent with water and carbon fluxes, assimilation of vegetation data

NPATCH = 12 mandatory (or 19)





ISBA standard vs A-gs

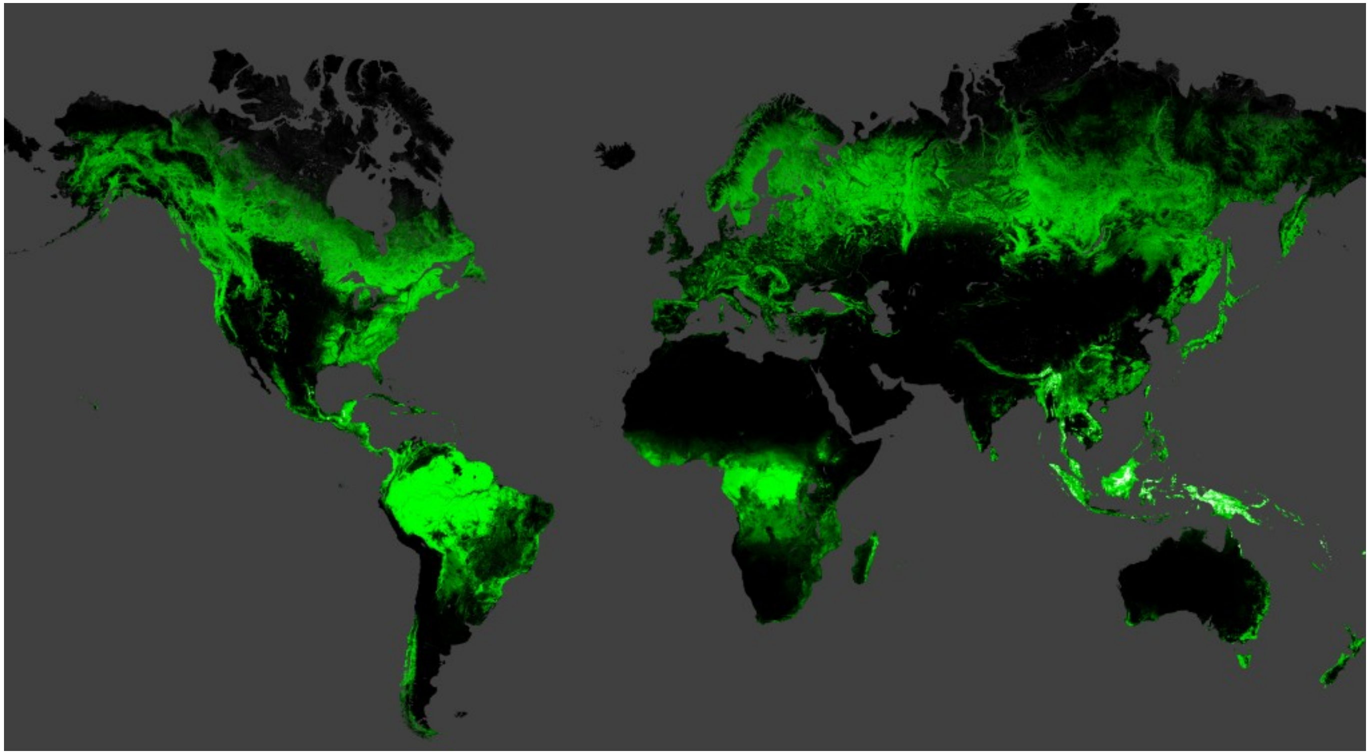


(Calvet et al, 1998)

ISBA : option CPHOTO

NON	ISBA-standard (default)
AGS*	NON + explicit photosynthesis
LAI*	AGS+LAI evolution
AST	AGS+ improved hydric stress
LST*	LAI+improved hydric stress
NIT	LST+nitrogen dilution

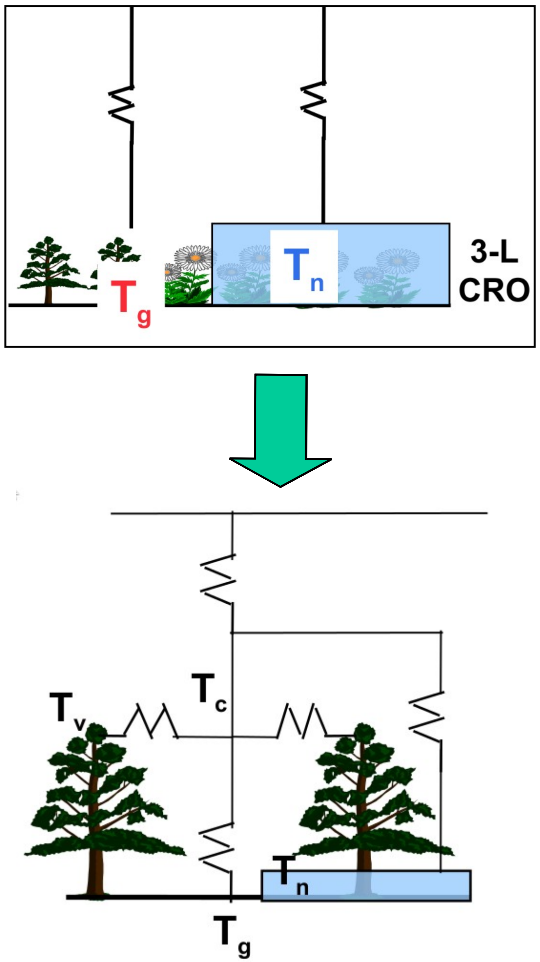
* : not recommended (obsolete)

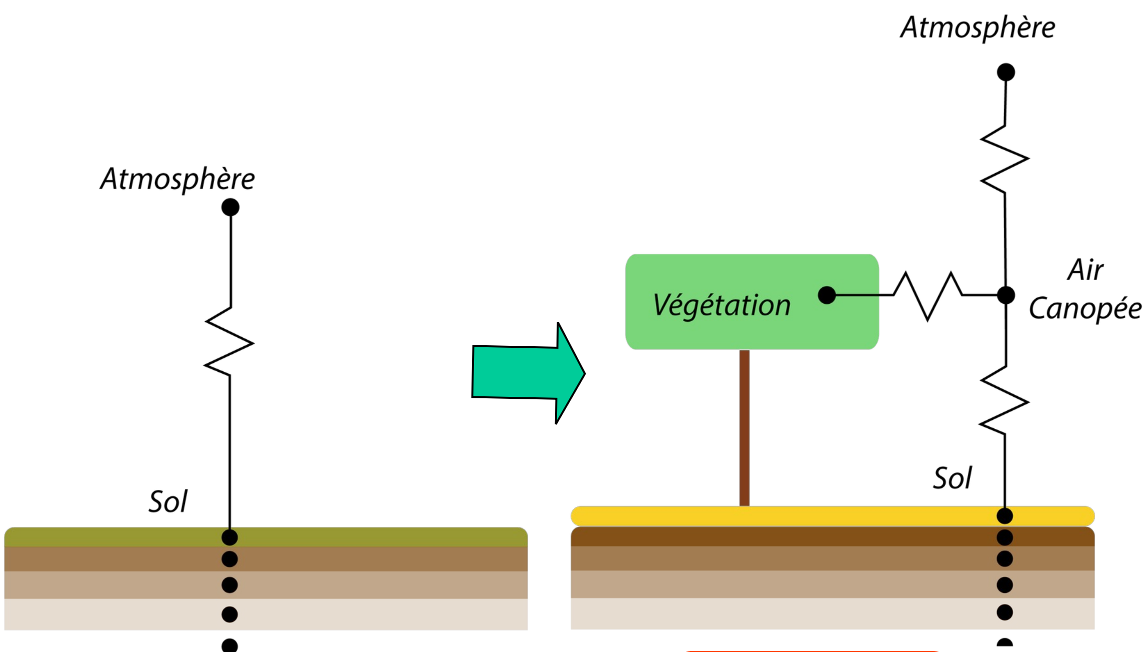


Global Forest Coverage = 30 %

The ISBA -MEB (multi-energy balance)

- **Now no interaction between high vegetation and snow or bare soil/lower vegetation**
- **Objectives : introduction of a diagnostic canopy air temperature that interacts with high/low vegetation**
- **Available starting for SURFEX-v8**





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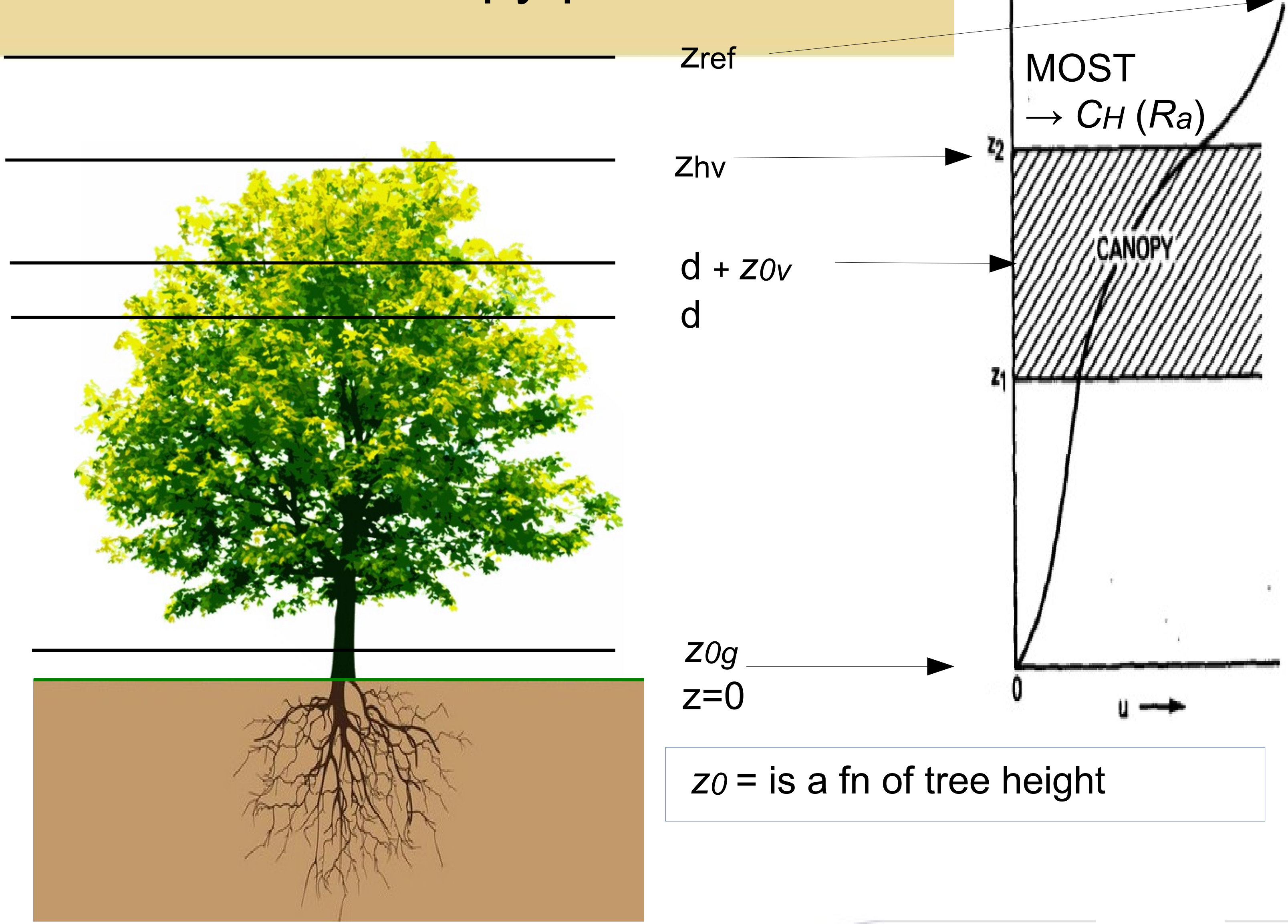
ISBA-MEB

Turbulence : V canopy profile



Model « Diffusion » N layers
CISBA=DIF + MEB

$$c\frac{\partial T}{\partial t} = \frac{\partial}{\partial z}\left(\lambda\frac{\partial T}{\partial z}\right) + L_f\Phi$$

$$G(z=0) = R_{net} - H - LE$$

MEB → no longer use a composite surface energy budget

$$c_g\frac{dT_g}{dt} = \frac{\partial}{\partial z}\left(\lambda\frac{\partial T_g}{\partial z}\right) + L_f\Phi_g$$

$$G(z=0) = R_{net,g} - H_g - LE_g$$

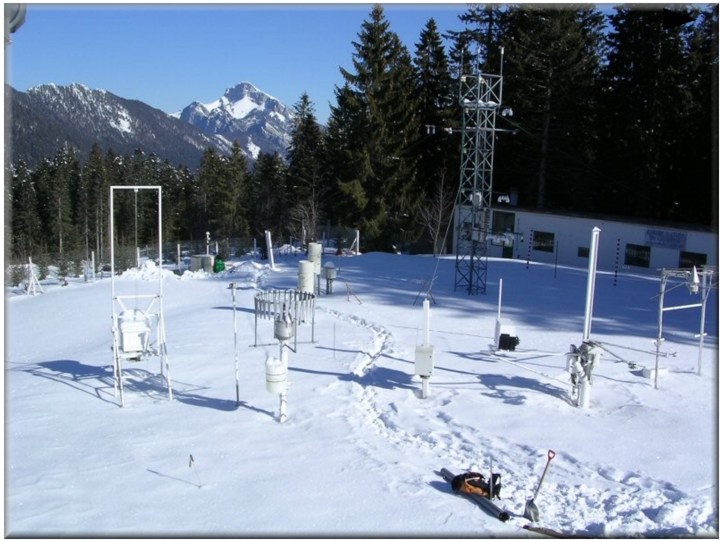
$$c_v\frac{dT_v}{dt} = R_{net,v} - H_v - LE_v - L_f\Phi_v$$

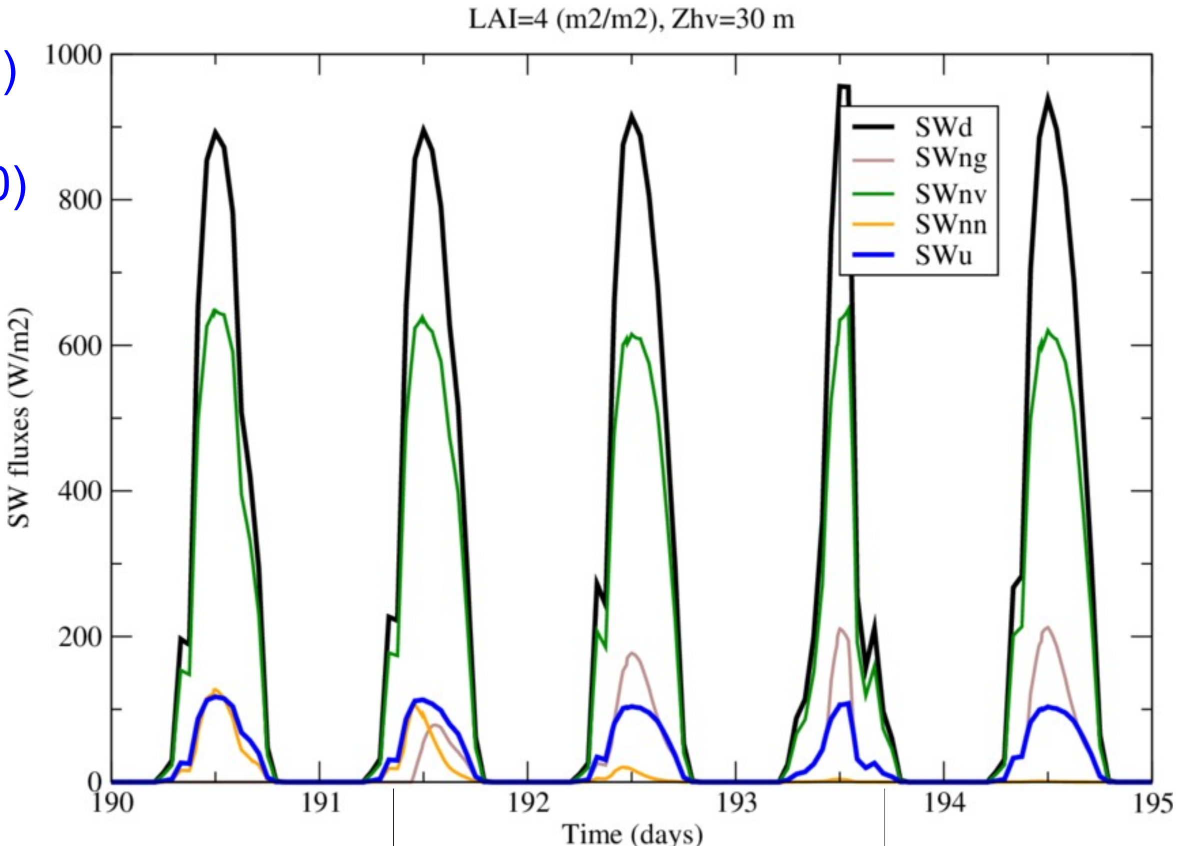
SW radiation balance : $SW_{nn} + SW_{nv} + SW_{ng} + SW_u = SW_d$

<u>Albédo (reflectance)</u>

Forêt ~0.05-0.20 (0.15)
Sol (litière) ~0.07-0.14 (0.12)
Neige ~0.50 – 0.95 (0.70)

Col de Porte
(CNRM/CEN)





Snow ablation

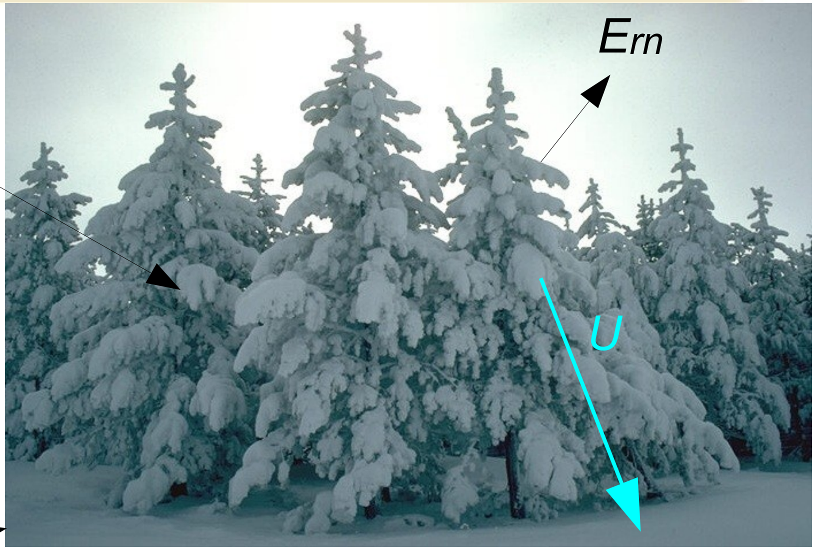
Water budget : snow

Intercepted snow

$$\frac{dW_{rn}}{dt} = P_n\, veg - E_{rn} - U - F_{rn}$$

F_{rn} = la fonte de neige interceptée

$U \Rightarrow f(V, T, W_{rn}, LAI)$



Snowpack (ground)

$$\frac{dW_n}{dt} = P_n\,(1 - veg) - E_n + U - F$$

$$+ \quad P_r\,(1 - veg) + C_r$$

Rain and runoff from the canopy

*note : snow mass loss, *F*, is a drainage flux of liquid water (melt and rainfall) which is not frozen & exceeds the snowpack liquid storage capacity

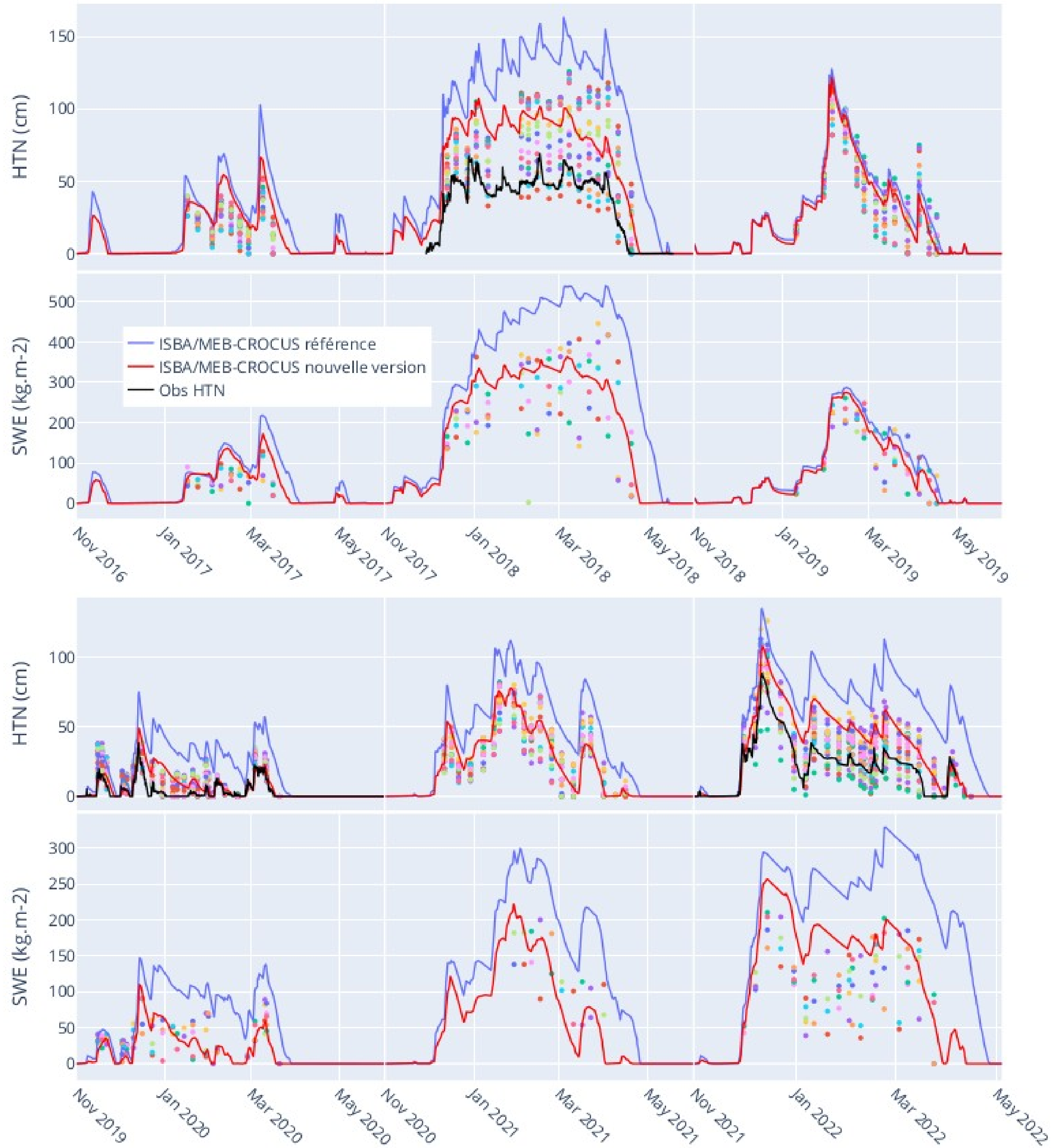
New updates to ISBA-MEB+CROCUS coupled physics (v9…)

Simulations at Col de Porte : below forest

HTN = snow depth
SWE = snow liquid water equivlant

Points – along stakes

Masters work by Axel Bouchet
(with Y. Lejeune & A. Boone)



ISBA : options and namelists

NAM_ISBA	NPATCH, CISBA, CPHOTO, NGROUND_LAYER,SAND,CLAY,WDRAIN,CTI
NAM_DATA_ISBA	Init PGD ISBA (ECOCLIMAP=.F.) : NTIME, VEGTYPE, VEG,LAI, Z0, EMIS, DG,ROOTFRAC,RSMIN, …
NAM_PREP_ISBA	Initial field for ISBA + date
NAM_PREP_ISBA_SNOW	CSNOW, initial field for SNOW, +date
NAM_PREP_ISBA_CARBON	RESPL
NAM_ISBAn	**XTSEP**, Options of calculation for some parameters (conduction, Z0)
NAM_SGH_ISBAn	**Options subgrid hydrology** (KSAT, WDRAIN, …
NAM_DIAG_ISBA	Diagnostics for ISBA
NAM_SOIL_TEMP_ARP	LTEMP_ARP (4 temperatures FR climat)

See the user's guide for output variables

Specific options: Sub-Grid Drainage

Allow a deep drainage under the field capacity (*Etchevers et al. 2001*). Especially relevant to simulate low summer discharges.

$$K_2 = \frac{C_3}{\tau d_2} \max\left[\omega_{d2}, \left(w_2 - w_{fc}\right)\right]$$

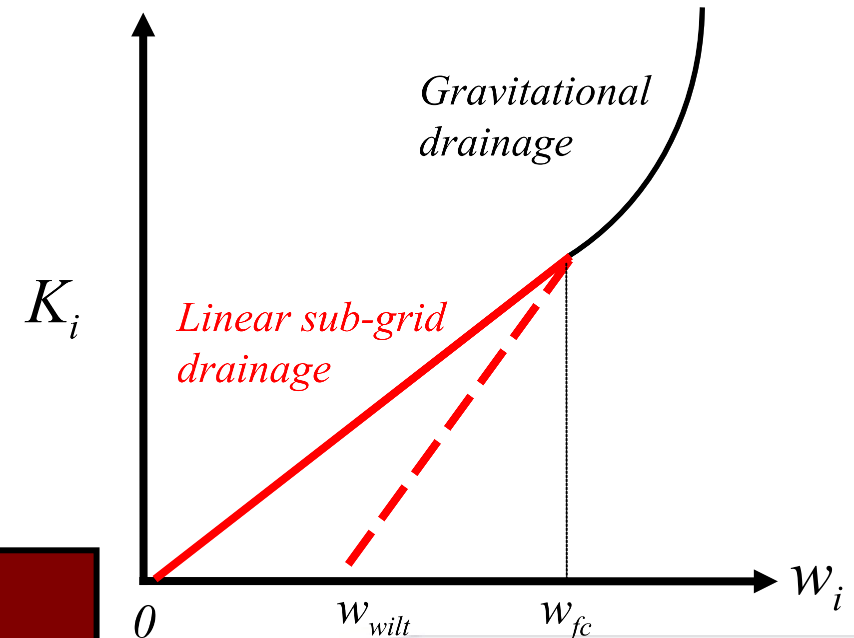
$$K_3 = \frac{C_3}{\tau\left(d_3 - d_2\right)} \max\left[\omega_{d3}, \left(w_3 - w_{fc}\right)\right]$$

$$\omega_{d_i} = w_{drain} \frac{\min\left(w_i, w_{fc}\right) - w_{min}}{w_{fc} - w_{min}}$$

w_{min}=0.001 or w_{wilt} with CKSAT='SGH'

w_{drain} uniform value (local or over a domain)

NAM_ISBA XUNIF_WDRAIN=0.0005

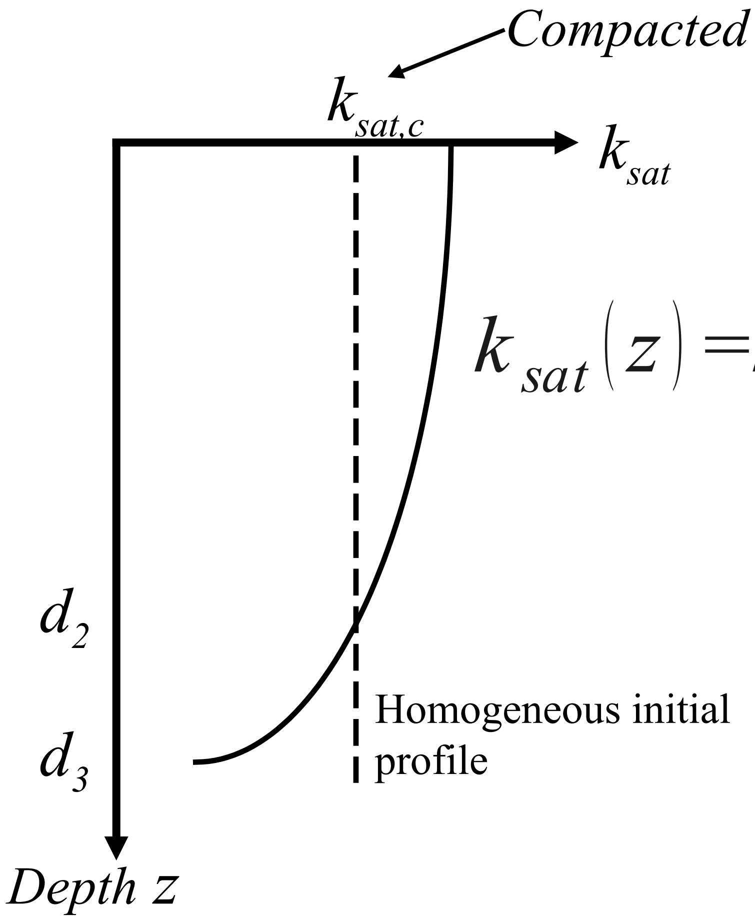


w_{drain} non uniform values over a domain

NAM_ISBA YWDRAIN='Input file name'
YWDRAINFILETYPE='input file format'

Specific options: Exponential profile of k_{sat}

The soil column assumes an exponential profile of k_{sat} with soil depth. The main hypothesis is that roots and organics matter favor the development of macropores and enhance the water movement near the surface while the soil compaction is an obstacle for deep soil percolation (*Decharme et al. 2006*).



$$k_{sat}(z) = k_{sat,c}\, e^{-f(z-d_c)}$$

$d_c = d_2$: *compacted depth*

$f <= 2m^{-1}$: *decay factor*

All force restore coefficient (*C1, C2, C3, C4*) as well as w_{geq} have been analytically re-calculated.

NAM_ISBA_SGH	***CKSAT='SGH'***