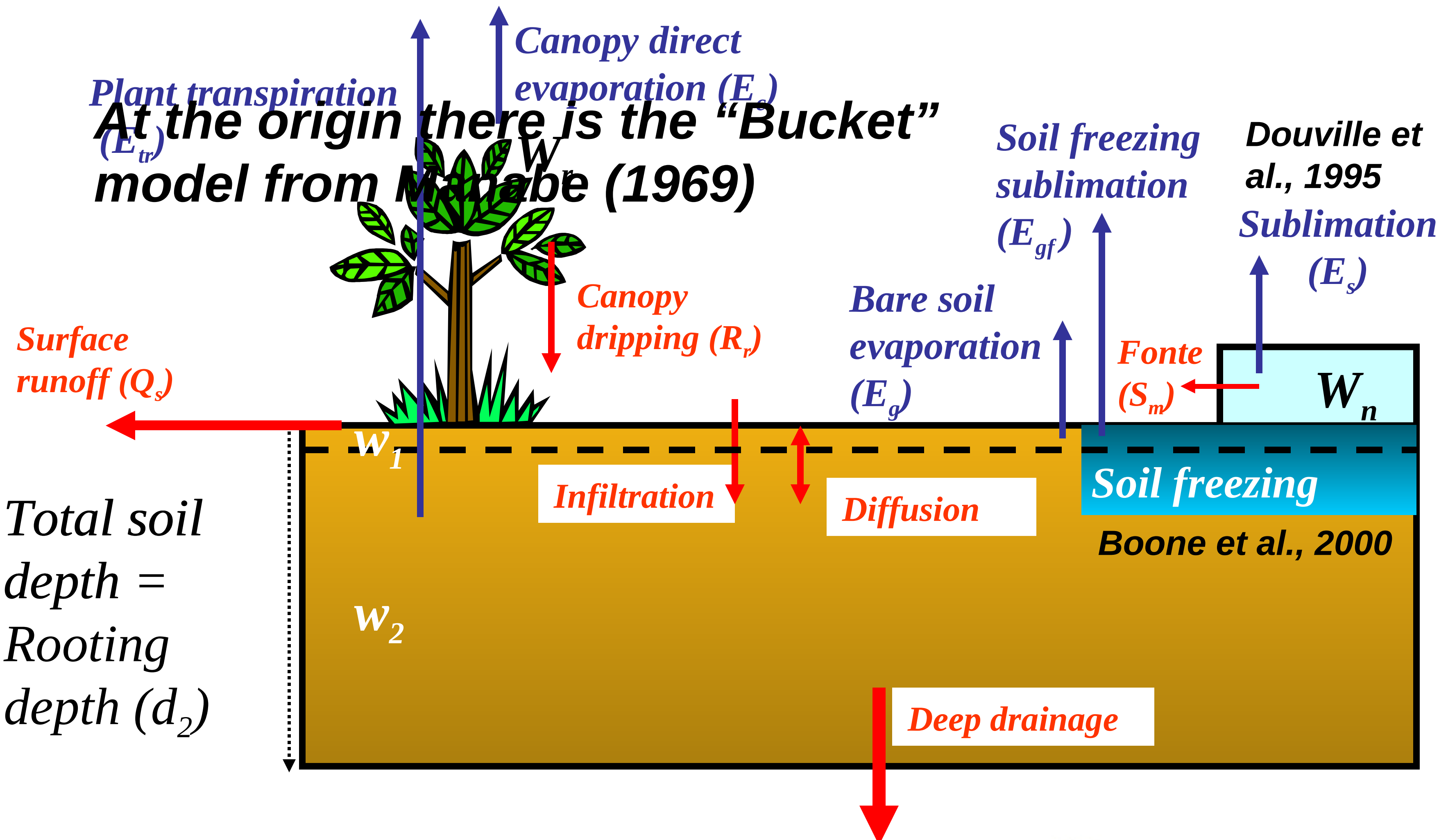
ISBA-FR

1. Introduction
2. Energy budget
3. Water budget
4. Specific hydrologic options

Introduction – ISBA 2-L

At the origin there is the "Bucket" model from Manabe (1969)

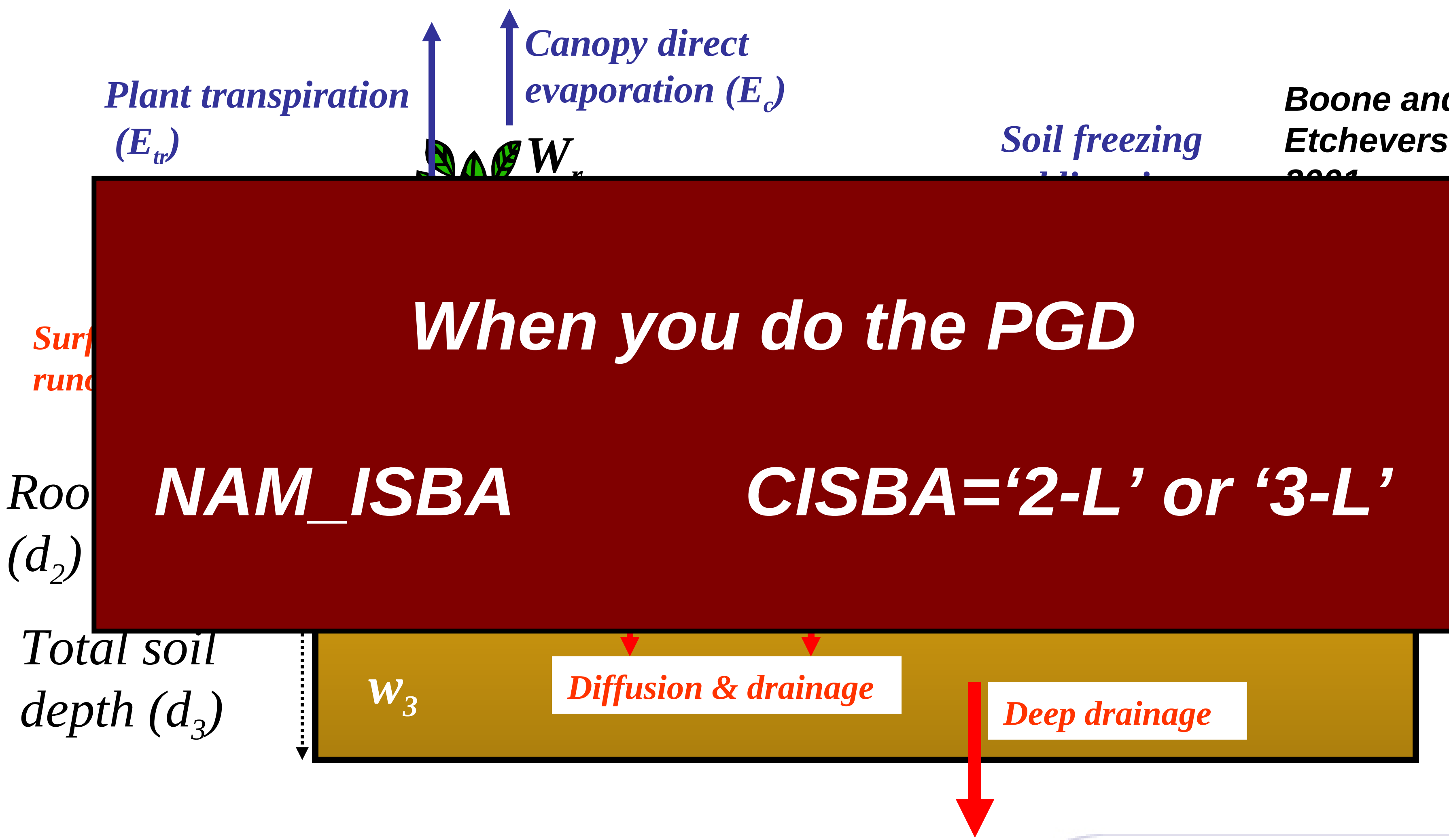


Noihlan and Planton, 1989

Mahfouf and Noihlan, 1996

METEO FRANCE

Introduction – ISBA 3-L



When you do the PGD

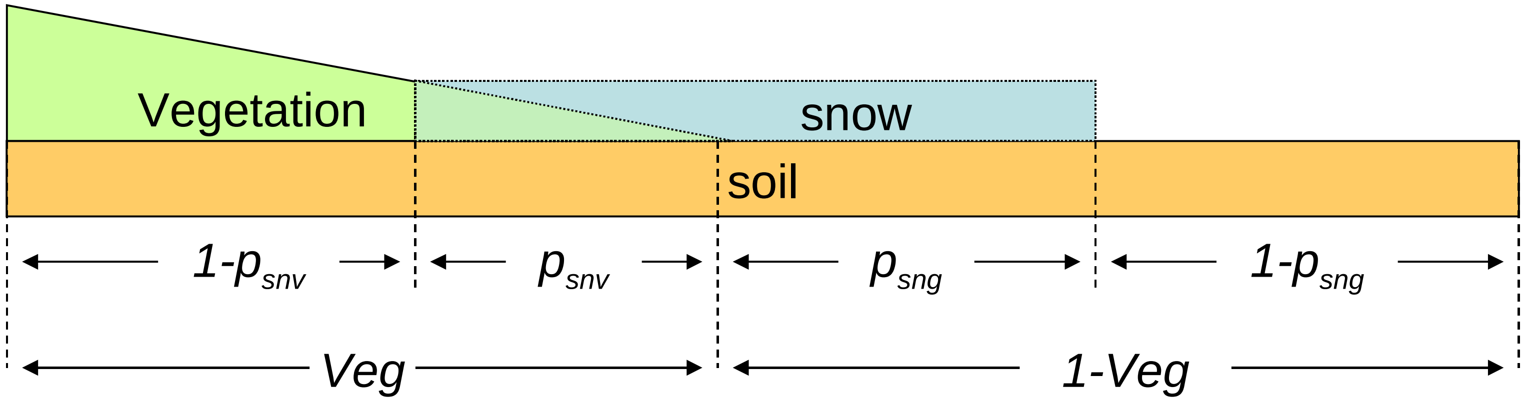
NAM_ISBA **CISBA='2-L' or '3-L'**

Boone et al, 1999

Introduction : Parameters

Primary parameters	***Secondary parameters***	***Symbols***
Soil		
Clay fraction		X_{clay}
Sand fraction		X_{sand}
	Saturation or porosity	w_{sat}
	Field capacity	w_{fc}
	Wilting point	w_{wilt}
Vegetation		
Type of cover		
	Minimal surface resistance	$R_{s\ min}$
	Leaf area index	LAI
	Roughness length for momentum and heat	z_0 and z_{0h}
	Fraction of vegetation	veg

Introduction : Composite Soil – Vegetation – Snow

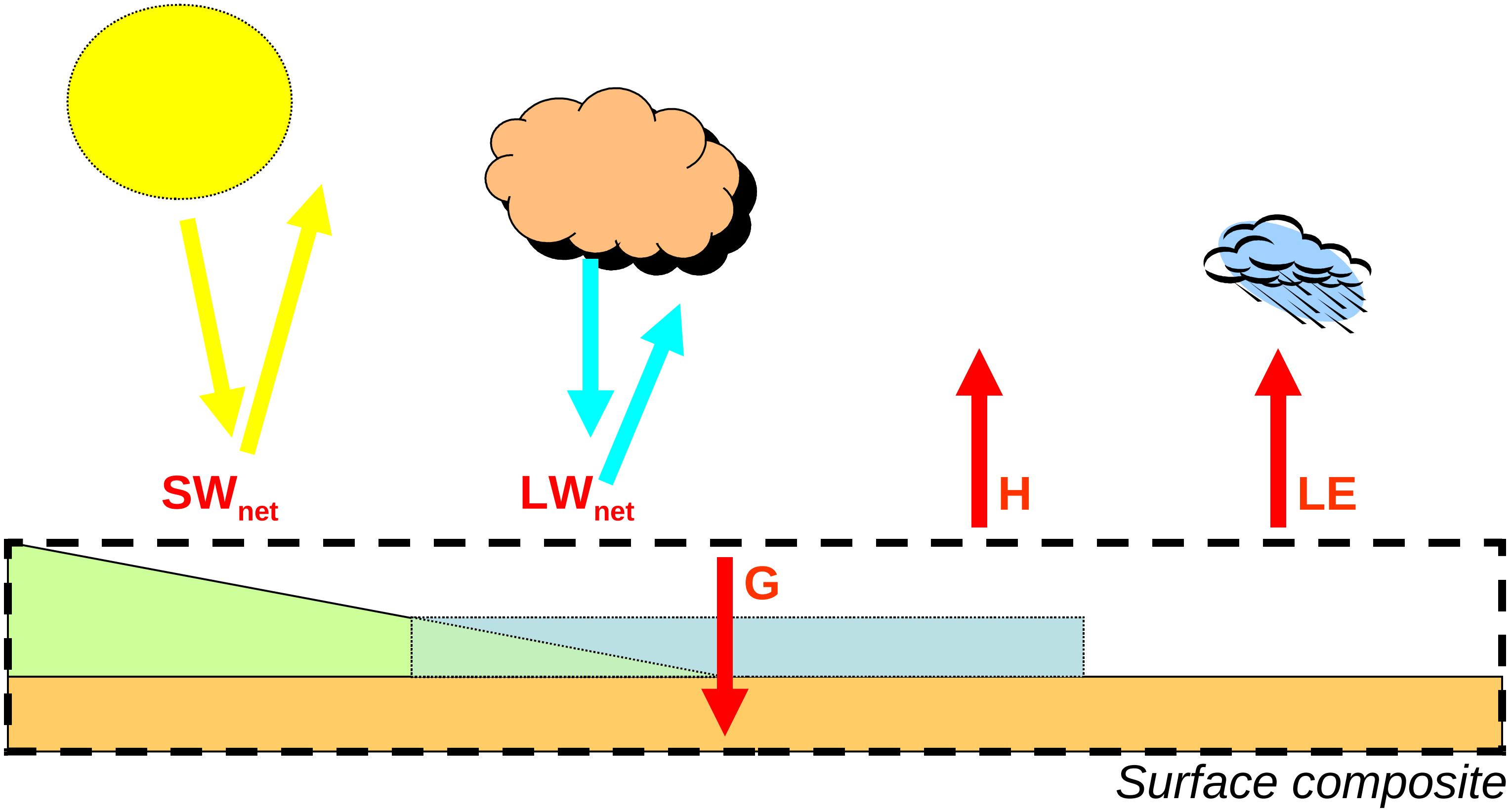


Snow fraction : $p_{sn} = p_{snv} + p_{sng}$

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

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

Energy budget : Ground heat flux



$$G = SW_{net} + LW_{net} - H - LE$$

Energy budget : Radiation budget

Surface net radiations :

$$Rn = SW_{net}^{t} + LW_{net}^{t}$$

Details :

$$SW_{net}^{t} = SW_{\downarrow}^{t}\left(1-\alpha_{total}^{t}\right)$$

$$LW_{net}^{t} = \varepsilon_{total}^{t} LW_{\downarrow}^{t} - \varepsilon_{total}^{t}\sigma_{SB} {T_s^t}^3\left(4T_s^{t+1} - 3T_s^t\right)$$

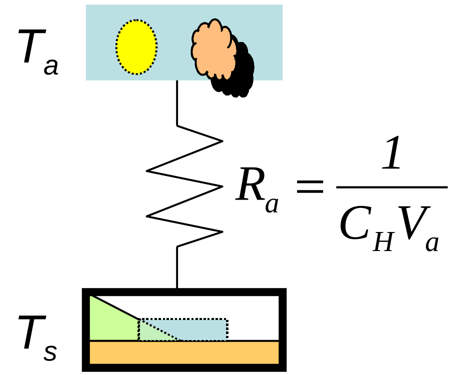
Not directly T_s^4 due to energy budget linearization

Energy budget : Sensible and Latent heat fluxes

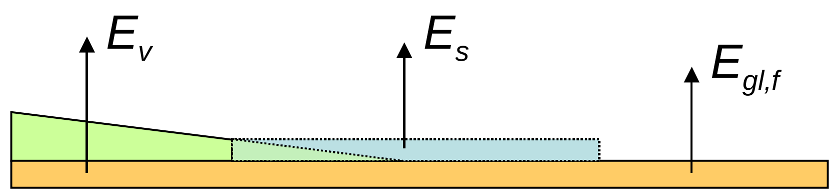
Sensible heat flux using classical low:

$$H = \rho_a c_p C_H V_a \left(T_s - T_a\right)$$

Surface specific heat



Latent heat flux depend on the surface type:



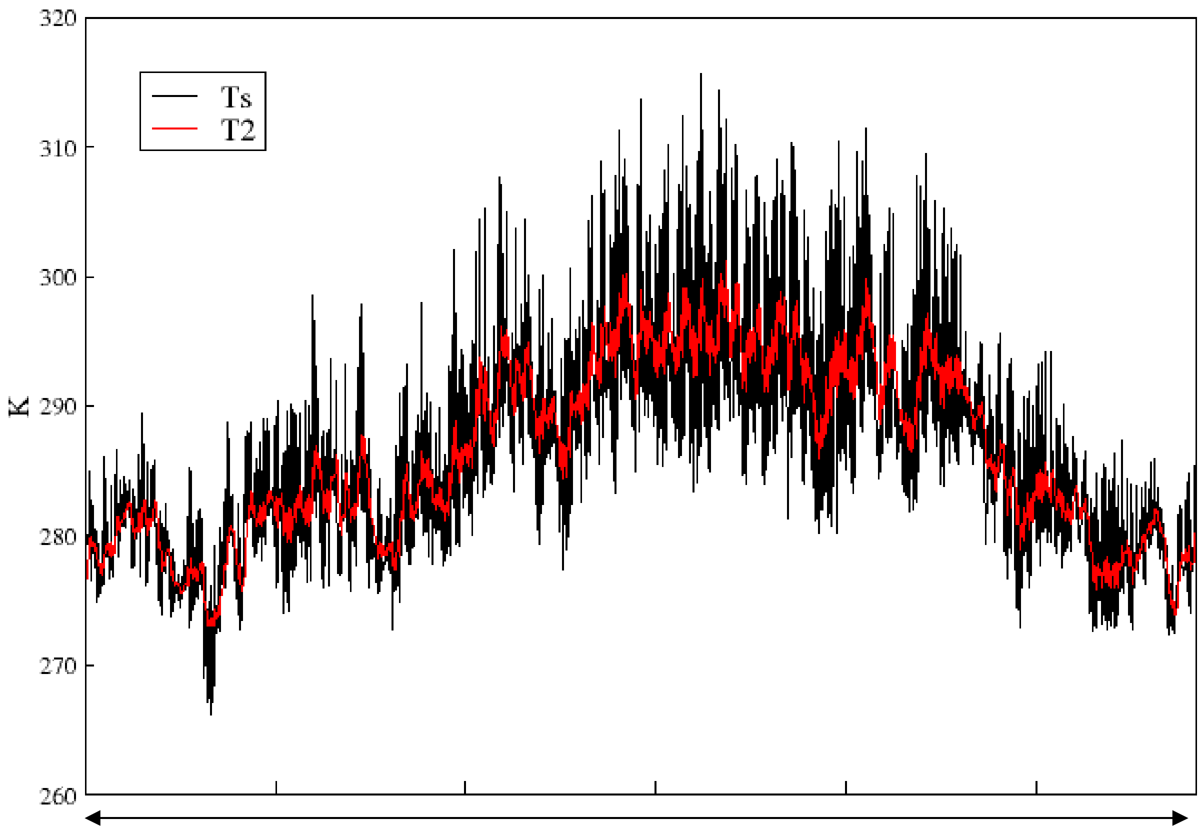
$$\begin{aligned}
LE &= LE_{g\,l} + LE_v + L_i\left(E_s + E_{g\,f}\right) \\
E_{g\,l} &= (1 - veg)(1 - p_{sng})\left(1 - \delta_i\right)\ \rho_a C_H V_a \left(h_u q_{sat}(T_s) - q_a\right) \\
E_v &= veg(1 - p_{snv})\rho_a C_H V_a h_v \left(q_{sat}(T_s) - q_a\right) \\
E_s &= p_{sn}\rho_a C_H V_a \left(q_{sat}(T_s) - q_a\right) \\
E_{g\,f} &= \left(1 - veg\right)\left(1 - p_{sng}\right)\ \delta_i\,\rho_a C_H V_a \left(h_{ui}\, q_{sat}\left(T_s\right) - q_a\right)
\end{aligned}$$

Energy budget : Soil temperature

2

[1976] :

HAPEX experiment near Toulouse (43.4°N – 1.3°E)



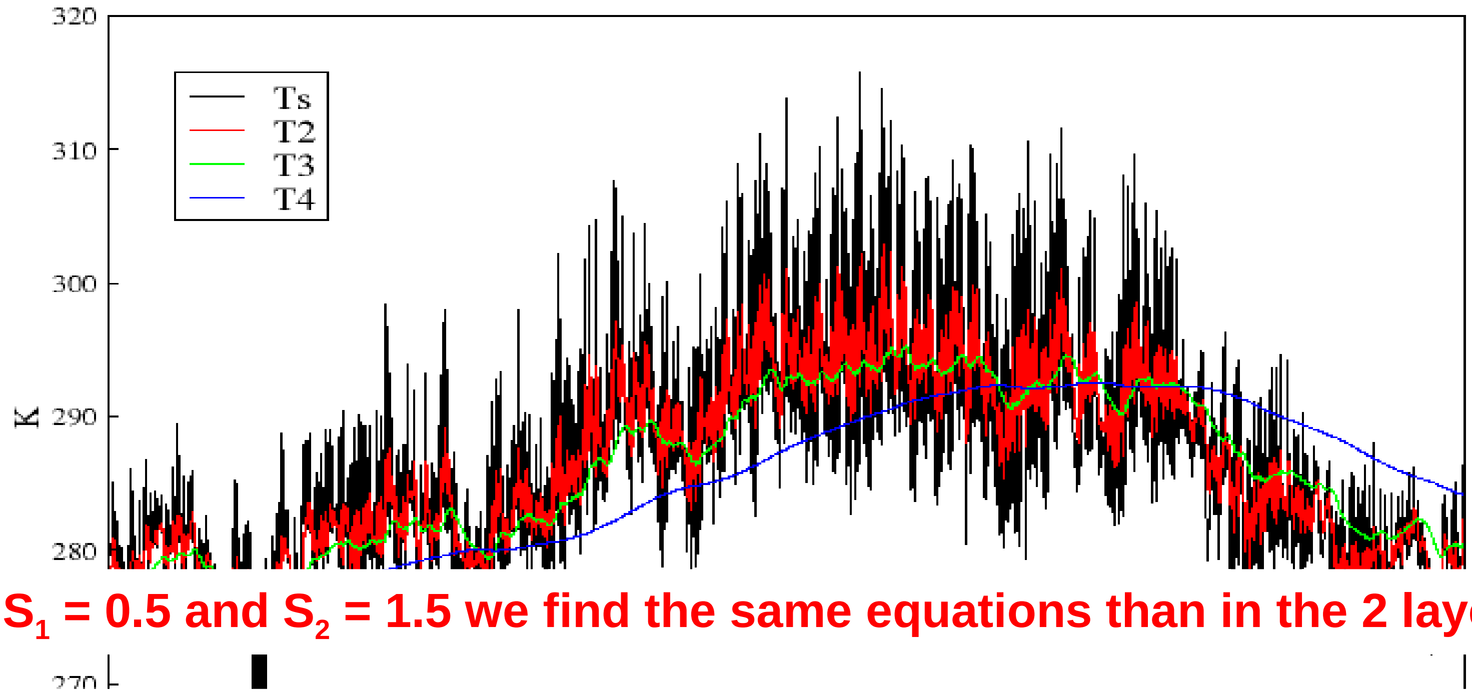
1 Year

Restoring term toward T_2

$- p_{sng})$

Energy budget : Soil temperature

HAPEX experiment near Toulouse (43.4°N – 1.3°E)

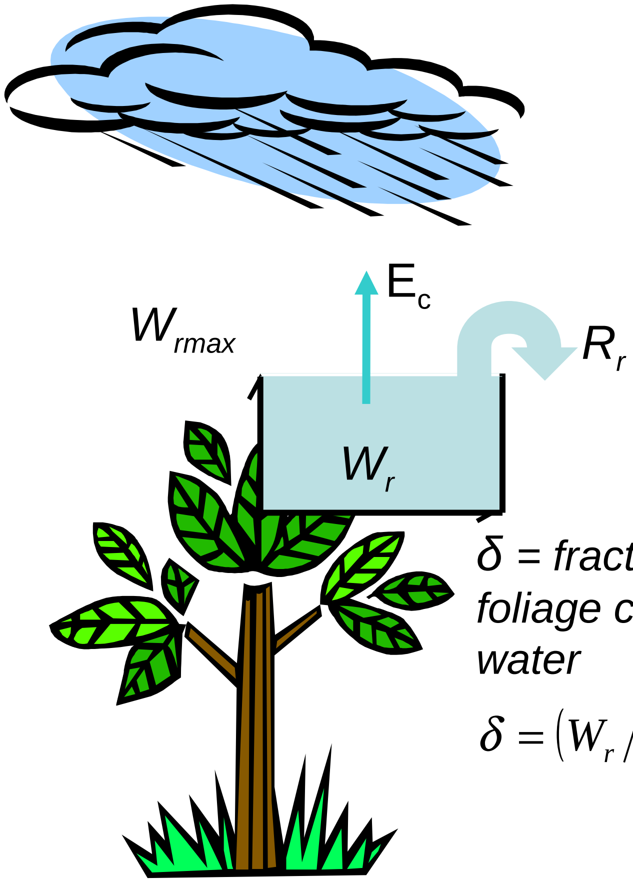


With S_1 = 0.5 and S_2 = 1.5 we find the same equations than in the 2 layers case.

This approach can be very useful over cold regions due to its impact on snow melt simulation.

Option LTEMP_ARP=.T. in NAM_SOILTEMP_ARP when you do the PREP

Water Budget : vegetation interception



δ = *fraction of the foliage covered by water*

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

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

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

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

Deardorff, 1978.

Water Budget : Evapotranspiration

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

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

Snow free vegetation fraction

Surface – Atmosphere exchange

Haltead coef

$$h_v = \underbrace{\delta}_{\text{Potential } E_c} + \underbrace{\left(1-\delta\right) R_a / \left(R_a + R_s\right)}_{R_a \times E_{tr}} \quad with \quad R_a = \frac{1}{C_h V_a}$$

Potential E_c

R_a x E_{tr}

Surface resistance

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

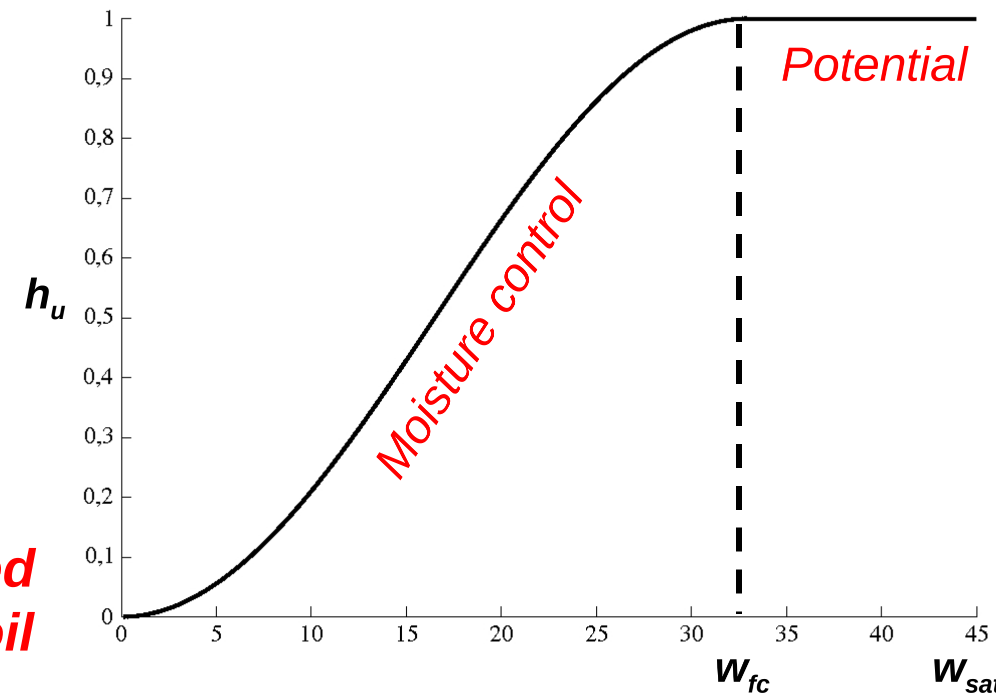
Water Budget : Bare soil evaporation

$$E_g = \underbrace{(1-veg)(1-p_{ng})(1-\delta_i)}_{\text{Soil fraction without freezing}} \underbrace{\rho_a C_H V_a \left[h_u q_{sat}(T_s) - q_a\right]}_{\text{Surface – Atmosphere exchange}}$$

Surface relative humidity

$$h_u = \frac{1}{2}\left[1-\cos\left(\pi\frac{w_1}{w_{fc}}\right)\right]$$

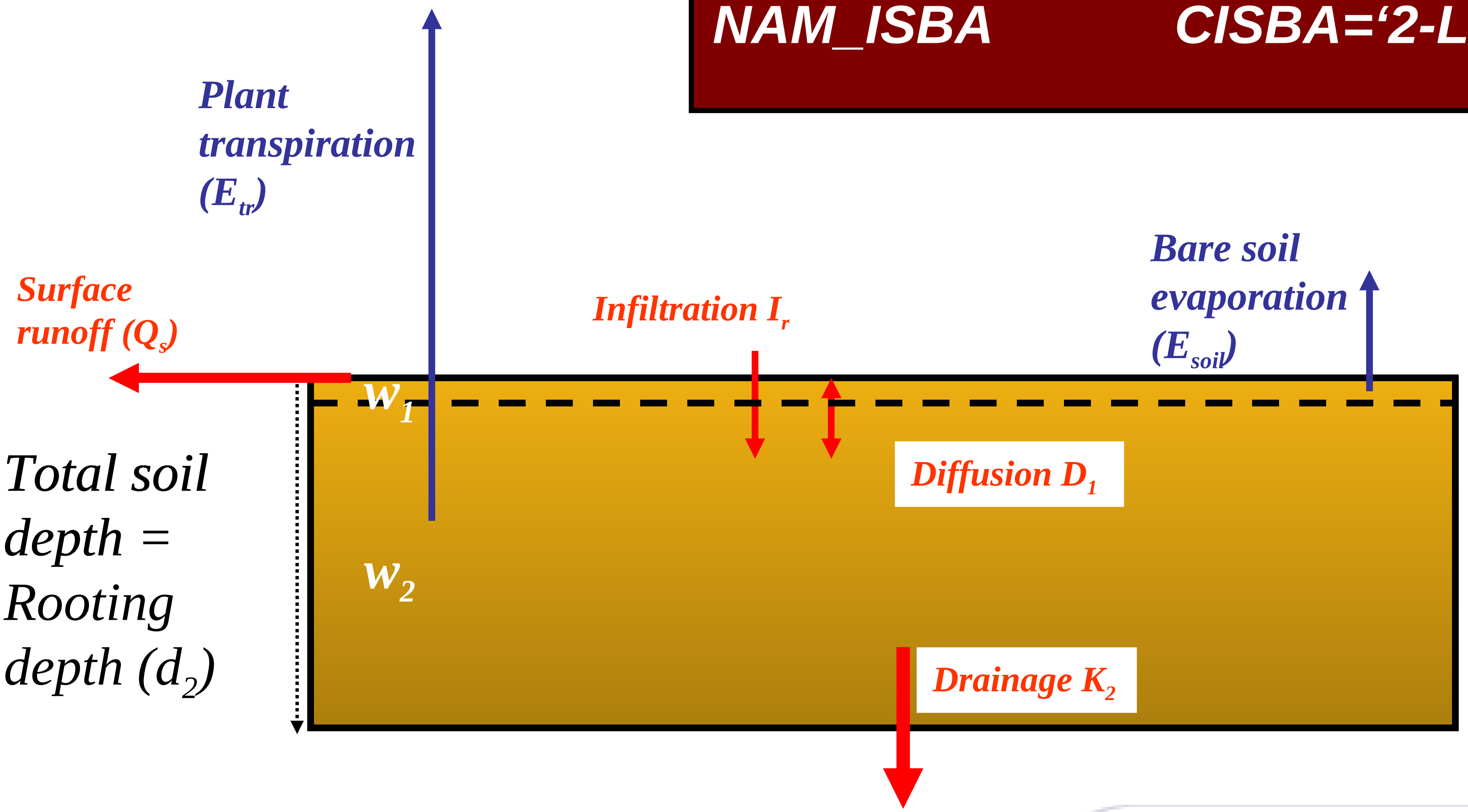
$$h_u = 1 \quad \forall w_1 \geq w_{fc}$$



The same approach are used for sublimation (E_{gf}) over soil freezing

Water Budget : Soil moisture

NAM_ISBA CISBA='2-L'



Water Budget : Soil moisture

Humidity exchange coefficient
between surface and atmosphere

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

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

Infiltration :

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

Défault surface runoff :

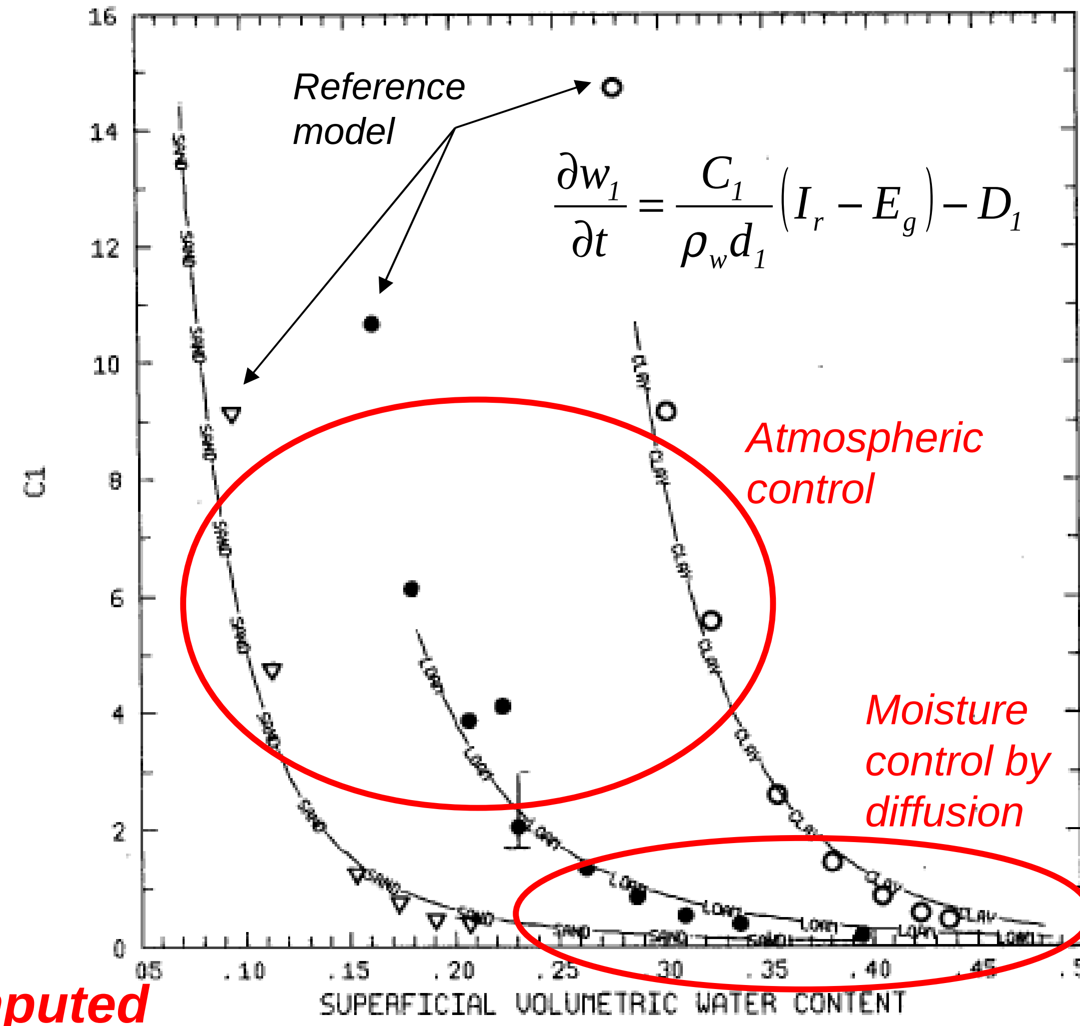
$$Q_s = \frac{d_2 \rho_w}{\Delta t} max\left(0, w_2 - w_{sat}\right)$$

Water Budget : Soil moisture

The C1 coefficient is determinat
(Darcy and/or Richards) and ass
surface is sinusoidal (*Noilhan an*

$$C_1 = 2\sqrt{\pi}\sqrt{\frac{w_{sat}}{b\tau|\psi_{sat}|k_s}}$$

$$C_{1sat} = 10^{-2}(5.58\,X_{cla}$$



For very dry soil, C_1 is computed via Gaussian expression taking into account soil temperature

Water Budget : Diffusion

Diffusion term between surface and root layer (*Noilhan and Planton 1989*):

$$D_1 = \frac{C_2}{\tau}\left(w_1 - w_{geq}\right)$$

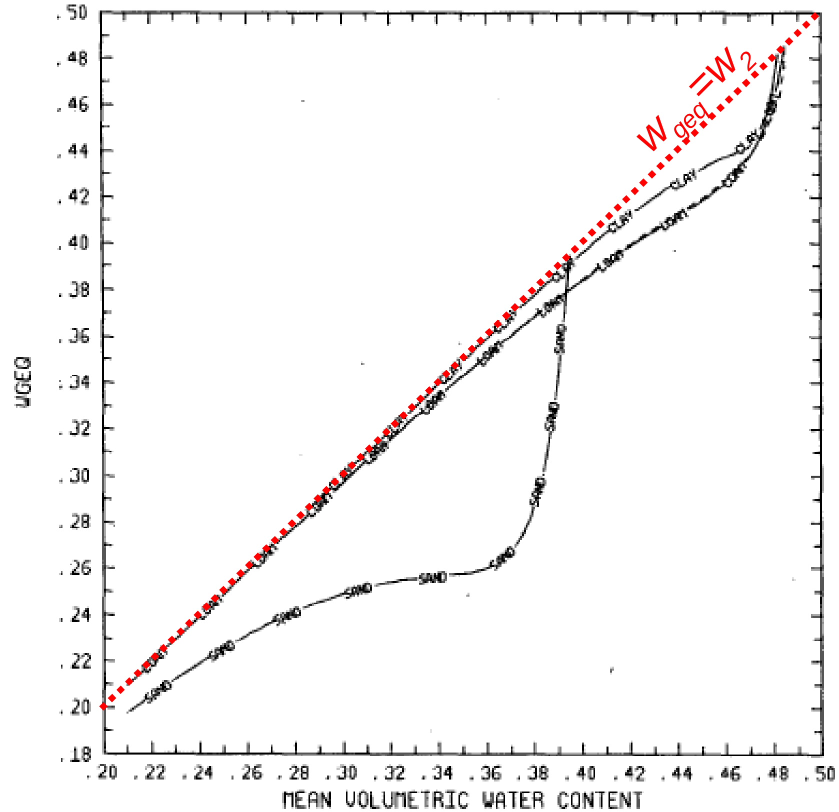
Equilibrium moisture between w_1 et w_2 when gravity balances the capillarity forces

$$w_{geq} = w_2 - a w_{sat}\left(\frac{w_2}{w_{sat}}\right)^p\left[1-\left(\frac{w_2}{w_{sat}}\right)^{8p}\right]$$

Velocity at which the water profile is restored to its equilibrium

$$C_2 = C_{2ref}\left(\frac{w_2}{w_{sat} - w_2 + w_{min}}\right)$$

Estimated from the mean C_2 value at $w_2=0.5w_{sat}$ using different initial textural profile (In ISBA $C_{2ref} \sim X_{clay}$).



Water Budget : Drainage

Gravitational drainage term (*Mahfouf and Noilhan 1996*):

$$K_{\square} = \frac{C_{\square}}{\tau d_{\square}} \max\left[\square, \left(w_{\square} - w_{fc}\right)\right]$$

Velocity at which the water profile is restored to the field capacity

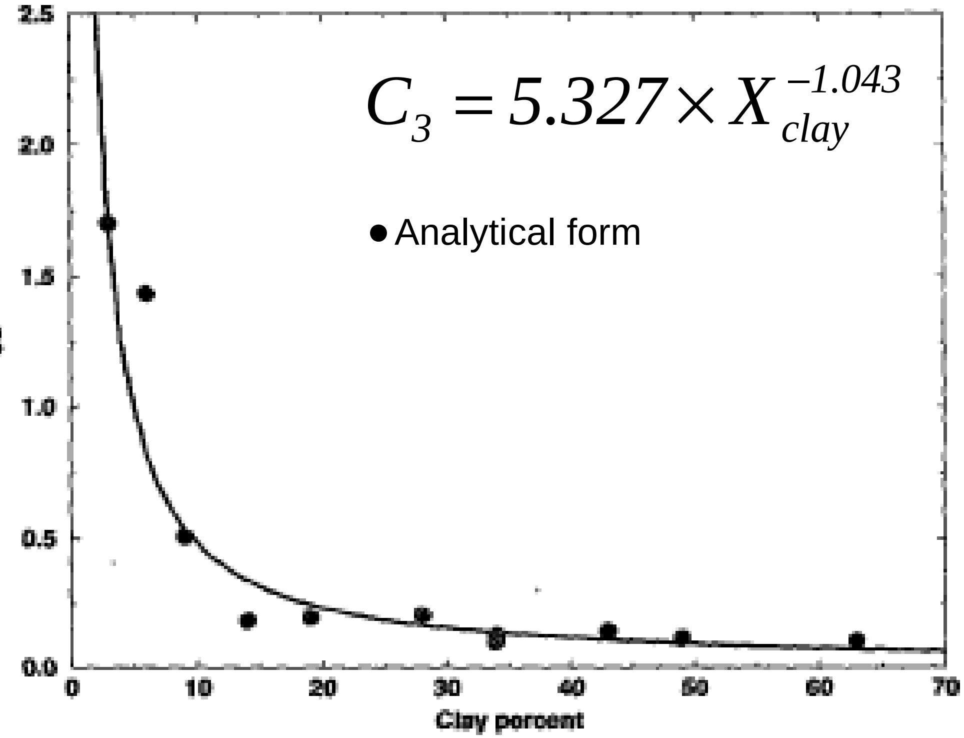
The C3 coefficient is determinate analytically via Darcy equation and no surface flux conditions using a (initial) saturated reservoir of 1m depth :

Force-res

Prognostic equations $\frac{\partial w}{\partial t} = -\frac{C_3}{d} w$ …

Time integration $w(t) = w_{fc} + \left(w_{sat}\right.$ …

So, at time $t = \tau\, d / C_3$



$\ldots\ w \ldots_{sat} \Big)^{2b+3} \ldots /(2b+2)$

Water Budget : Drainage

Importance of gravitational drainage term (from *Mahfouf and Noilhan 1996*):

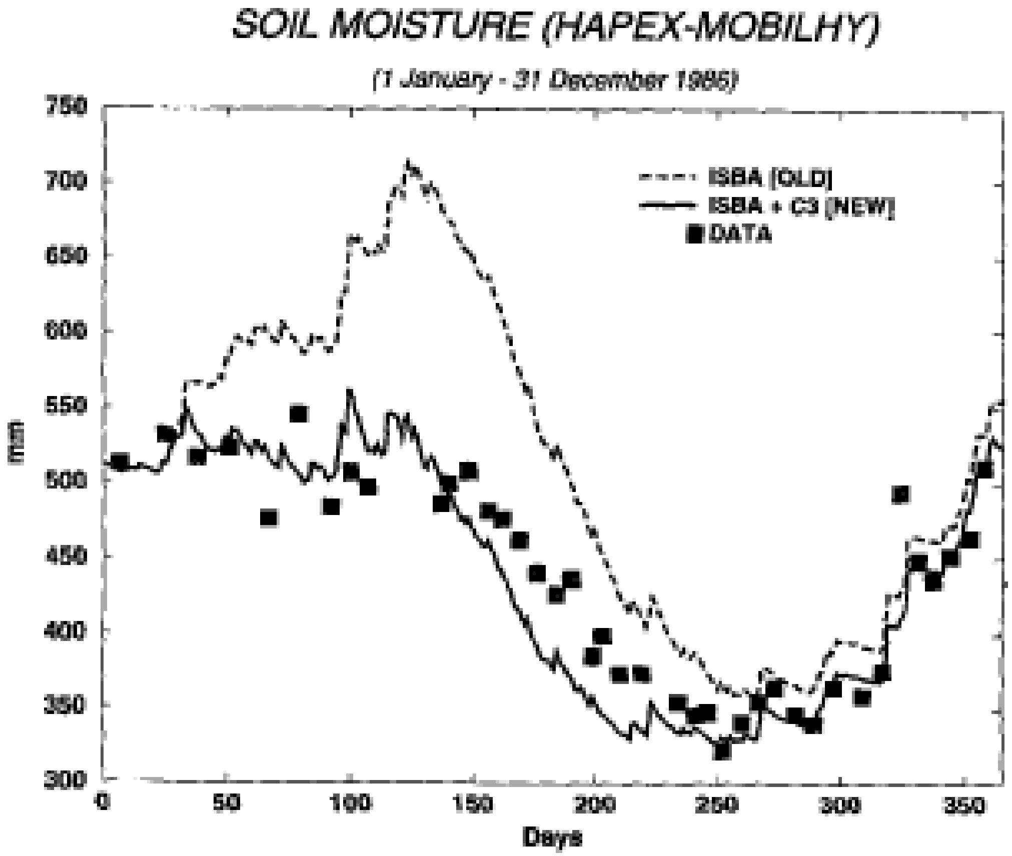
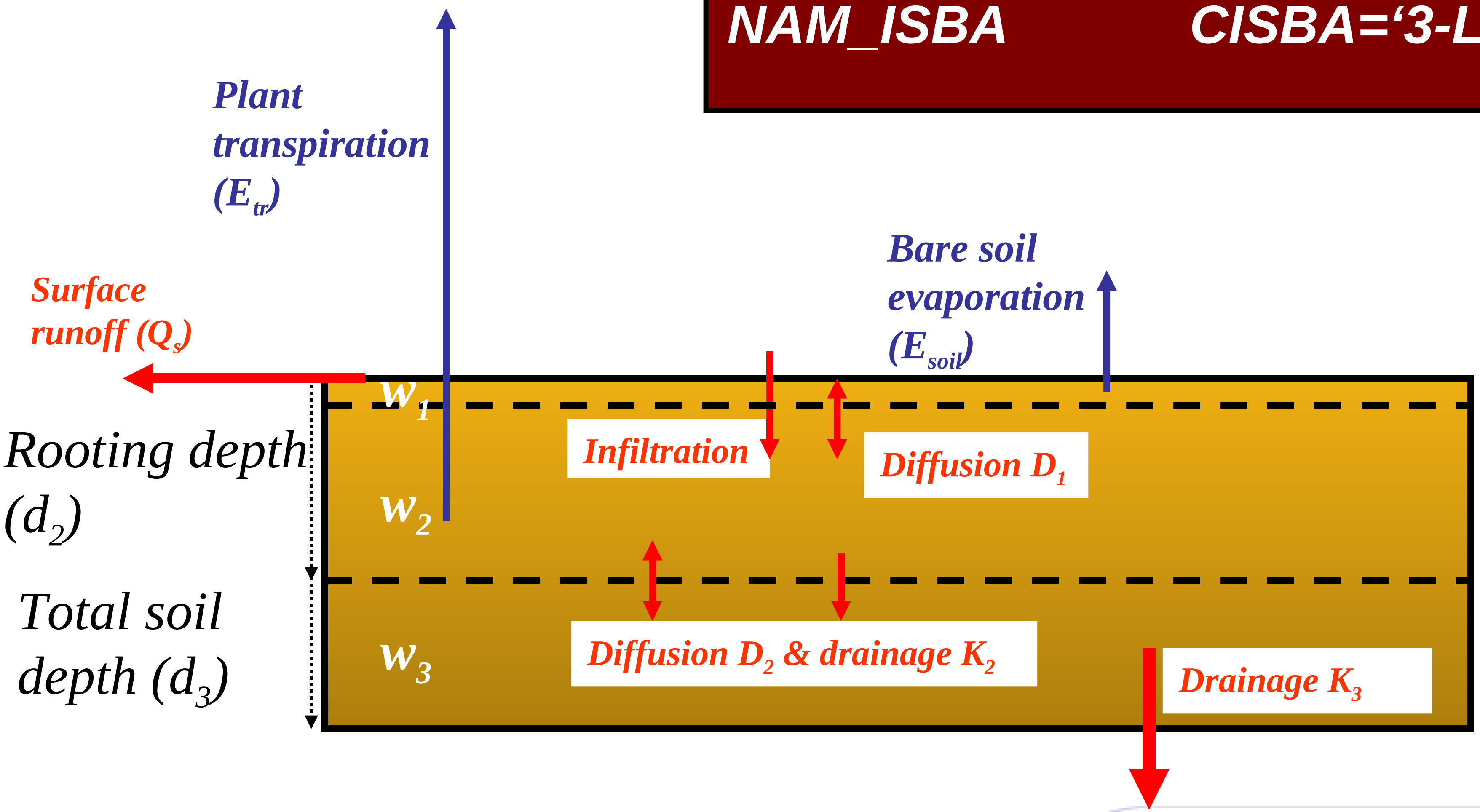


FIG. 3. Annual cycle of total soil water content (mm) in the top 1.6 m simulated by ISBA with (solid line) and without drainage (dotted line) and in comparison with HAPEX data (solid squares).

Water Budget : Soil moisture

NAM_ISBA CISBA='3-L'



Water Budget : 3-L Soil moisture

Inclusion of a deep soil layer to distinguish between rooting zone and deep soil (*Bonne et al. 2000*):

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

$$\frac{\partial w_{\square}}{\partial t} = \frac{\square}{\rho_w d_{\square}}\left(I_r - E_g - E_{tr}\right) - K_{\square} \qquad w_{min} \le w_2 \le w_{sat}$$

New Diffusion

$$\frac{\partial w_3}{\partial t} = \frac{d_2}{\left(d_3 - d_2\right)}\left(K_2 + D_2\right) - K_3 \qquad w_{min} \le w_3 \le w_{sat}$$

New prognostic equation

Gravitational drainage as previously

$$K_3 = \frac{C_3}{\tau\left(d_3 - d_2\right)} max\left[0,\left(w_3 - w_{fc}\right)\right]$$

Water Budget : 3-L Soil moisture

Diffusion term between root layer and deep soil (*Boone et al. 1999*):

D_2

The C… es

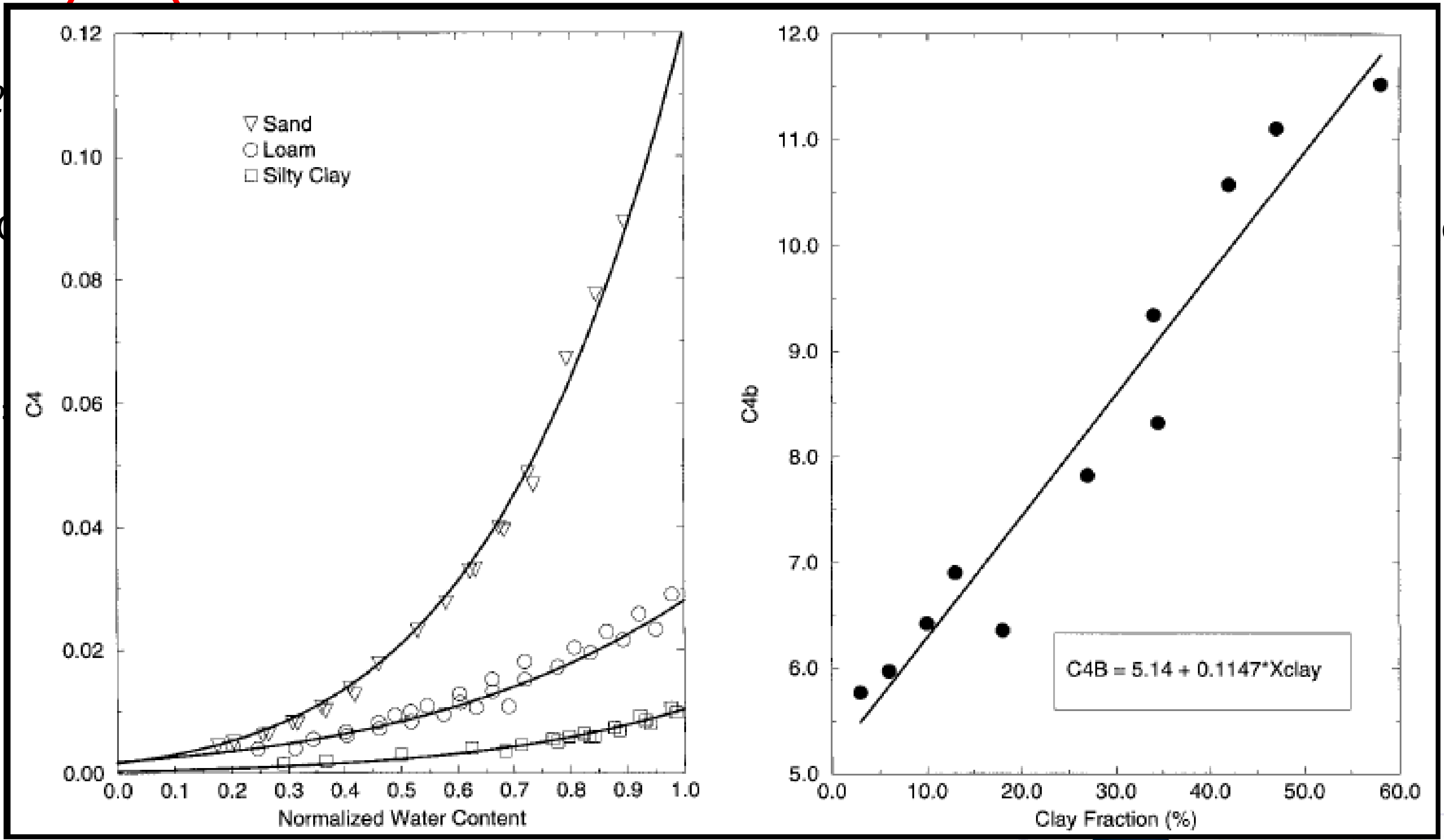
cond…

C_4

It is

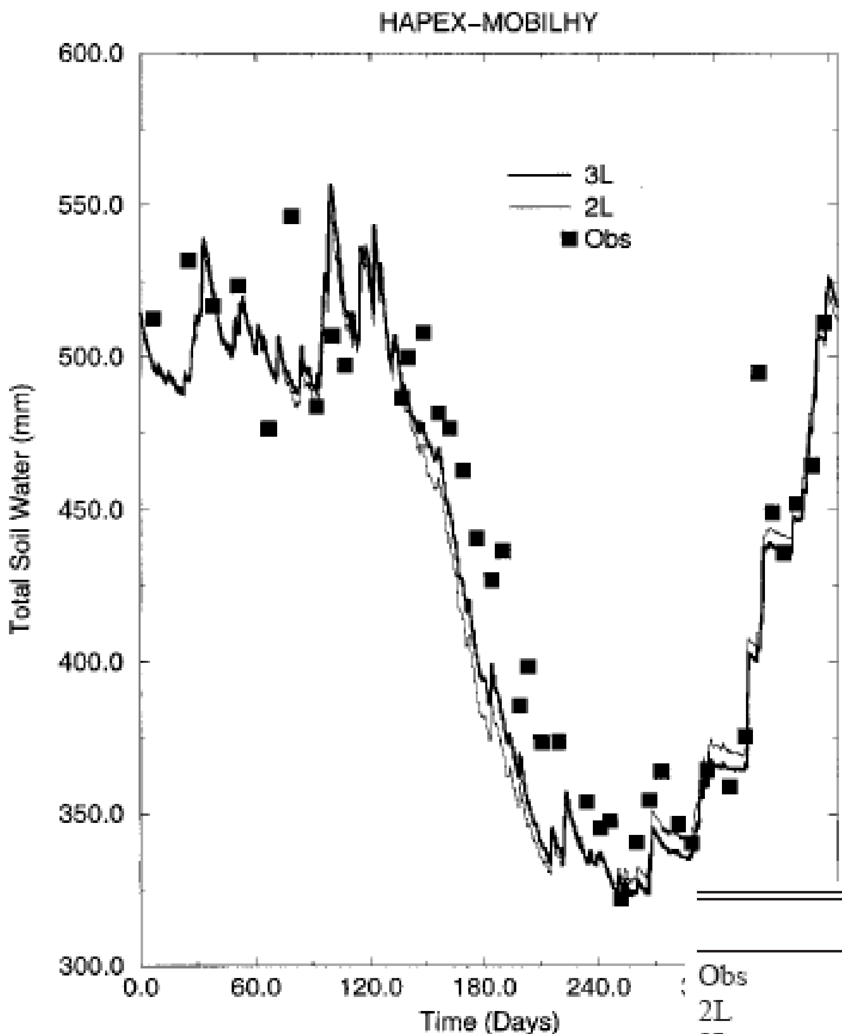
C_4

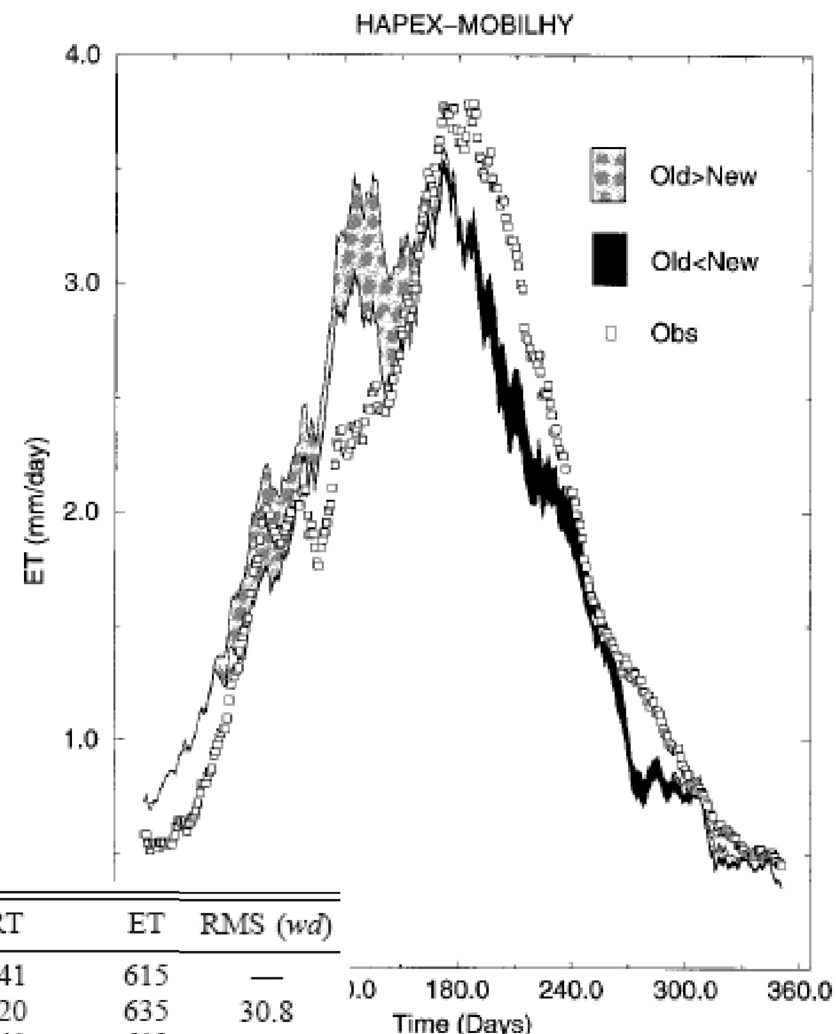
$\overline{w}_2$



Water Budget : 3-L Soil moisture

From *Boone et al. 1999*:





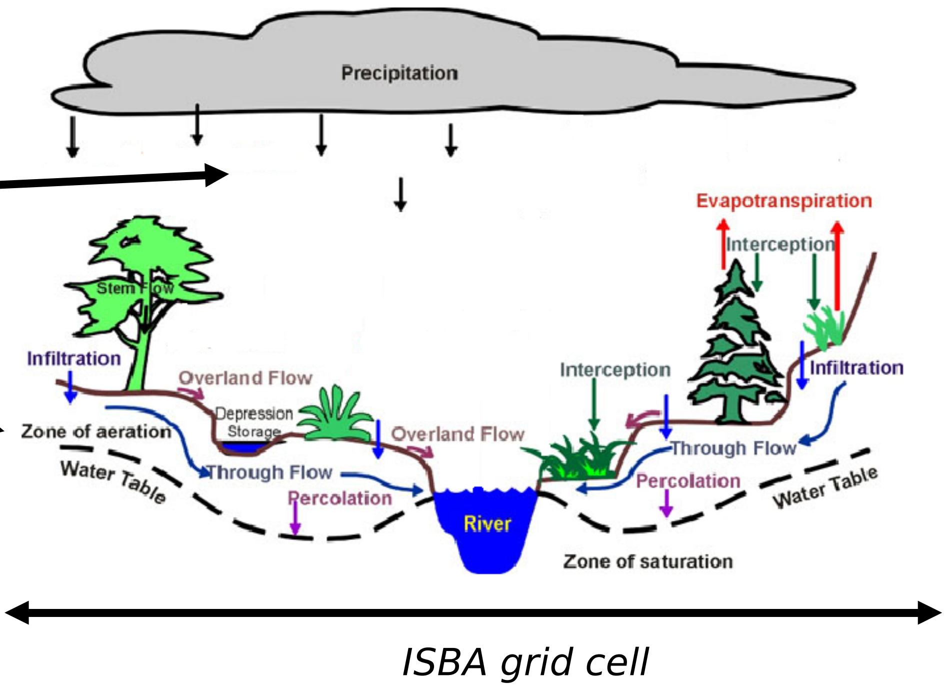
	RT	ET	RMS (*wd*)
Obs	241	615	—
2L	220	635	30.8
3L	241	613	28.4

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

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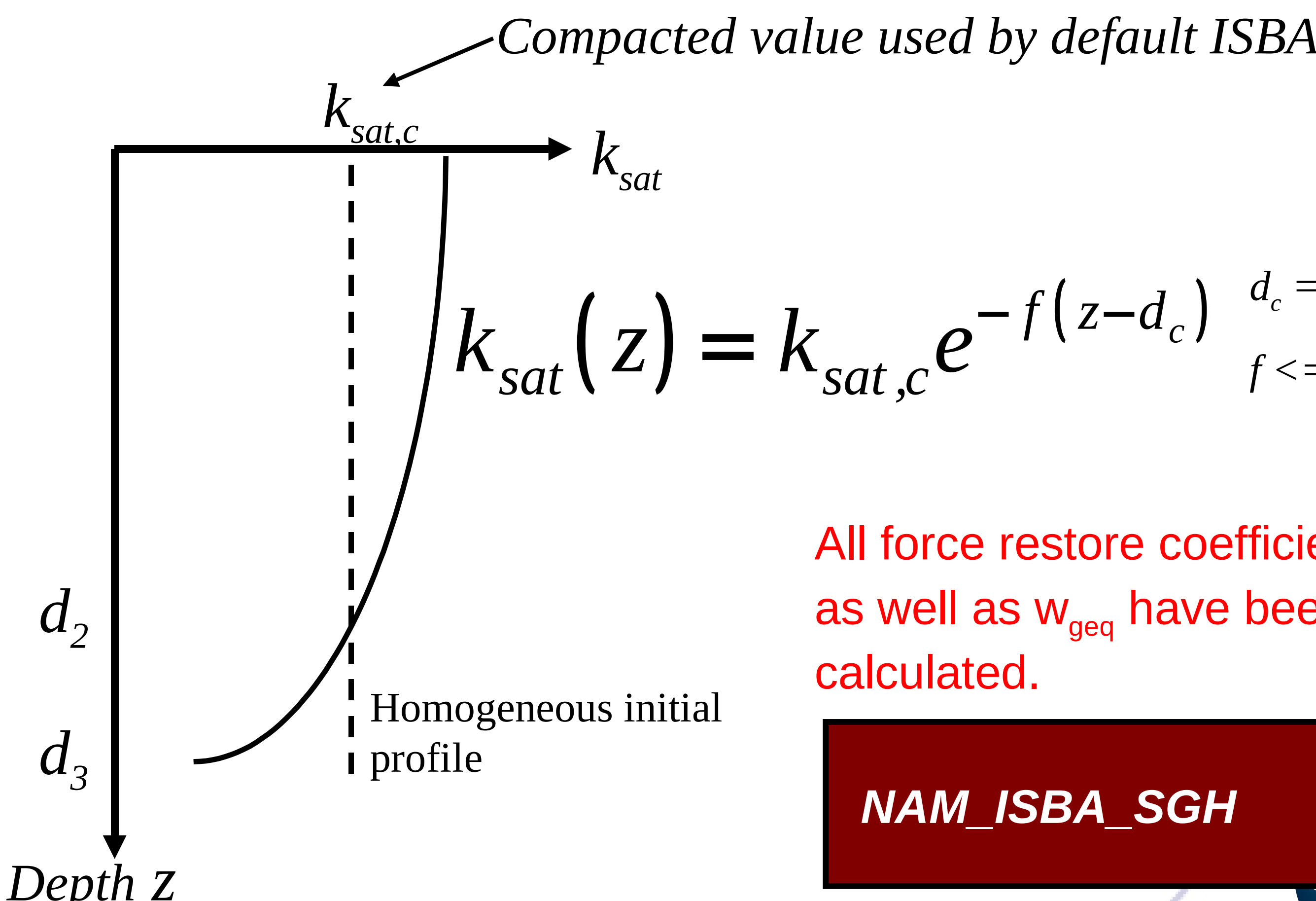
Specific options: Exponential profile of k_{sat}

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 macrospores 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 (C_1, C_2, C_3, C_4) as well as w_{geq} have been analytically re-calculated.

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

Specific options: Sub-Grid Drainage

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

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

$$K_{\square} = \frac{C_{\square}}{\tau\left(d_{\square} - d_{\square}\right)} max\left[\omega_{d\square}, \left(w_{\square} - w_{fc}\right)\right]$$

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

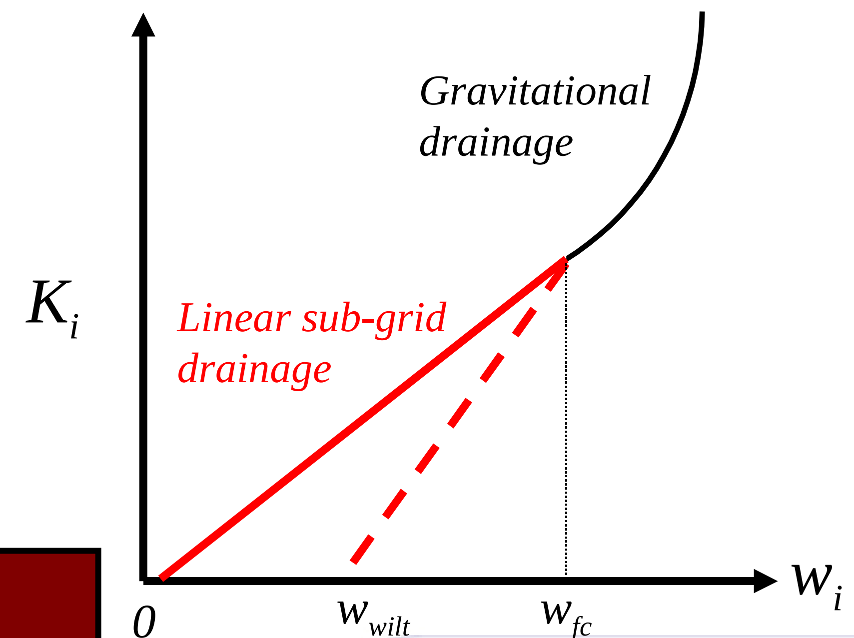
w_{min}=0.001 or w_{wilt} with CKSAT='SGH'

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

NAM_ISBA XUNIF_WDRAIN=0.0005

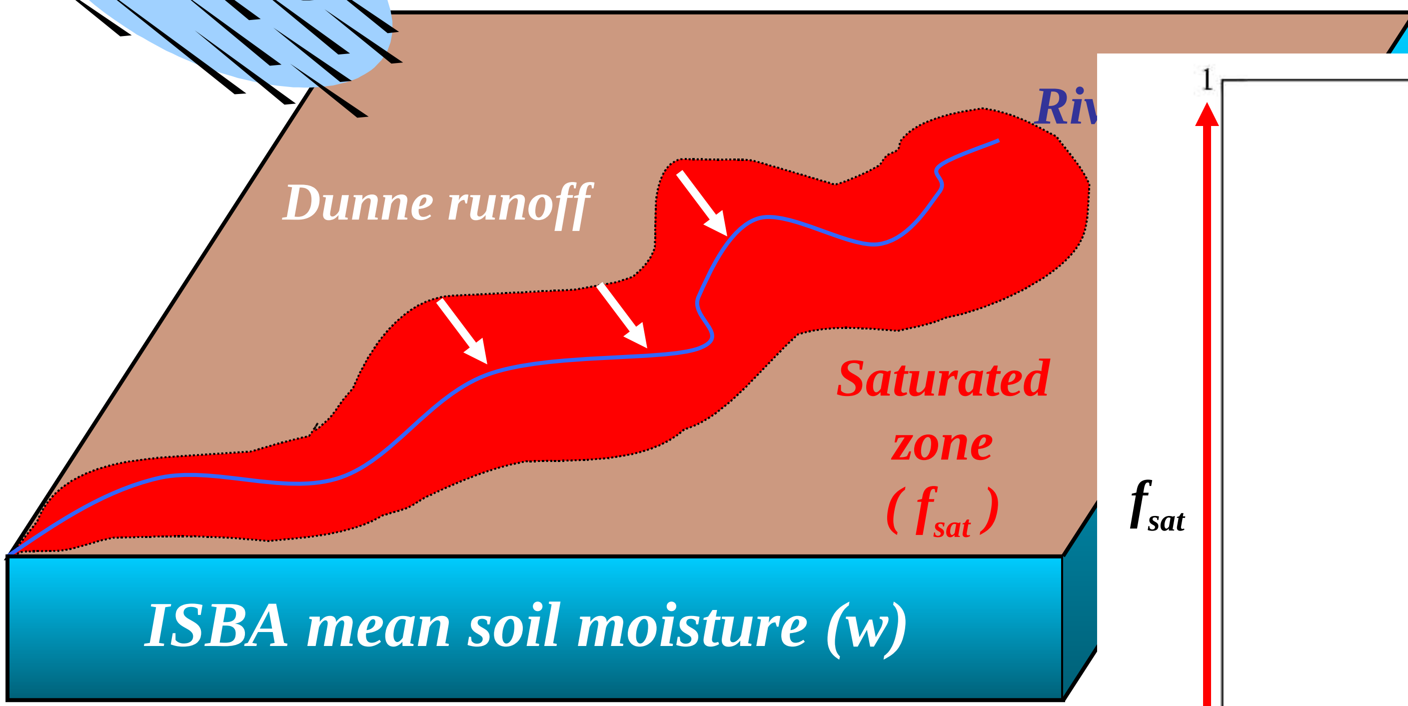
w_{drain} non uniform values over a domain

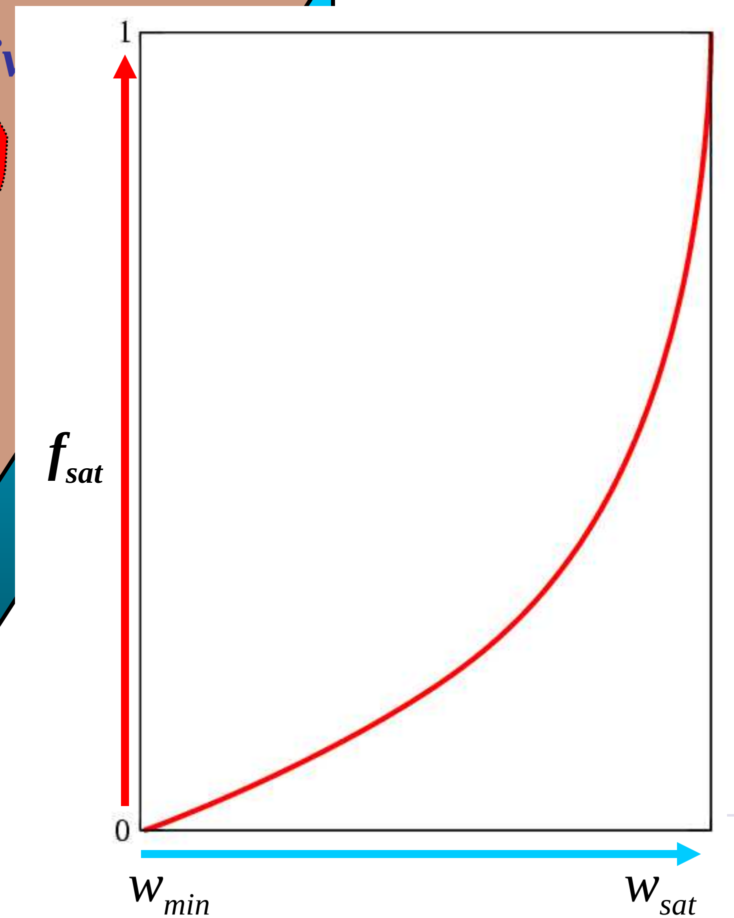
NAM_ISBA YWDRAIN='Input file name'
YWDRAINFILETYPE='input file format'



Specific options: Sub-grid surface runoff

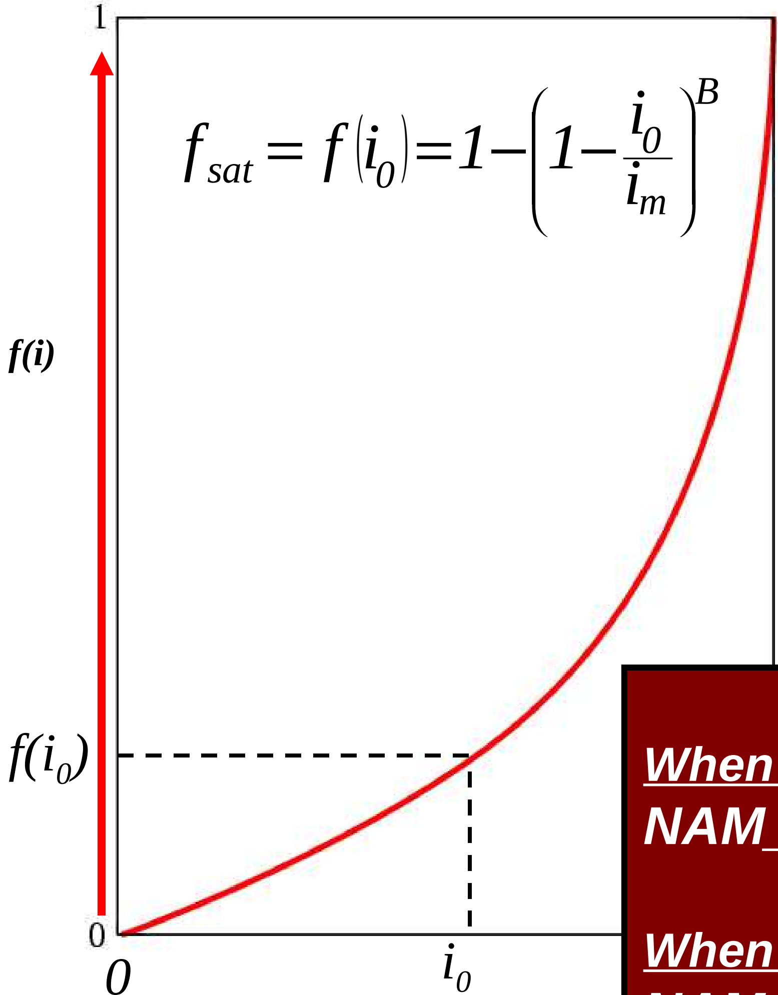
Problem : How to represent the surface flow area that contribute to feed the river over a grid cell ?





Answer : To determine a relationship between w et f_{sat}

Sub-grid surface runoff: VIC approach



$$f_{sat} = f(i_0) = 1 - \left(1 - \frac{i_0}{i_m}\right)^B$$

The grid cell consists of an infinite number of reservoir with a variable infiltration capacity (VIC) : $0 < i < i_m$

ISBA

Following dt92, Habets et al 1999 :

$$i_0 = 1 - \left(1 - \frac{w_2 - w_{wilt}}{\dots}\right)^{\frac{1}{B+1}}$$

When you do the PGD

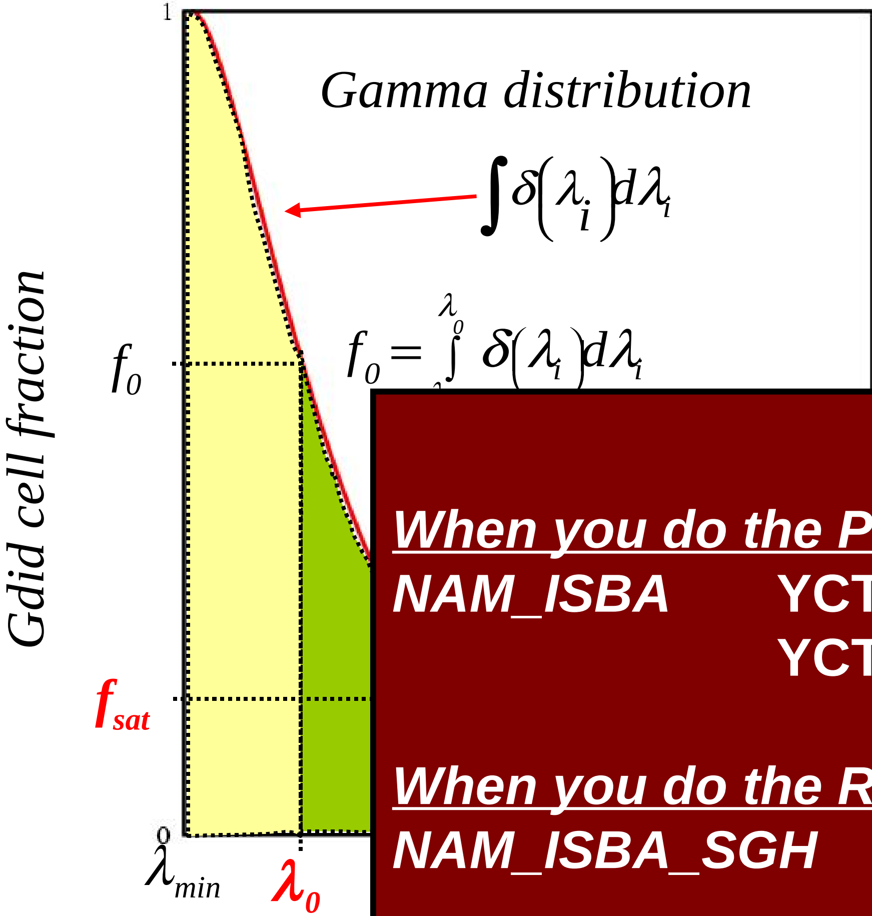
NAM_ISBA XBRUNOFF=0.5

When you do the RUN

NAM_ISBA_SGH CRUNOFF='DT92'

Dümenil et Todini, 1992 (
Wood et al, 1992

Sub-grid surface runoff: TOPMODEL approach



<u>*Mean deficit :*</u> $D_t = \int_{fractions} d_{i,t} \, df$

$$\frac{D_t}{M} = (1 - f_0 - f_{sat})(\lambda_{sat} - \bar{\lambda}') + f_0 \frac{d_0}{M}$$

<u>*Maximum*</u> $d_0 = (w_{sat} - w_{wilt}) d_2$

<u>When you do the PGD</u>

NAM_ISBA **YCTI = ‘file name'**

YCTIFILETYPE = ‘file format'

<u>When you do the RUN</u>

NAM_ISBA_SGH ***CRUNOFF=‘SGH’***

<u>*Mean index :*</u>

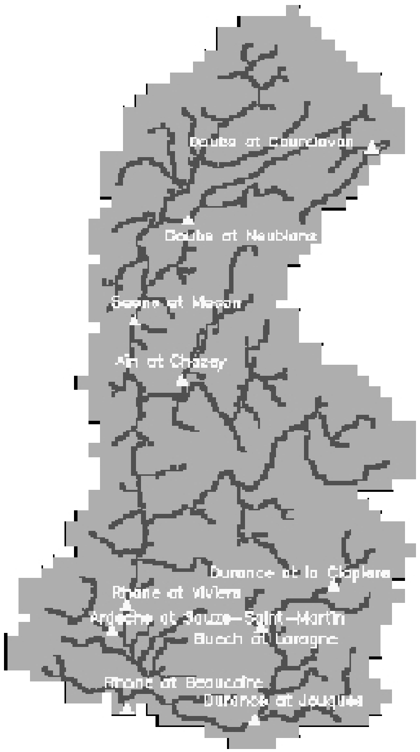
$$\bar{\lambda}' = \int_{\lambda_0}^{\lambda_{sat}} \lambda_i \delta(\lambda_i) d\lambda_i \Big/ \int_{\lambda_0}^{\lambda_{sat}} \delta(\lambda_i) d\lambda_i$$

<u>Relation mean deficit / soil moisture :</u>

$$D_{t,ISBA} = (w_{sat} - w_2) d_2$$

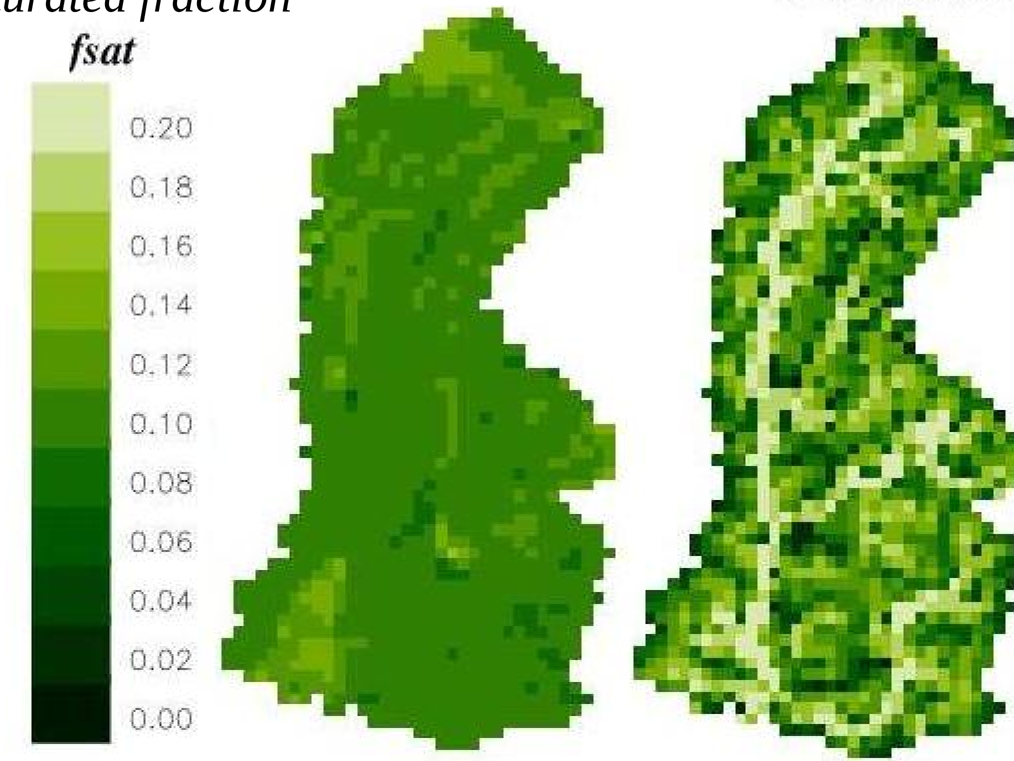
Sub-grid surface runoff: DT92 vsTOPMODEL

Réseau hydrographique



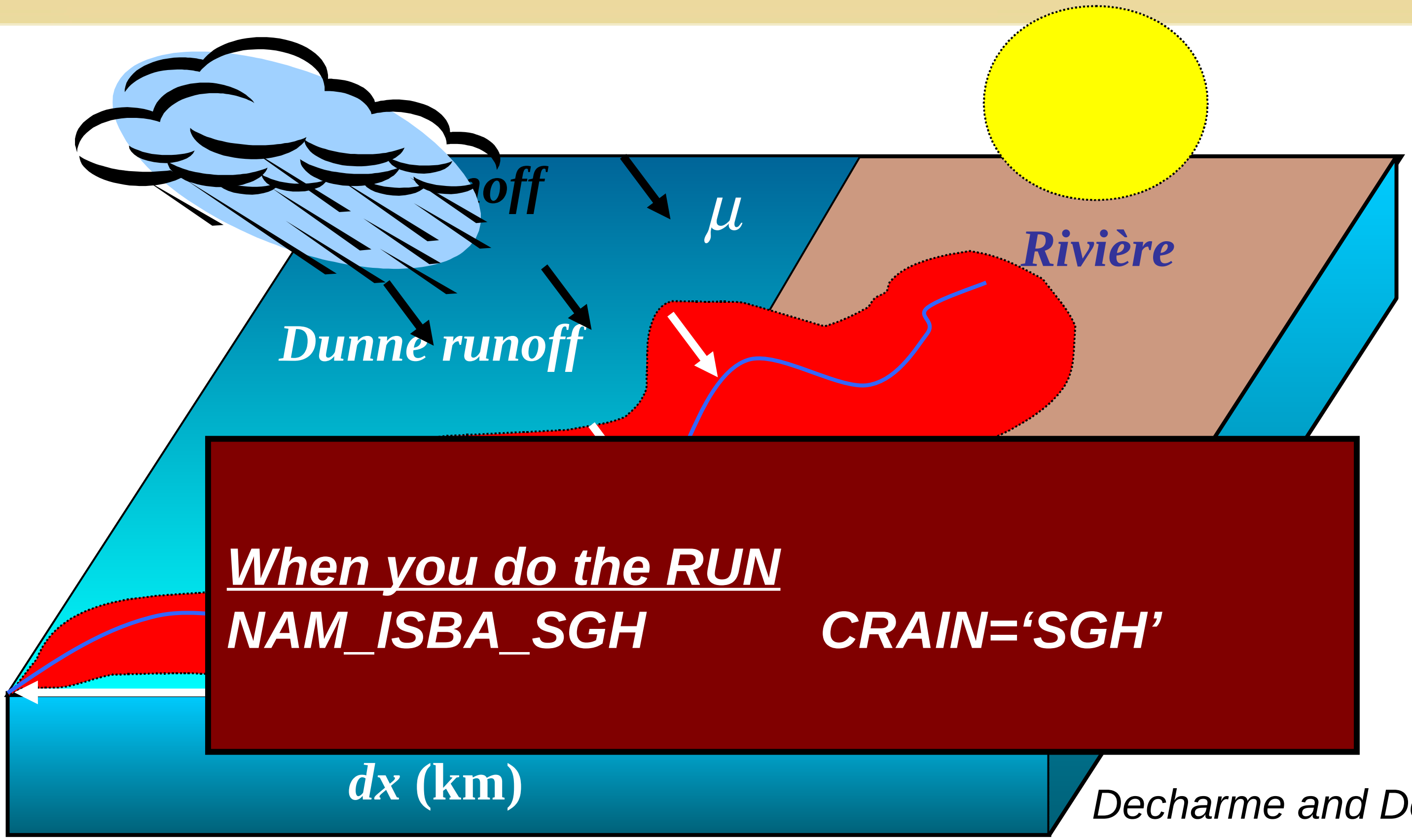
Saturated fraction ***fsat***

Dt92 (B=0.5) **TOPMODEL**



Analytical comparison for a given soil moisture value (w_{fc})

Specific options: Sub-grid precip & Horton runoff



<u>When you do the RUN</u>

NAM_ISBA_SGH CRAIN='SGH'

Decharme and Douville, 2006

$$\mu = 1 - e^{-\beta \overline{P}}$$

$$\beta = 0.2 + 0.5 e^{-0.01 dx}$$

$\overline{P}$ = mean precipitation

(Fan et al. 1996, Peters-Lidard et al. 1997)

$$f(P_i) = \frac{\mu}{\overline{P}} e^{-\mu \frac{P_i}{\overline{P}}}$$

P_i = Local precipitations

(Entekhabi et Eagleson 1989)

Canopy dripping : $d_r = P\ e^{\frac{\mu}{R_r}\frac{(W_r - W_{r\,max})}{\Delta t}}$

Specific options: Horton runoff

$$Q_s = \underbrace{f_{sat}\mu\int_0^\infty P_i f(P_i)dP_i}_{\text{Dunne}\,:\,Q_s^D} + \underbrace{(1-f_{sat})\mu\int_{I_i}^\infty (P_i - I_i) f(P_i)dP_i}_{\text{Horton}\,:\,Q_s^H}$$

I_i = Local maximum infiltration capacity of soils

Exponential distribution of local maximum infiltration capacity of soils

$$g(I_i) = \frac{1}{\bar{I}} e^{-I_i/\bar{I}}$$

Fraction of soil freezing δ_f

$$Q_s^H = \mu\left[\underbrace{(1-\delta_f)\int_0^\infty\int_{I_{unf,i}}^\infty (P_i - I_{unf,i}) f(P_i) g(I_{unf,i}) dP_i dI_{unf,i}}_{\text{Soil}} + \underbrace{\delta_f\int_0^\infty\int_{I_{f,i}}^\infty (P_i - I_{f,i}) f(P_i) g(I_{f,i}) dP_i dI_{f,i}}_{\text{Soil freezing}}\right]$$

Decharme and Douville, 2006

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Specific options: Horton runoff

With sub-grid precipitation (CRAIN='SGH') :

$$Q_s^H = (1-\delta_f)\left[\frac{\overline{P}}{1+\overline{I_{unf}}\,\dfrac{\mu}{\overline{P}}} + max\left(1, S_m - \overline{I_{unf}}\right)\right] + \delta_f\left[\frac{\overline{P}}{1+\overline{I_f}\,\dfrac{\mu}{\overline{P}}} + max\left(1, S_m - \overline{I_f}\right)\right]$$

Without sub-g

$$Q_s^H = (1-\delta_f)$$

When you do the RUN

NAM_ISBA_SGH CHORT='SGH'

Non frozen so ... llowing

Green-Ampt approximation: Johnsson and Lundin (1991) :

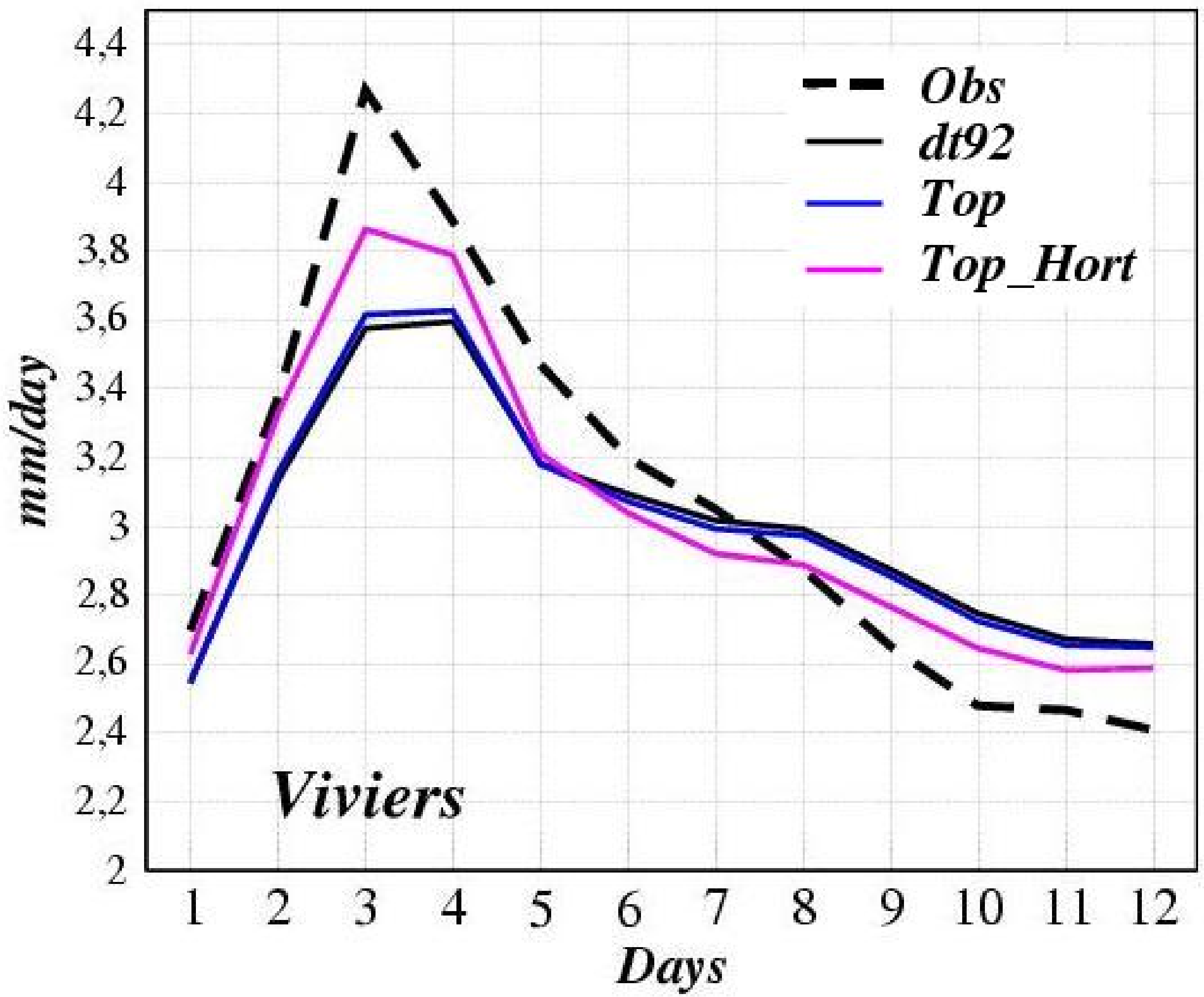
$$I_{unf,i} = k_{sat,i}\left[\frac{b\psi_{sat}}{\Delta z}\left(\frac{w_2}{w_{sat}} - 1\right) + 1\right]$$

$$I_{f,i} = k_{sat,i}\left(\frac{w_2}{w_{sat}}\right)^{2b+3} \times 10^{-6\frac{w_{I2}}{w_{I2}+w_2}}$$

Decharme and Douville, 2006

Specific options: Horton runoff

Composit of flood events at Viviers (Simulation over the Rhône basin at 8km during 1986-1989).



Now Aaron’s turn !

Summary of hydrologic specific options

Simulation of river discharges over the Rhône river basin at high and low resolution during 1986-1989 period.

88 observed stations are distributed over all domain.

Decharme and Douville, 2006