Land Surface Parameterizations

Aaron Boone
CNRM-GAME, Météo-France

And....thanks to
(P. Le Moigne, B. Decharme,....et al.)

ECMWF Annual Seminar-Sept. 2015

Talk Outline

1 Objective of the Land Surface Model (LSM) parameterization

2 Coupling Aspects

3 Physiographic Parameters

4 Process Parameterizations

5 Summary of Current Important Issues

1 LSM Objective

Historically :

Provide the lower boundary condition for radiation and turbulence schemes (i.e. SWup, LWup, fluxes of heat, mass, momentum between the land surface and the atmosphere)

More Recently :

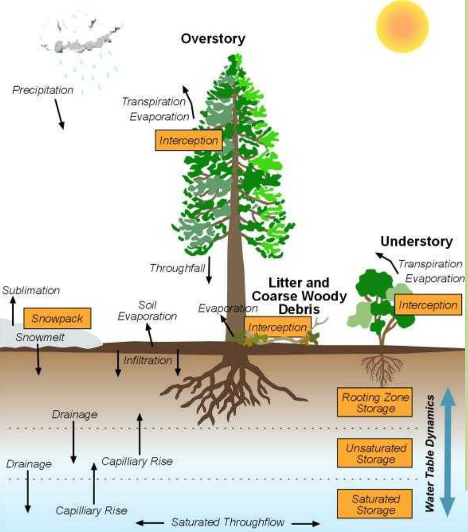
In addition to the above, Carbon fluxes, aerosol fluxes/emission, soil moisture metrics (drought index, flash flood algorithms...), vegetation metrics and/or evolution (LAI), runoff and drainage (exchanges with ground water), snowdepth/coverage, urban « comfort index »....

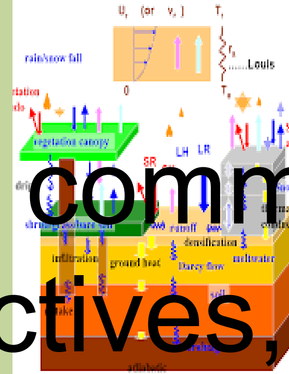
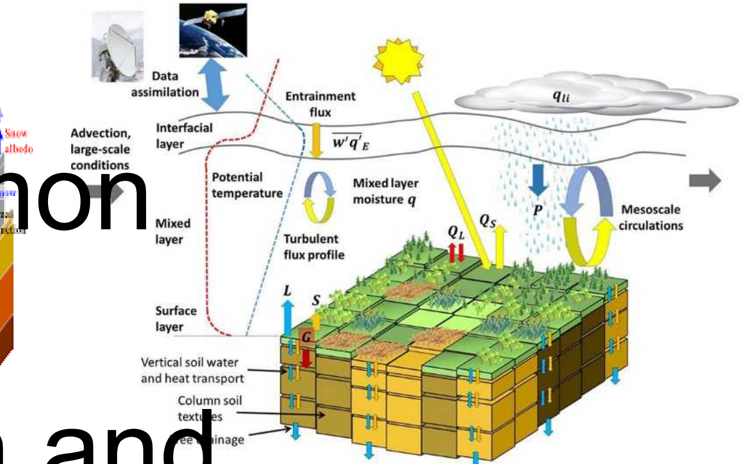
- Of course, significant impact on « sensible weather » diagnostics at 2m i.e. what humans experience on a daily basis

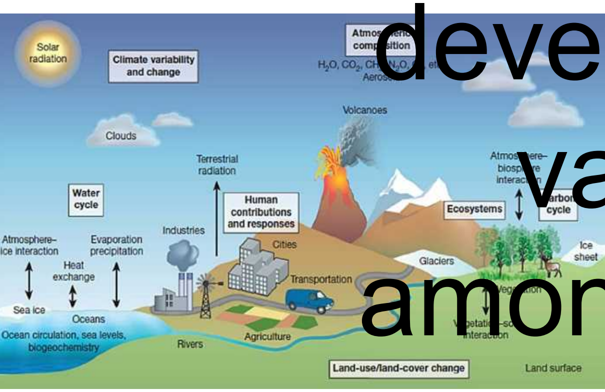
Development has greatly benefited from International Projects :

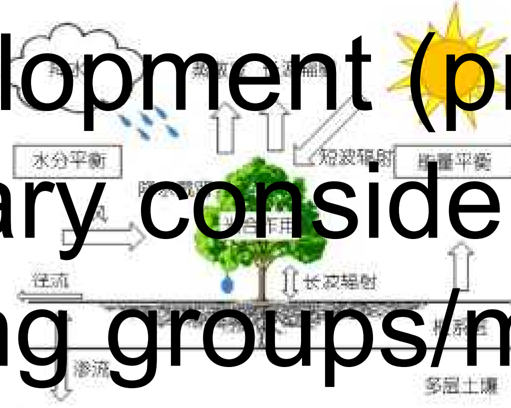
Project for the Intercomparison of Land Surface Parameterization Schemes (PILPS), Global Soil Wetness Project, SnowMIP, Rhone-AGG, etc... – many under the auspices of GEWEX-GLASS (new initiatives on Benchmarking, coupling...)

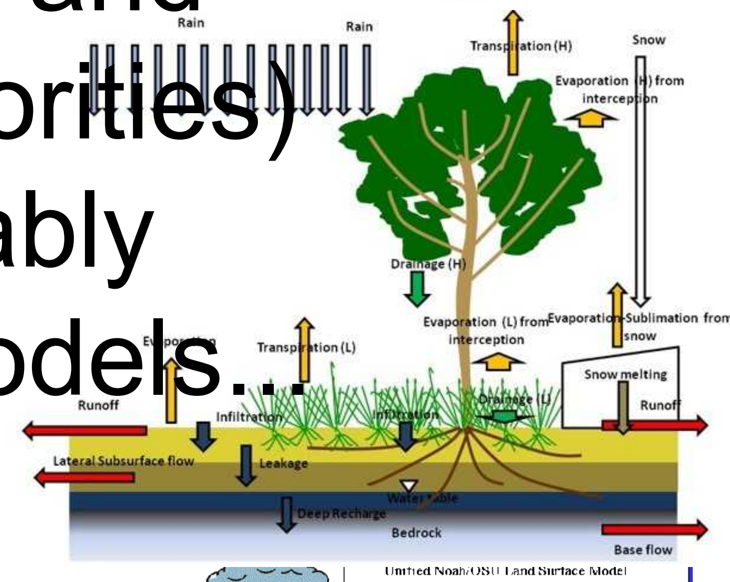
Despite common objectives, implementation and development (priorities) vary considerably among groups/models...

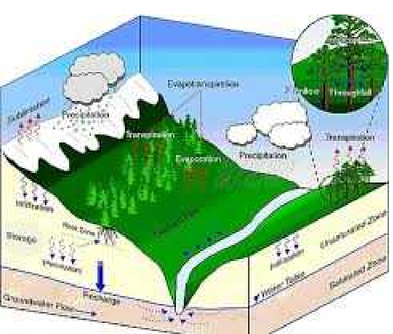
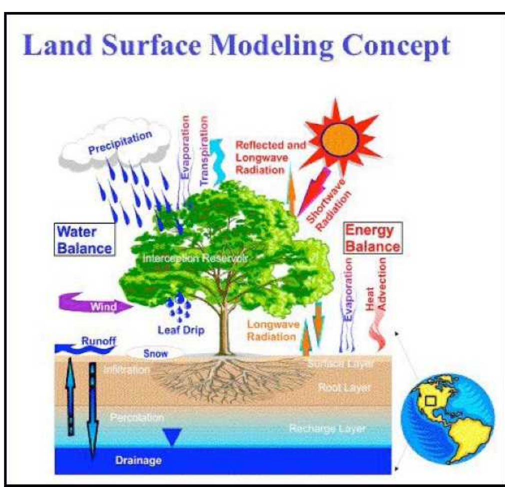


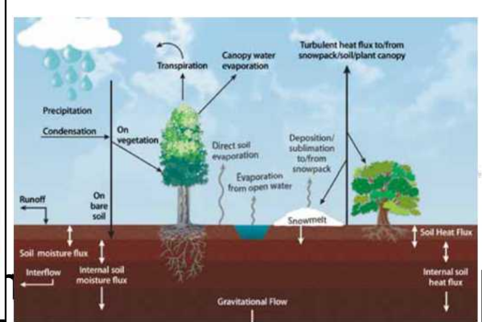




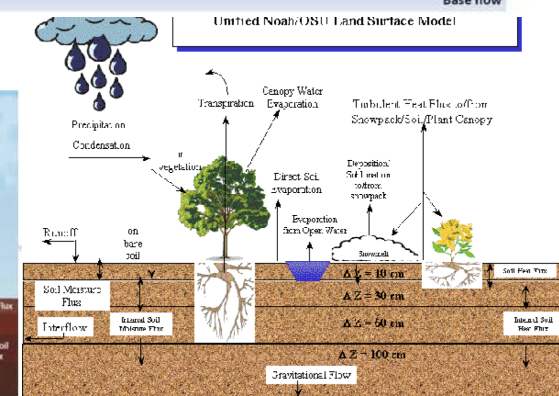


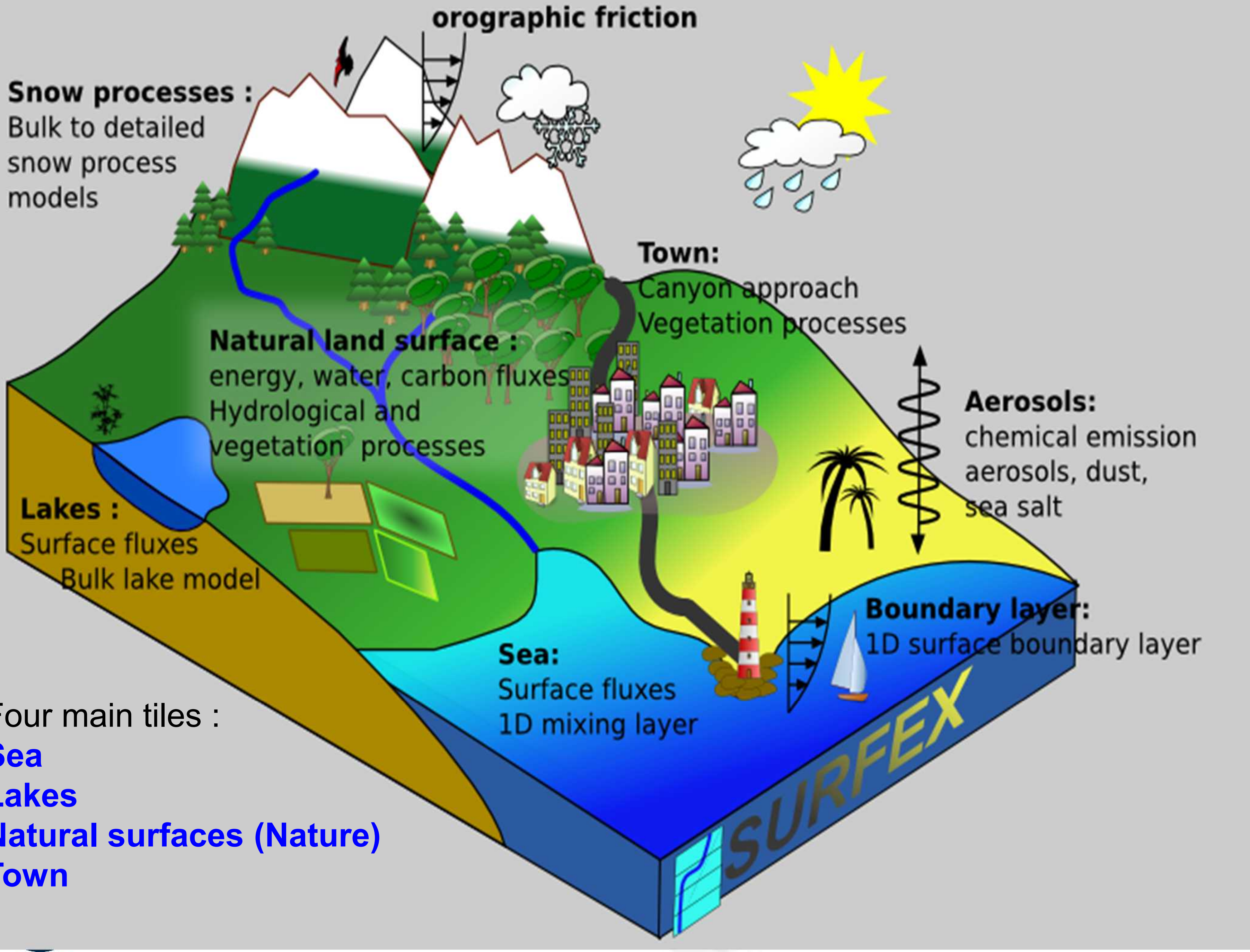










Four main tiles :

Sea

Lakes

Natural surfaces (Nature)

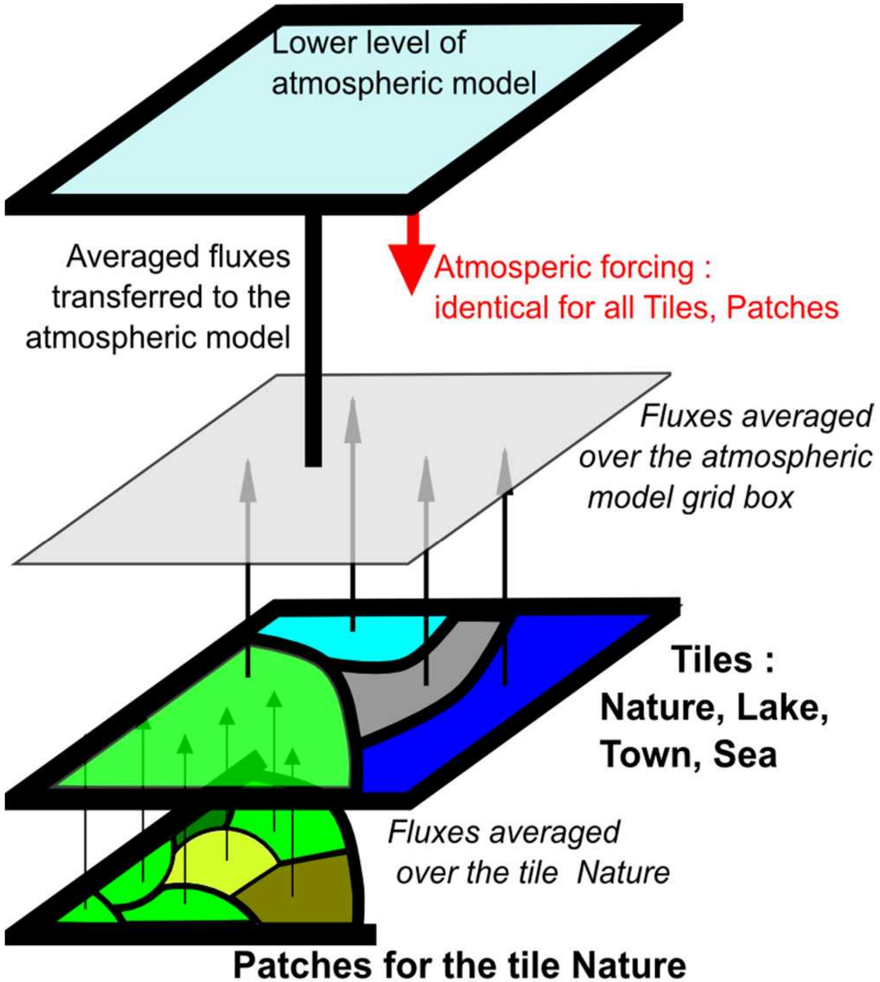
Town

1 LSM Objectives

How can we represent the surface heterogeneity in a grid ? An Explicit (« tile ») Approach

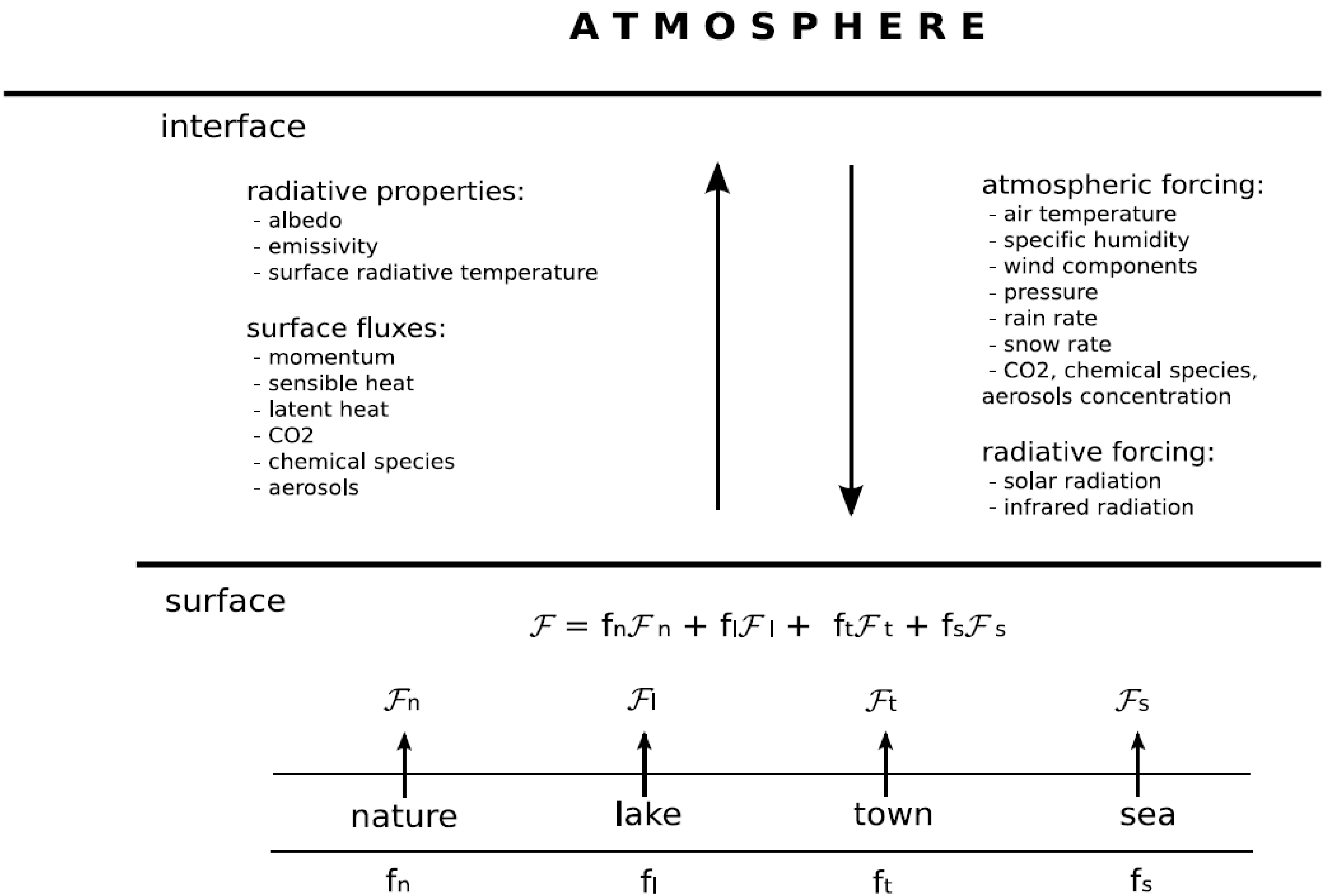
- **Within a grid mesh, the surface is divided into several homogeneous components.**
- **Each component « sees » the same atmospheric forcing**
- **Each component calculates fluxes**
- **Fluxes are aggregated and returned to the atmosphere**

- **No horizontal transfer with the surface/between tiles**
- **Not geo-referenced**
- **Altitude bands a special case (but not without issues)**



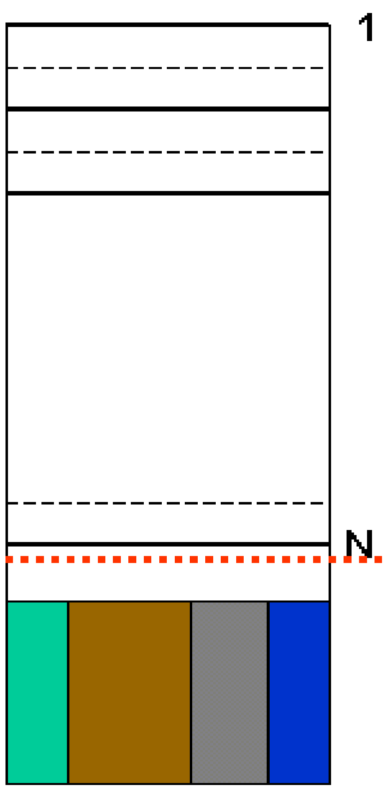
tiling and coupling with an atmospheric model

2 Coupling


ATMOSPHERE
interface
radiative properties:
- albedo
- emissivity
- surface radiative temperature
surface fluxes:
- momentum
- sensible heat
- latent heat
- CO2
- chemical species
- aerosols
atmospheric forcing:
- air temperature
- specific humidity
- wind components
- pressure
- rain rate
- snow rate
- CO2, chemical species, aerosols concentration
radiative forcing:
- solar radiation
- infrared radiation
surface
$\mathcal{F} = f_n\mathcal{F}_n + f_l\mathcal{F}_l + f_t\mathcal{F}_t + f_s\mathcal{F}_s$
$\mathcal{F}_n$
$\mathcal{F}_l$
$\mathcal{F}_t$
$\mathcal{F}_s$
nature
lake
town
sea
f_n
f_l
f_t
f_s

2 Coupling : with turbulence (implicit numerics)

In case of long time step to avoid instabilities in the coupling with the atmosphere. The surface is called in the middle of the vertical diffusion loop (Polcher et al., 1998, Best et al., 2004, Essery et al., 2003).



Vertical diffusion

$$\begin{cases} X \equiv u, v, \theta, q \\ X_i^+ - X_i^- = -\omega_{i,i}\left(X_{i+1}^+ - X_i^+\right) + \omega_{i-1,i}\left(X_i^+ - X_{i-1}^+\right) \\ F_{X,0} = 0 \end{cases}$$

Downward sweep

$$\begin{cases} X_i^+ = A_{X,i}^- X_{i+1}^+ + B_{X,i} \\ A_{X,i} = f\left(\omega_{i-1,i}, \omega_{i,i}, A_{X,i-1}\right) \\ B_{X,i} = f\left(\omega_{i-1,i}, \omega_{i,i}, B_{X,i-1}, X_{X,i-1}\right) \end{cases}$$

Lower atmospheric level

$$X_N^+ = A_{X,N}^- F_{X,S}^+ + B_{X,N}^-$$

Surface Ts + Fluxes on each tiles, Average fluxes

$$\begin{cases} H^+ = \rho C_p V_N^- C_H^- \left(\beta_S T_S^+ - \beta_N T_N^+\right) \\ \dfrac{C_s}{\Delta t}\left(T_S^+ - T_S^-\right) = R_n^+ - H^+ - LE^+ - G^+ \end{cases}$$

Upward sweep

3 Physiographic Parameters

The surface needs several types of parameters :

Orography

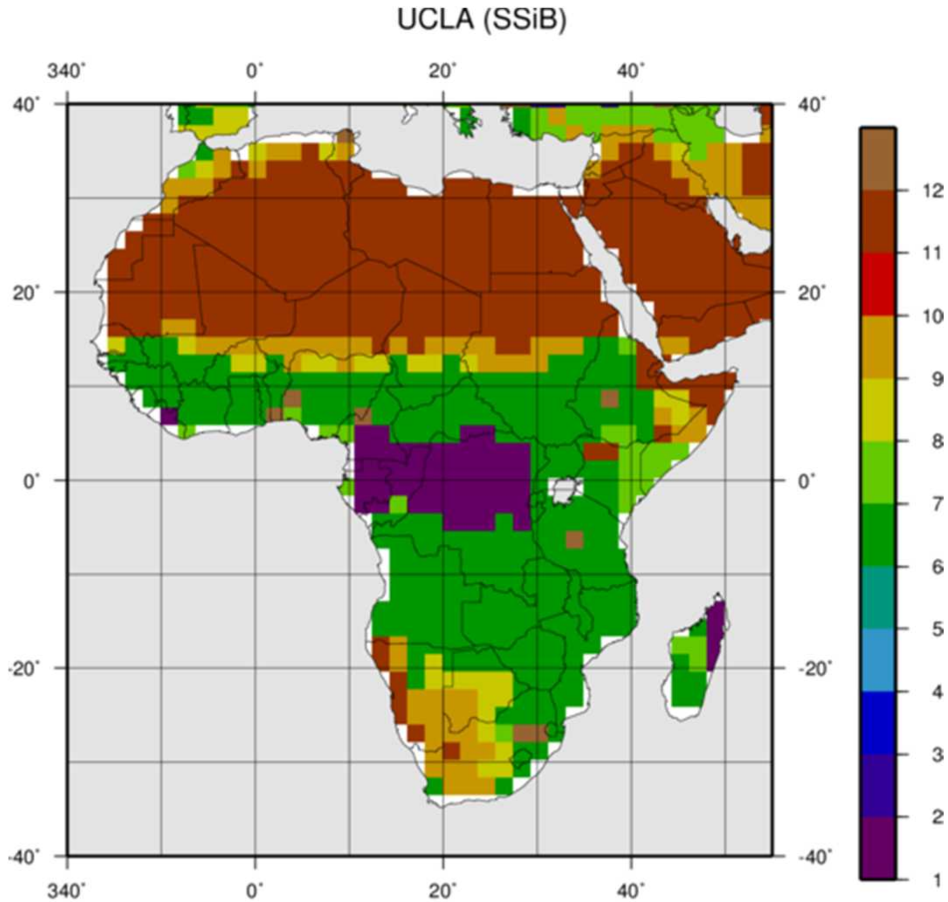
Type of the surface (tile) and vegetation types (patches) for « Nature »

- Nature (land): Albedo, leaf area index, soil texture, organics, veg class…
- FLAKE : lake depth, radiation extinction coefficient …

The databases :

- Land cover database using blend of classification/land use, satellite data, climatological maps, surveys...
- Topography (e.g. Gtopo30 at 1 km or SRTM for higher resolution, from which the mean grid-cell altitude and sub-grid topography parameters are derived).
- Soil properties (clay and sand proportions, organic matters) derived from FAO or HWSD databases.
- Lake depth and optical water properties (Kourzeneva et al., 2011)
- Local scales (often not valid/representative)
- Need for unified high res dataset for ALL LSMs ?

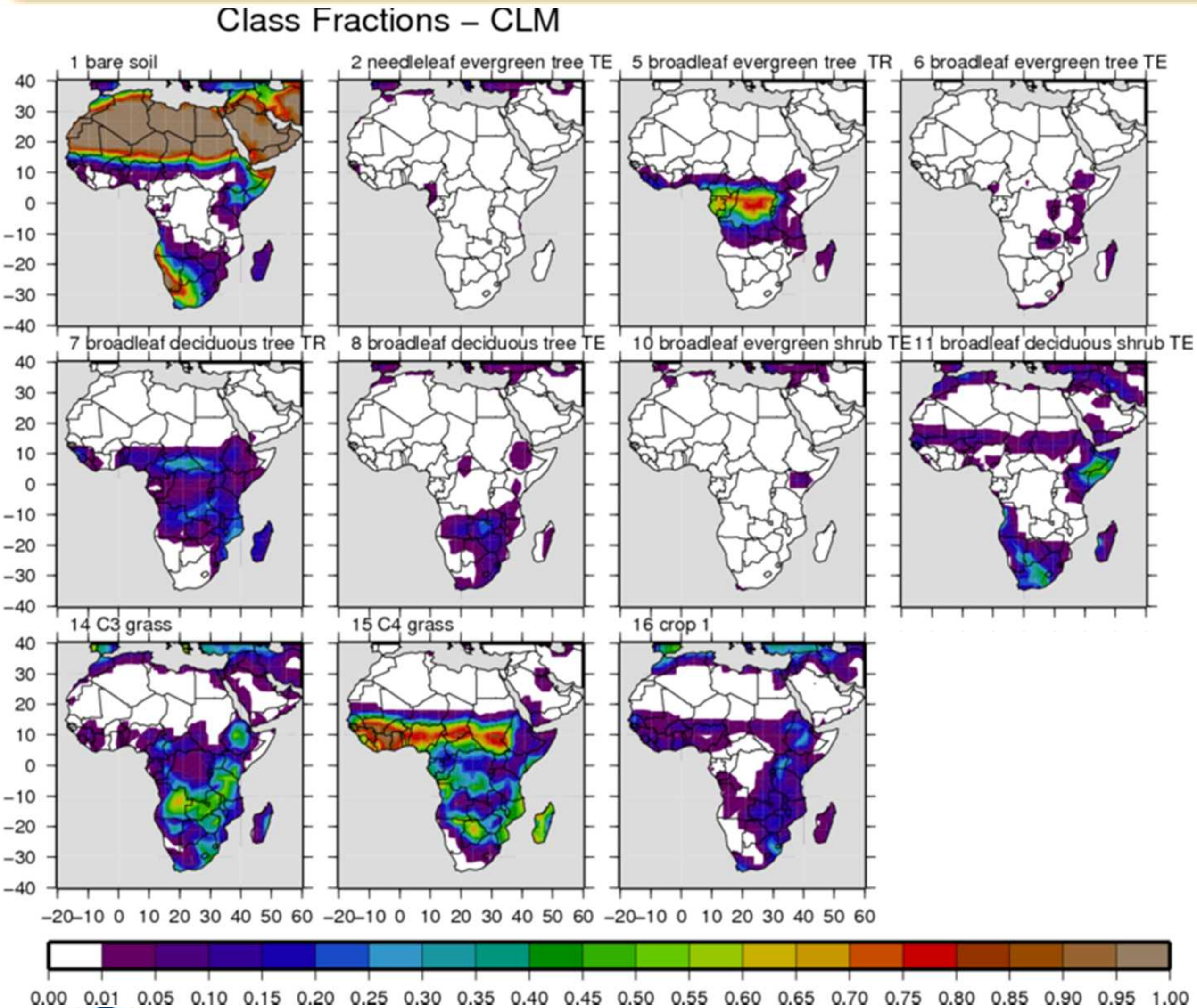
3 Physiographic Parameters



Classical dominant class approach (widely used in GCMs and NWP). Advantage-ease of implementation, computationally inexpensive

Possible disadvantages are when two (or more) contrasting classes nearly equal in coverage in the same grid box...

3 Physiographic Parameters



PFT (tile) fractions can evolve in time owing to dynamic vegetation, anthropogenic land cover change...

Several projects looking at land use-land cover change (LULCC) issues at regional (WAMME2), and global (LUCID, LUMIP (CMIP6)) scales....

ECOCLIMAP :
A global database of surface parameters

A land cover map at 1 km resolution in lat-lon projection

Fully coupled to SURFEX, or available separately for any LSM

ECOCLIMAP I : global (215 covers)

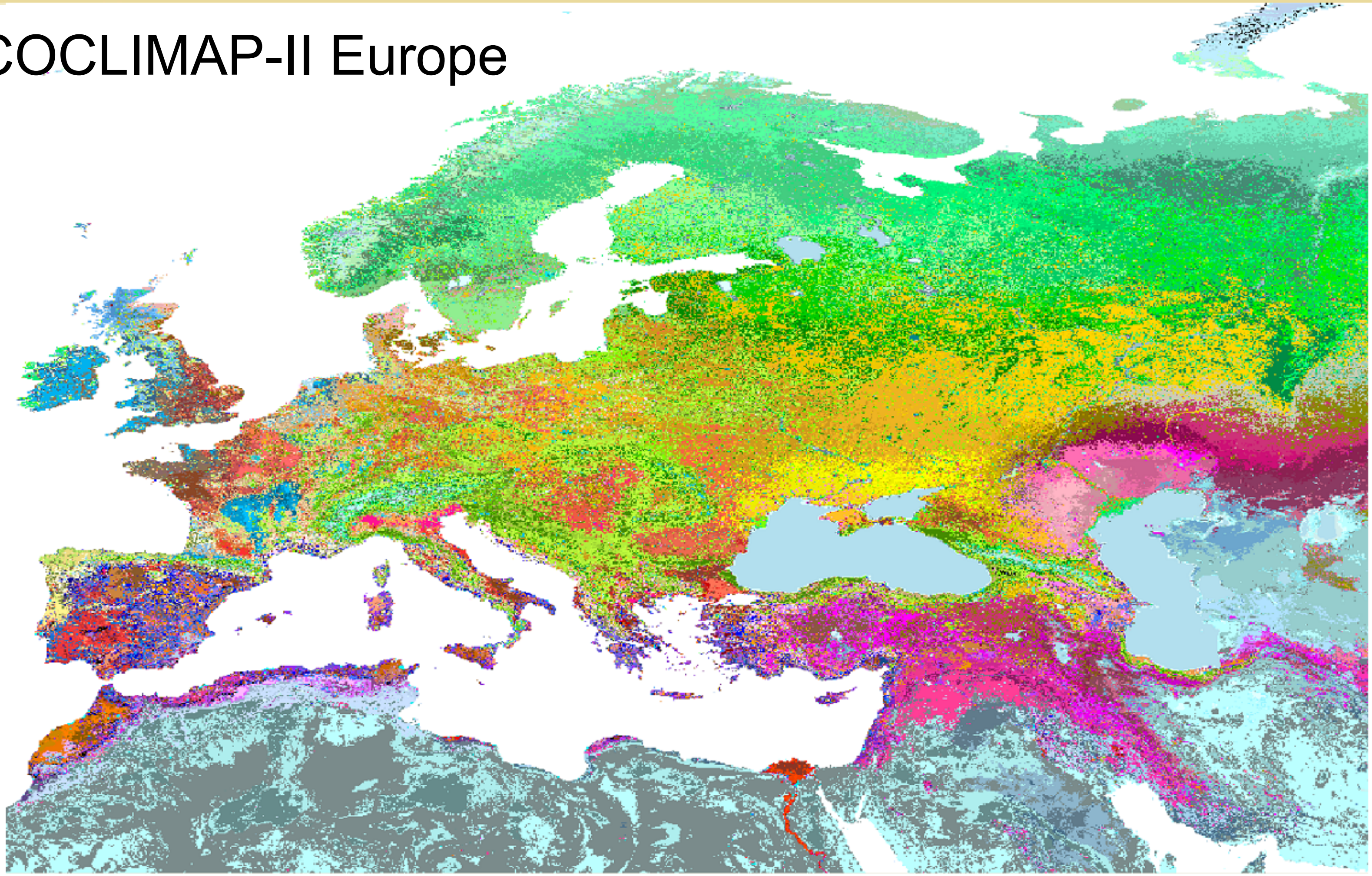
ECOCLIMAP II Europe (273 covers)

10-day period surface parameters: LAI, fraction of vegetation veg, roughness length, emissivity, greeness fraction.

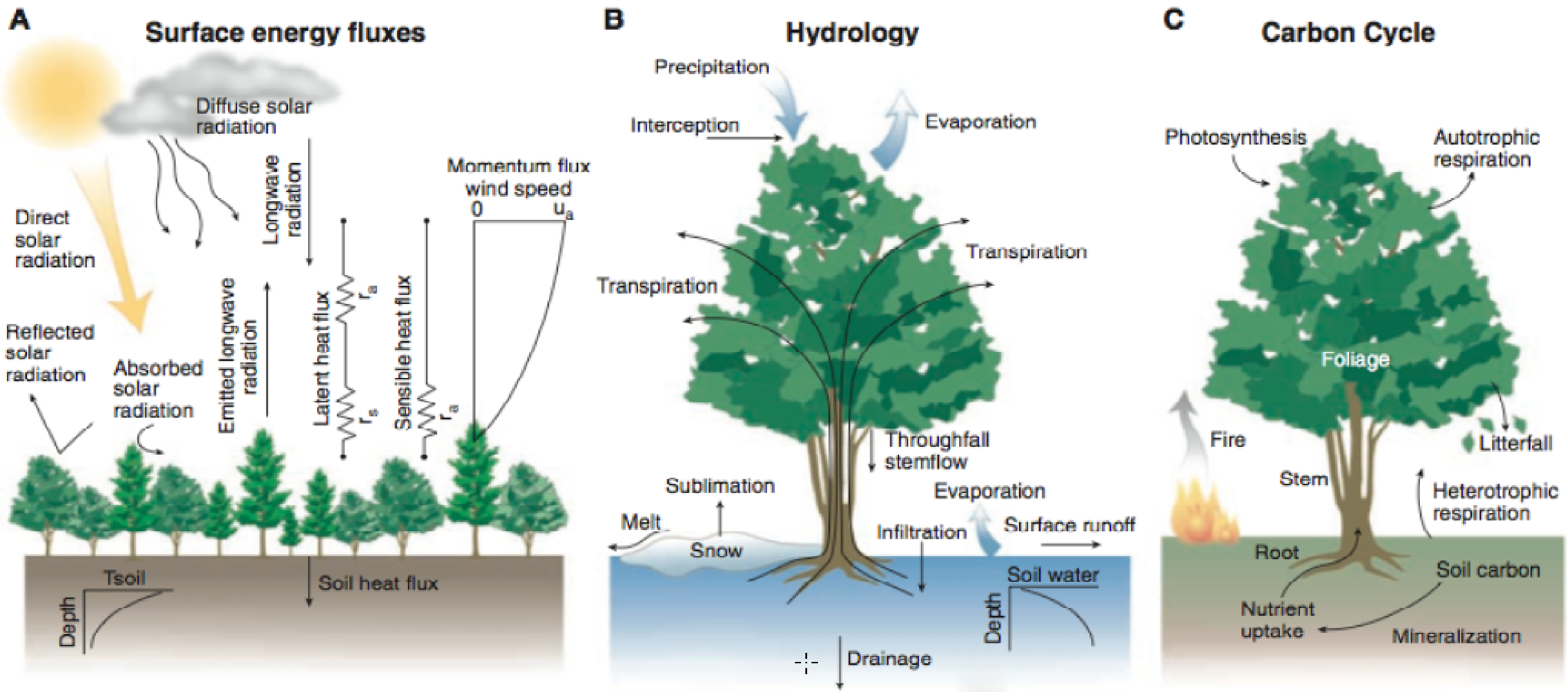
Time Constant surface parameters: visible / nir / uv albedos, minimum stomatal resistance…

3 Physiographic Parameters

ECOCLIMAP-II Europe



4 Processes



Taken from Bonan (2008) : Fundamental mechanisms of interactions between terrestrial vegetation and climate.

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4 Processes

Energy Budget :

$$c_v \frac{\partial T_s}{\partial t} = SW_{net} + LW_{net} - H - LE - G$$

$$R_{net} = H + LE + G$$ (general case)

Evapotranspiration components :

$$E = E_{tr} + E_{int} + E_g + E_{sub}$$

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

Carbon (vegetation) budget :

$$\frac{\partial b_m}{\partial t} = NPP - S$$

$$b_m = \varphi \, LAI$$

Water Budget :

$$\frac{\partial W}{\partial t} = P_r - E - Q_s - Q_{sb}$$

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4 Processes

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4 Processes

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Water Budget :

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Natural Surface - Main physical options

LSM	Soil	Force restore type (analytical, calibrated using detailed model): 2-4 Layers for water (phase changes) Diffusion : multilayer (temperature, water liq and solid)
	Vegetation	Jarvis A-gs (photosynthesis and CO2 fluxes) A-gs and interactive vegetation Slow carbon processes (wood and roots), dynamics
	Hydrology	Subgrid surface runoff (Dunne & Horton, drainage) River flow, storage (& flooding) Ground water exchanges (drainage to, capillary rise from) Lakes/reservoirs
	Snow	1 layer bulk scheme, albedo, density variable or fixed 2 layer bulk-type Multilayer (3 +) albedo, density, SWE (liquid water content, grain size, historical variable..)

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

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

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

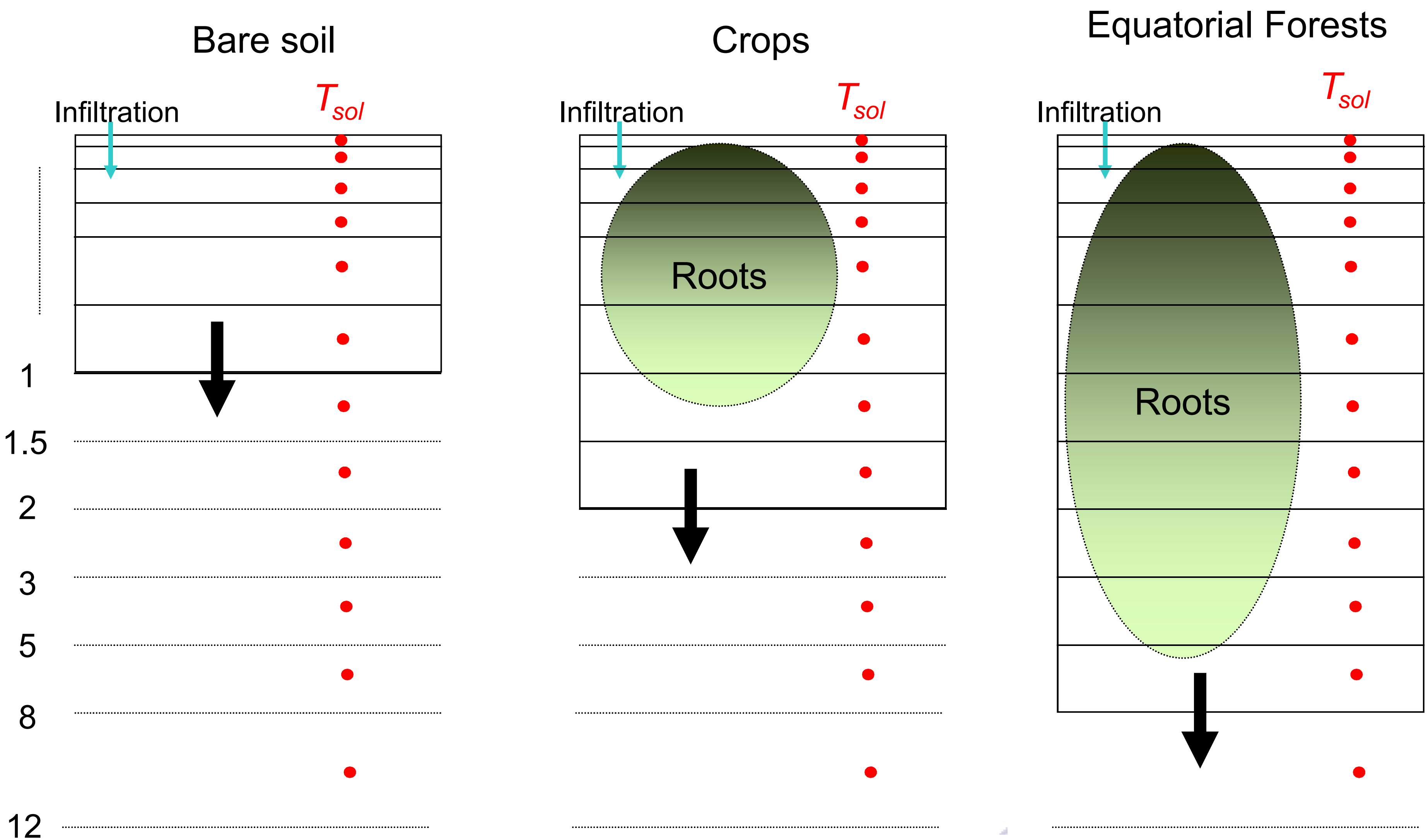
$$\frac{\partial w_l}{\partial t} = -\frac{\partial F}{\partial z} - \frac{\Phi_g}{L_f \rho_w} - \frac{S_l}{\rho_w} \qquad (w_{min} \leq w_l \leq w_{sat} - w_i)$$

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

Total soil water $\quad w = w_l + w_i$

Darcy's law (heterogenous form) $\quad F = k(w)\left[\frac{\partial \psi(w)}{\partial z} - 1\right]$

4 Processes : soil vertical water and heat transfer

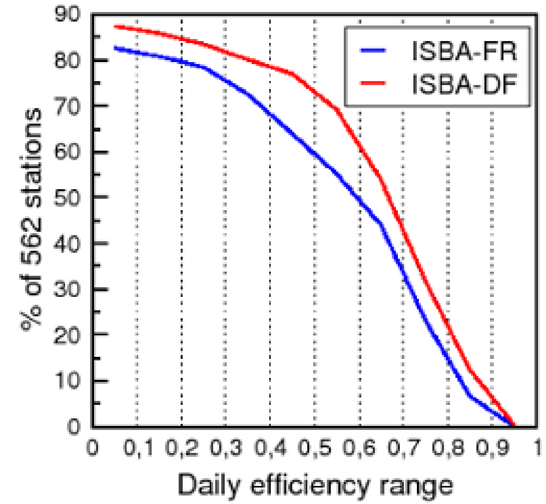


(from B. Decharme)

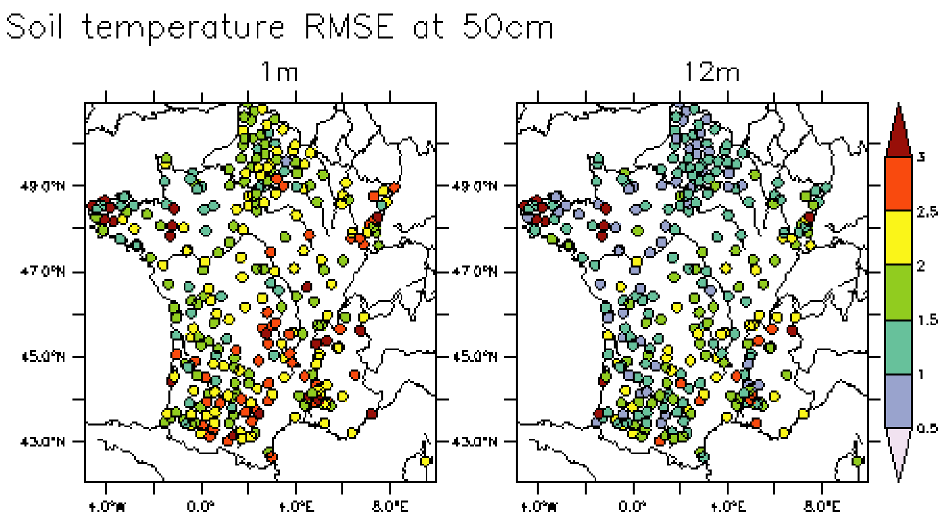
4 Processes : soil vertical water and heat transfer

Spatially distributed evaluation of DIF in terms of hydrology and soil temperature

Discharge from the SIM system, comparison between the 3-L Force Restore hydrology and 12L DIF



Temperature sensitivity at 50 cm to the total soil depth



B. Decharme, E. Martin

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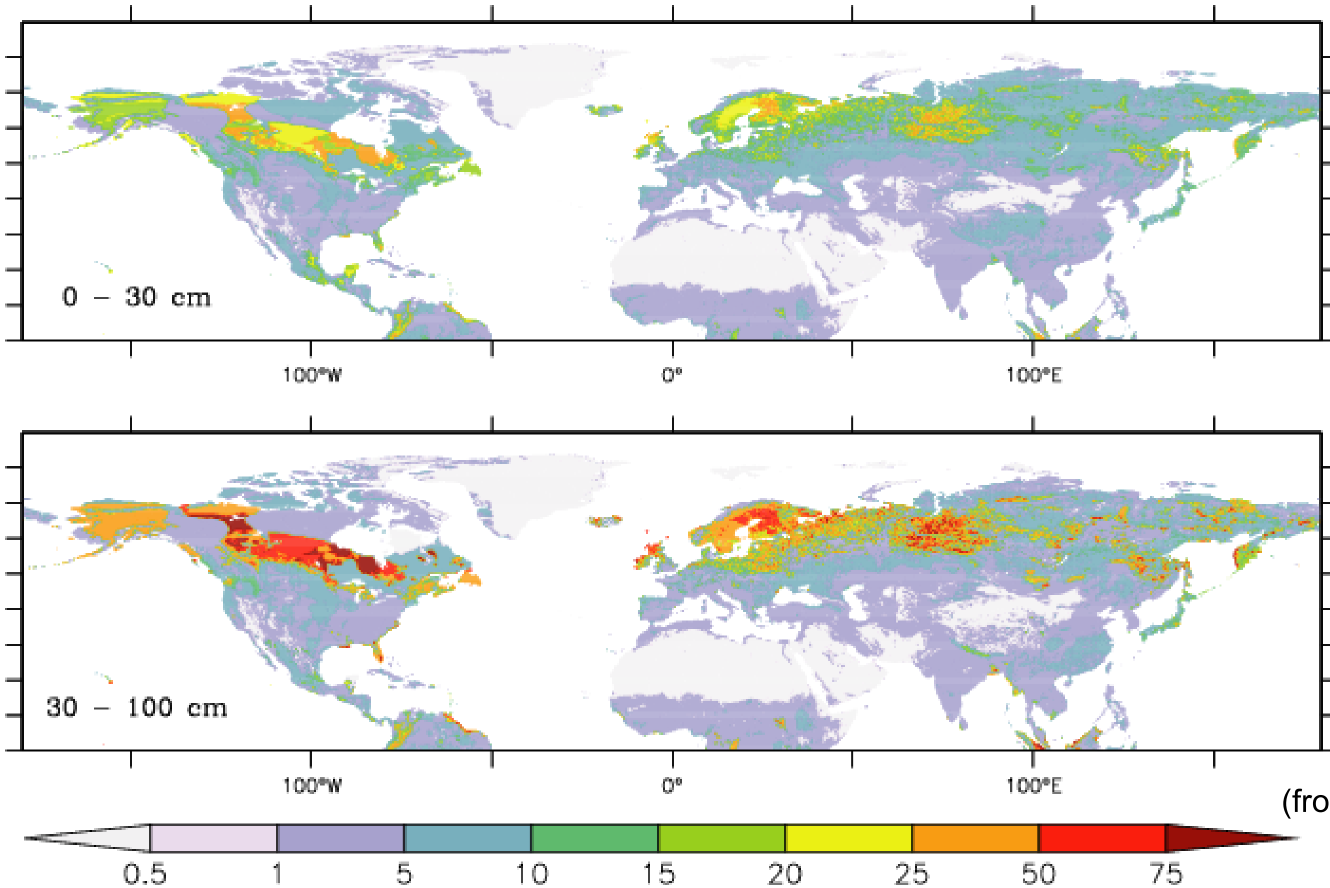
3 Physiographic Parameters

Problem: Many LSMs only account for mineral soil hydro and thermal properties while Organic Carbon is largely present high latitude regions



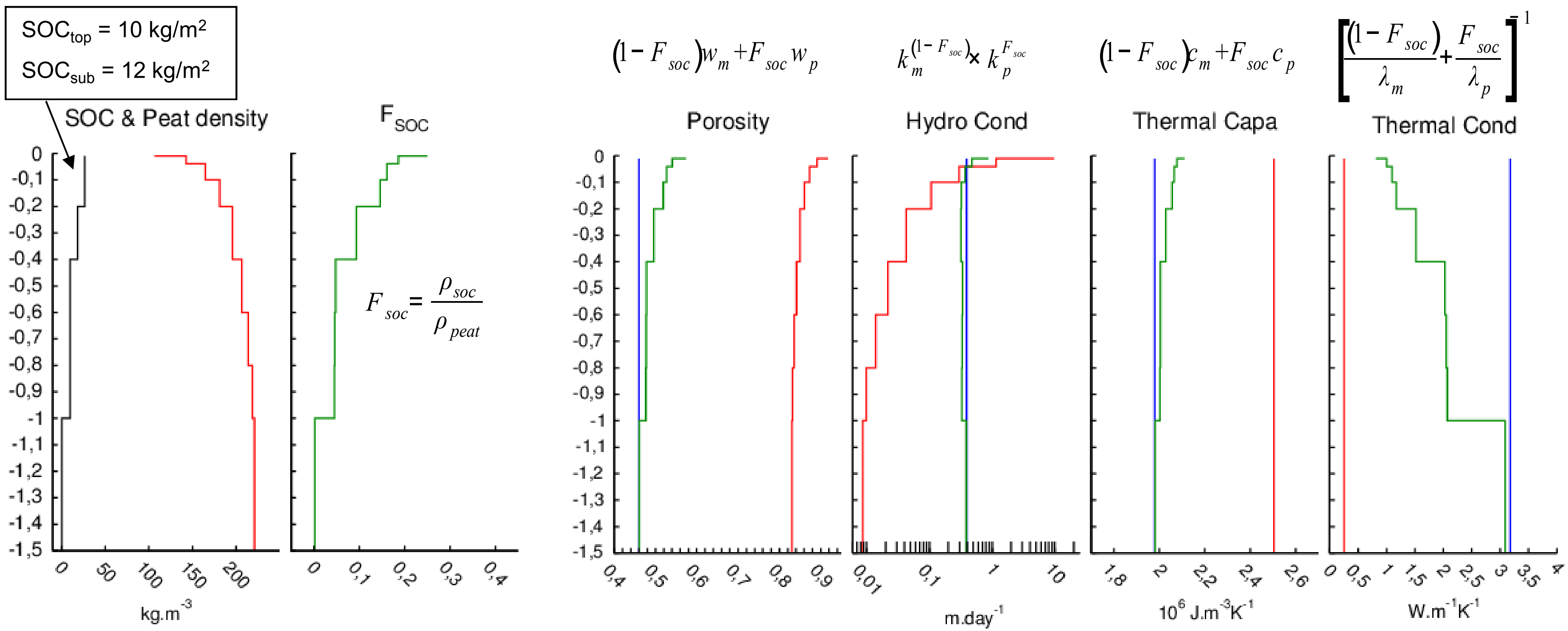
(from B. Decharme)

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

3 Physiographic Parameters

Adjustment of (mineral) soil properties using peat properties

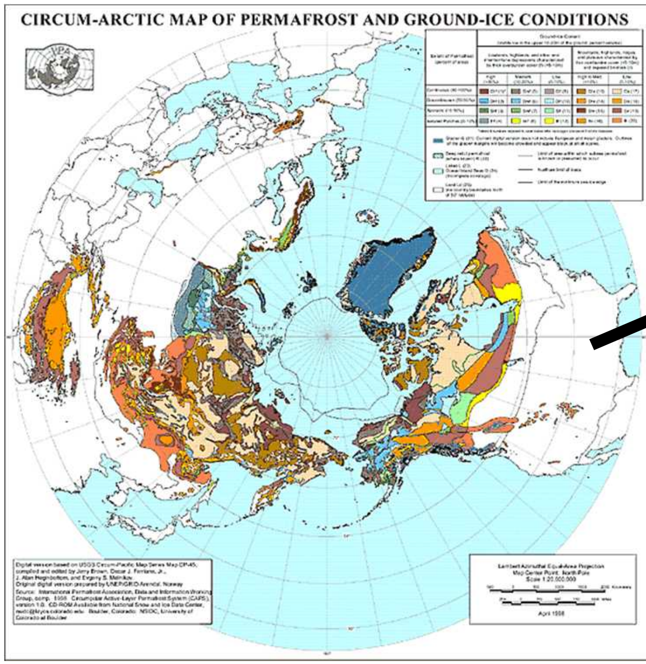
Fraction of organic carbon in the soil (Lawrence et Slater 2008) → Mineral, Peat, and Combined Soil Properties

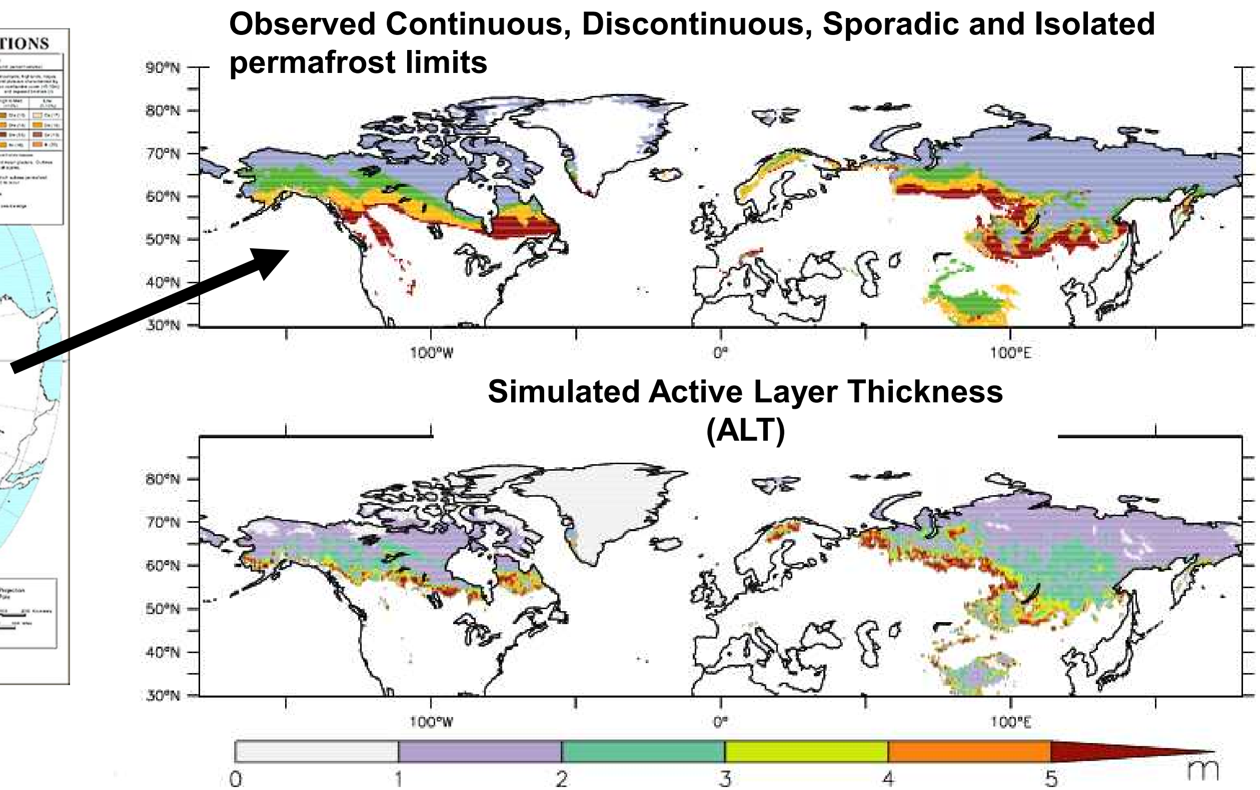


(from B. Decharme)

3 Physiographic Parameters

Global Scale Permafrost Simulation





- Permafrost types given by NSIDC (Brown et al. 2001)

- 0.5°x0.5° simulation using WFDEI forçing 1979-2012 and ISBA (SURFEX)

(Simulated area with an ALT < 3m can be considered as continuous permafrost)

(from B. Decharme)

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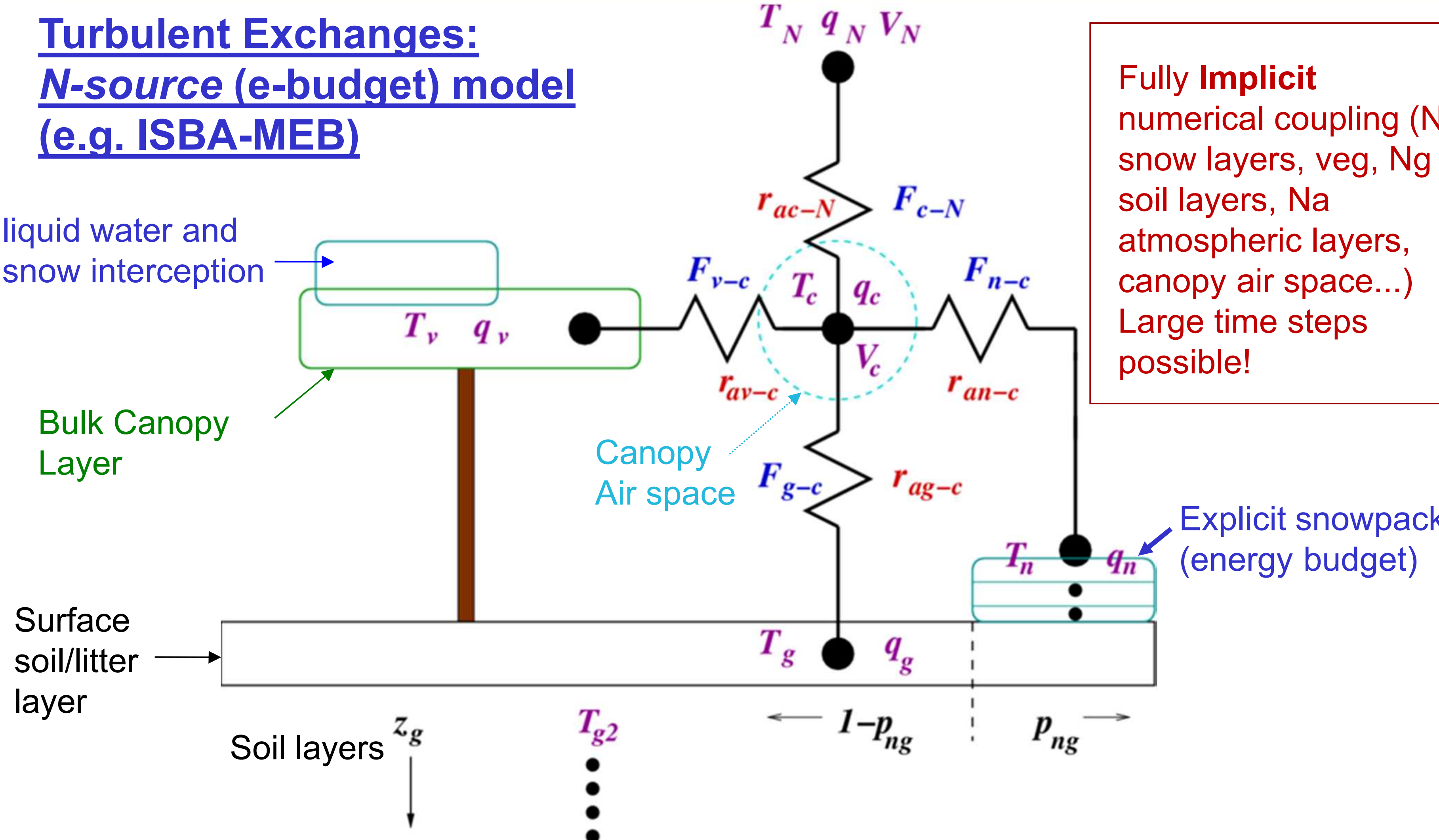
4 Processes

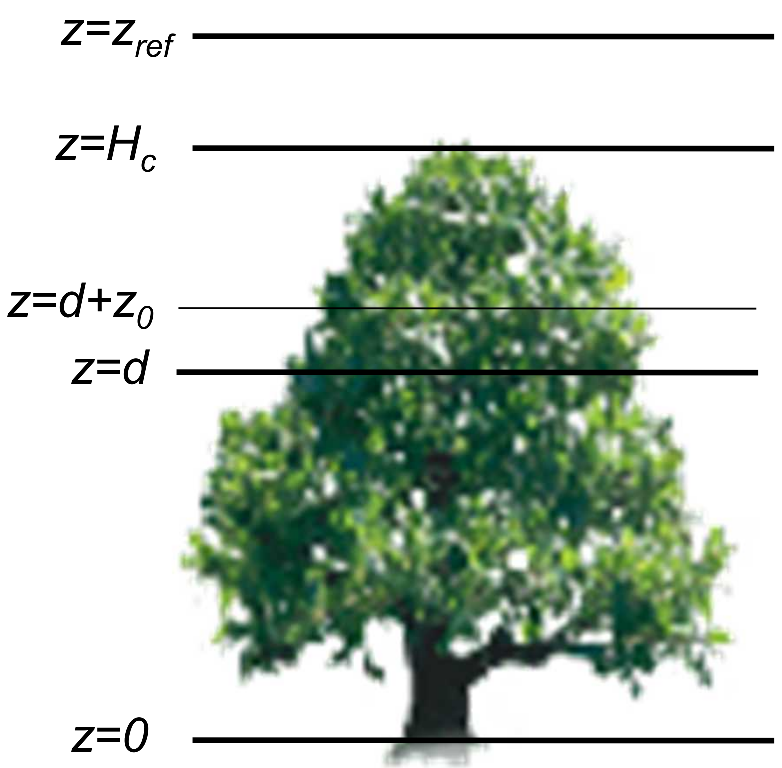
Turbulent Exchanges: *N-source* (e-budget) model (e.g. ISBA-MEB)



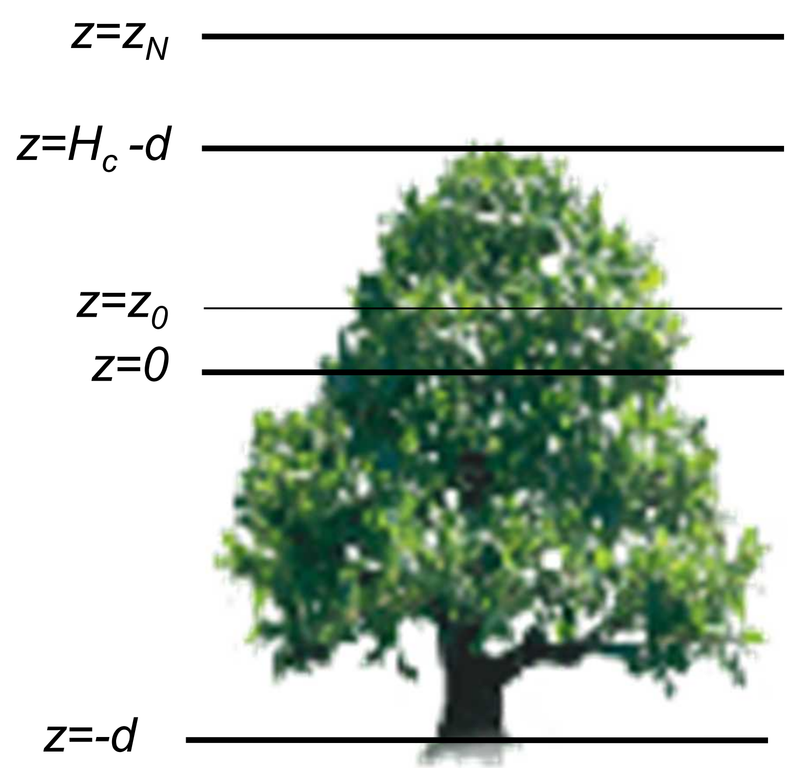
Fully **Implicit** numerical coupling (Ns snow layers, veg, Ng soil layers, Na atmospheric layers, canopy air space...) Large time steps possible!

4 Processes : vegetation

→ OFFLINE



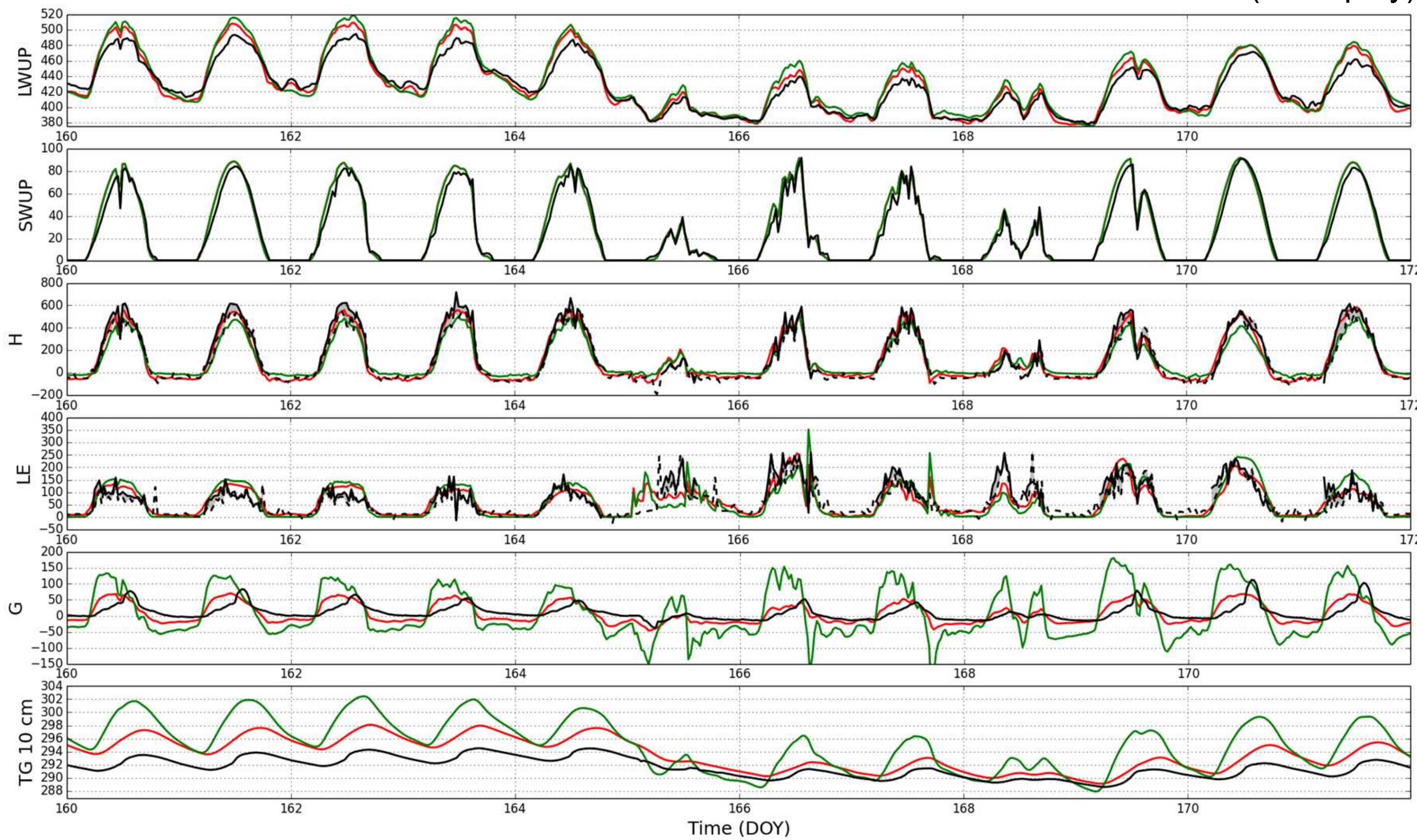
→ Coupled with atmosphere (where $H_c > z_N$)



4 Processes : vegetation

Example of changes owing to explicit vegetation and forest litter (Napoly et al., 2015) Compsite sfc, Explicit canopy and litter, Observations (in ISBA)

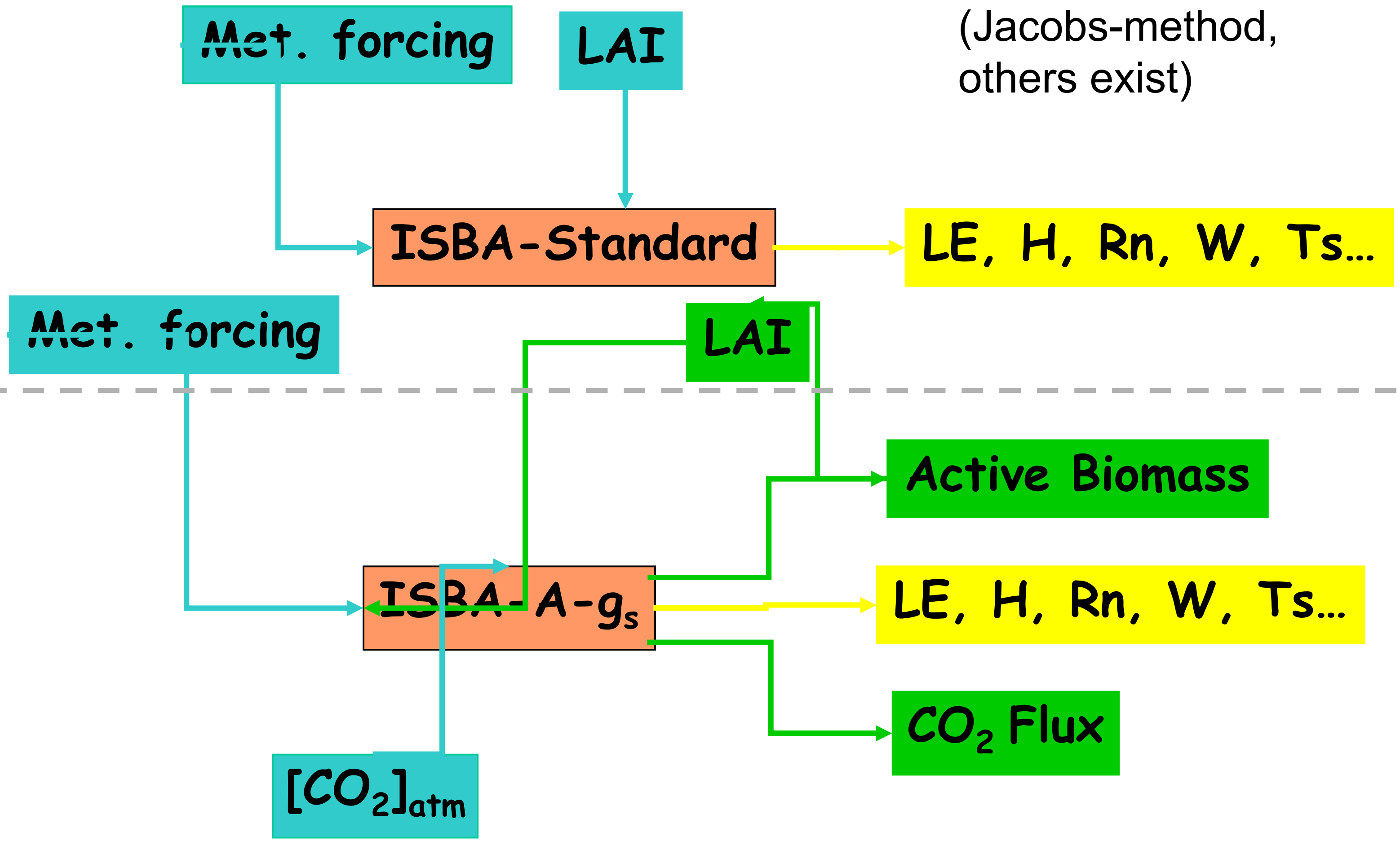
(A. Napoly)



4 Processes : vegetation – interactive phenology

ISBA standard vs A-gs

(Jacobs-method, others exist)



(Calvet et al, 1998)

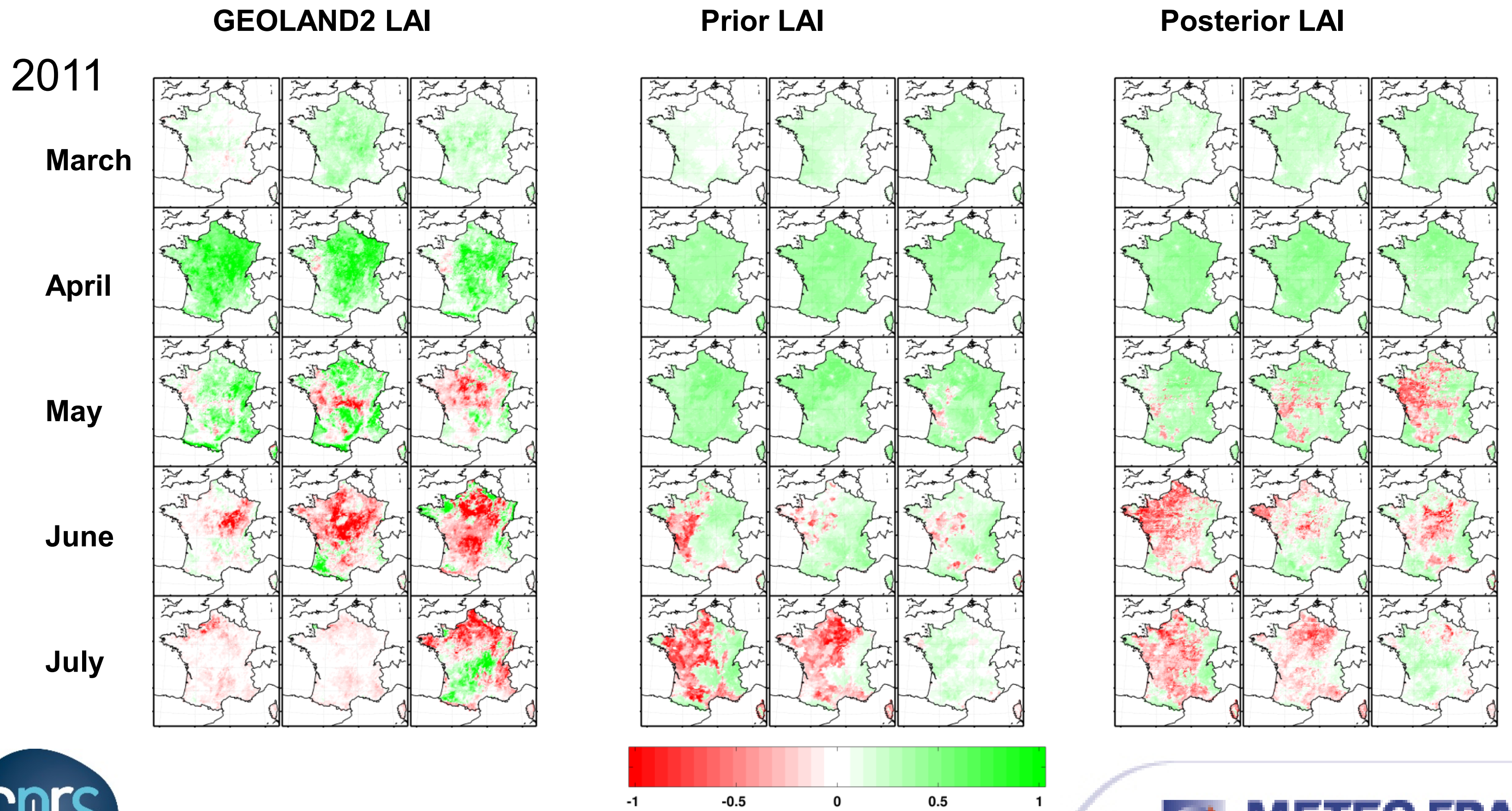
4 Processes : vegetation – interactive phenology

LDAS-France

(J-C Calvet)

Barbu et al. 2012

10-daily LAI change (m2/m2) in 2011



4 Processes : cryosphere

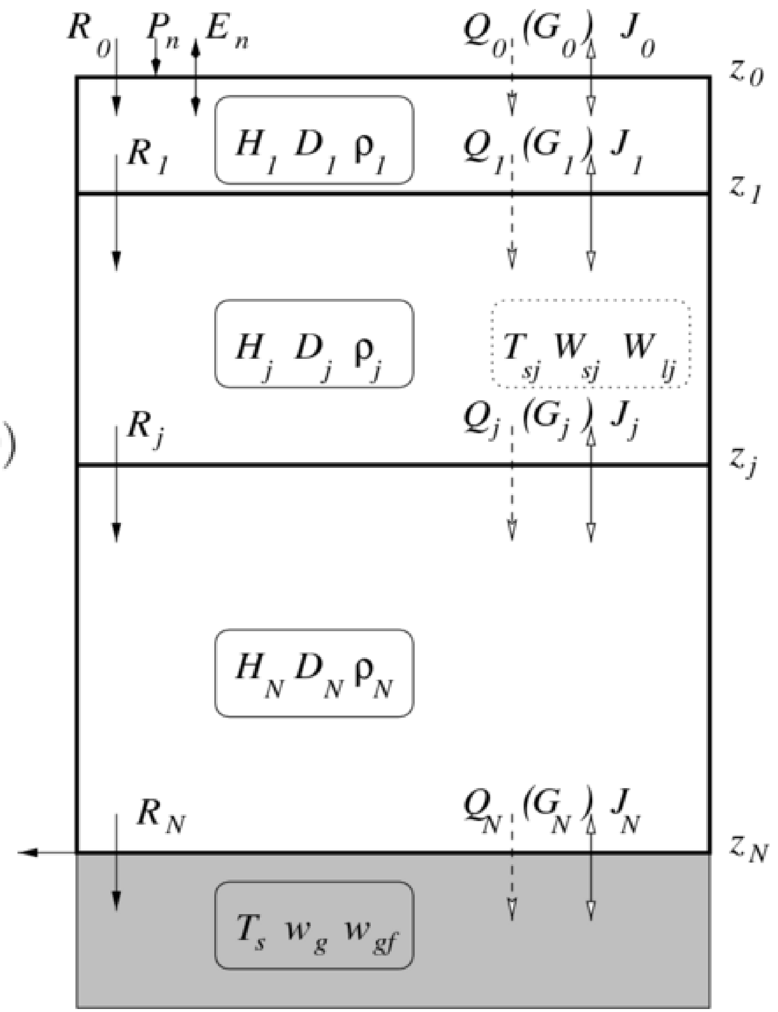
Snow ; Density, SWE, liq...
Enthalpy concept (Steiglitz, Loth and Graf, Sun, Boone & Etchevers etc...)

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

2 prognostic variables for the price of 1

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

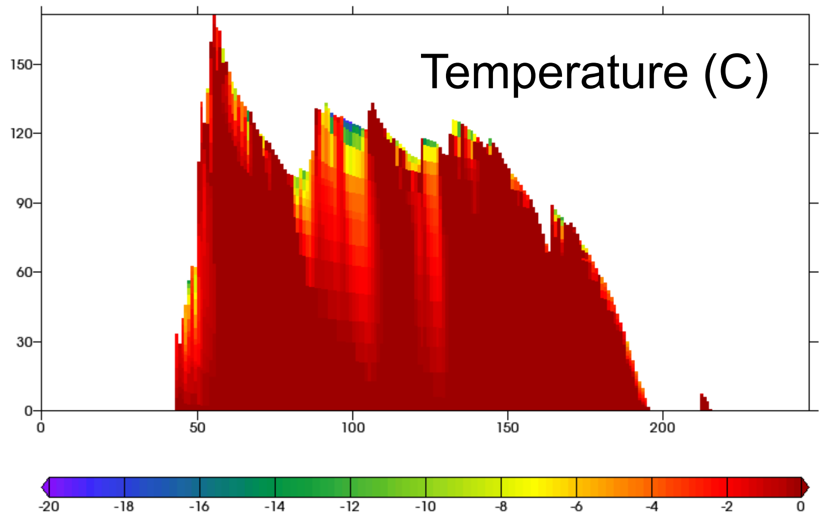
$$W_{l\,i} = W_{s\,i} + (H_{s\,i}/L_f) \qquad (T_{s\,i} = T_f)$$

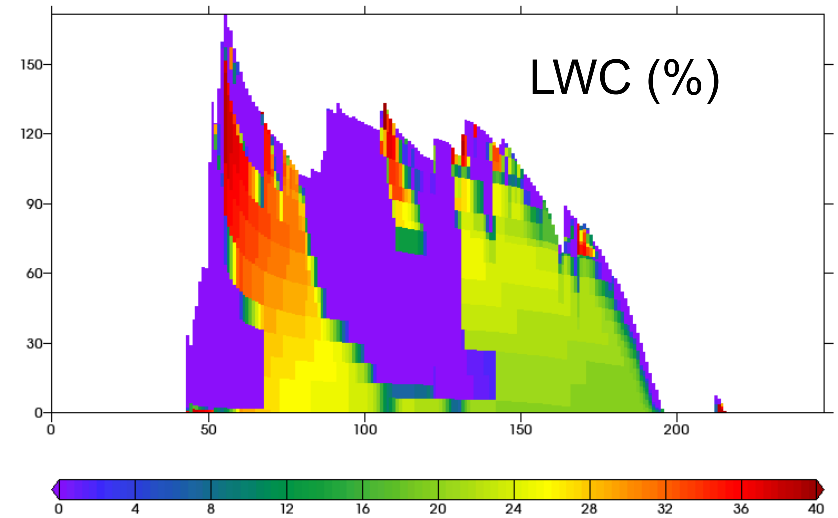


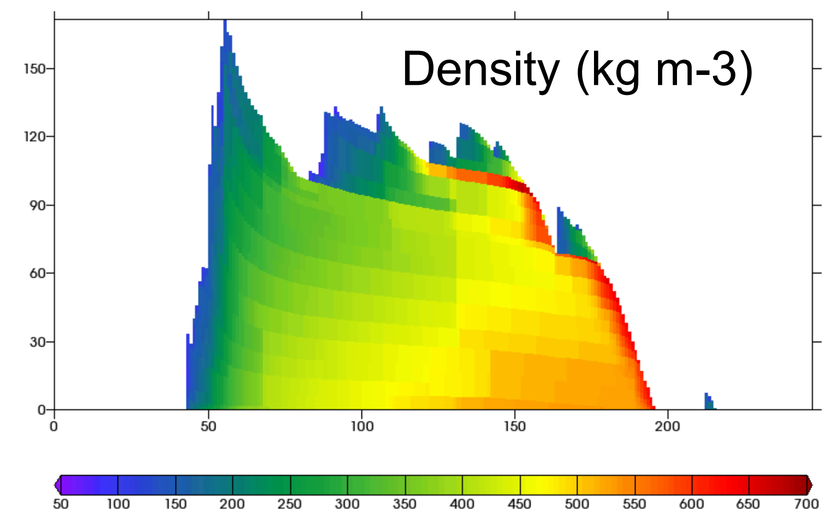
- Refreezing of snowmelt (important for near sfc hydrology and for lower atmos/sfc at night)
- Compaction (density/depth)
- Numerical resolution (strong gradients)
- Explicit interception by canopy, unloading

Longstanding ISSUE :
Snow fraction !!!

4 Processes : cryosphere







Profile – Simulations for Col de Porte

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

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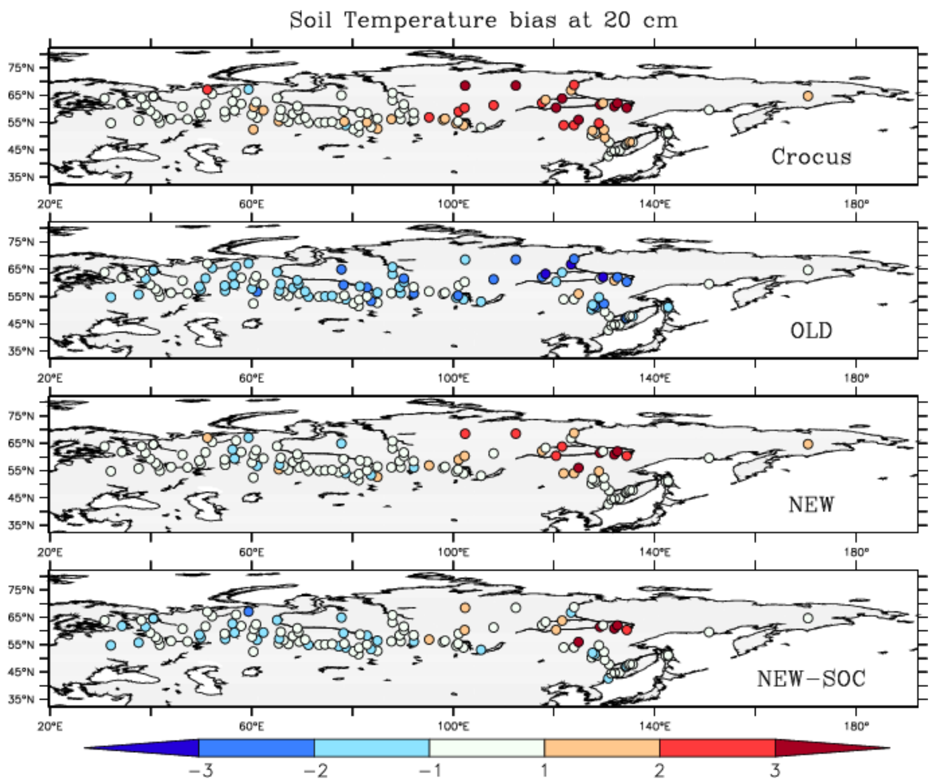
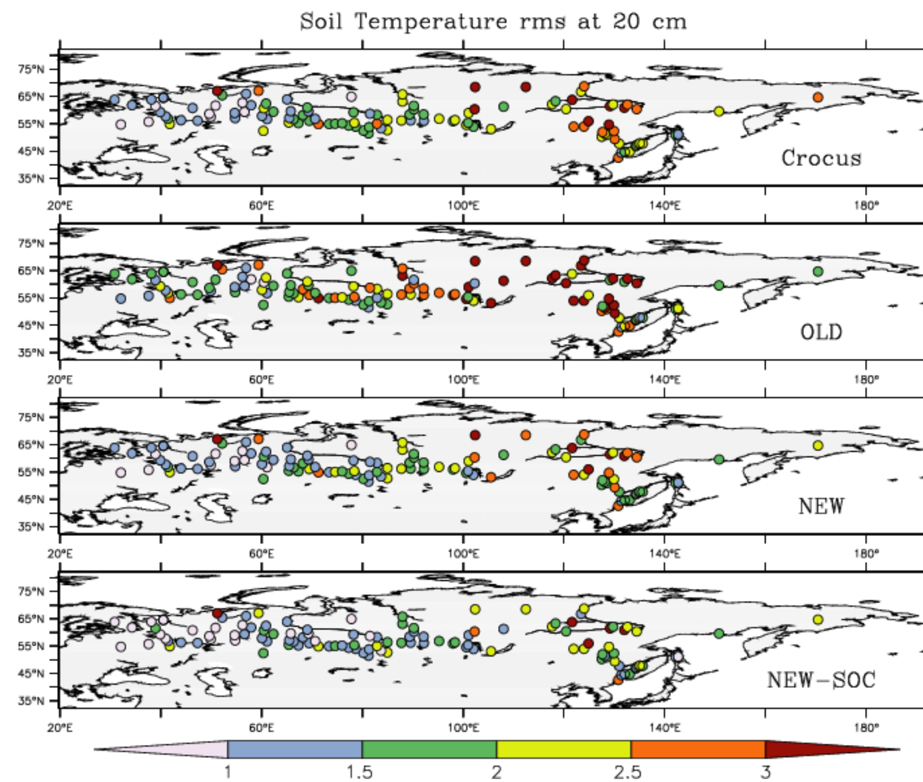
4 Processes : cryosphere

Soil Temperature at -20cm: global statistics over 1979 – 1993 (WFDEI forcing)



bias



rms of anomalies

(from B. Decharme)

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4 Parameterizations : sub-grid hydrology

LSMs simulate this :

Vertical transfers over a homogeneous (possibly tiled) soil

We need to simulate this :

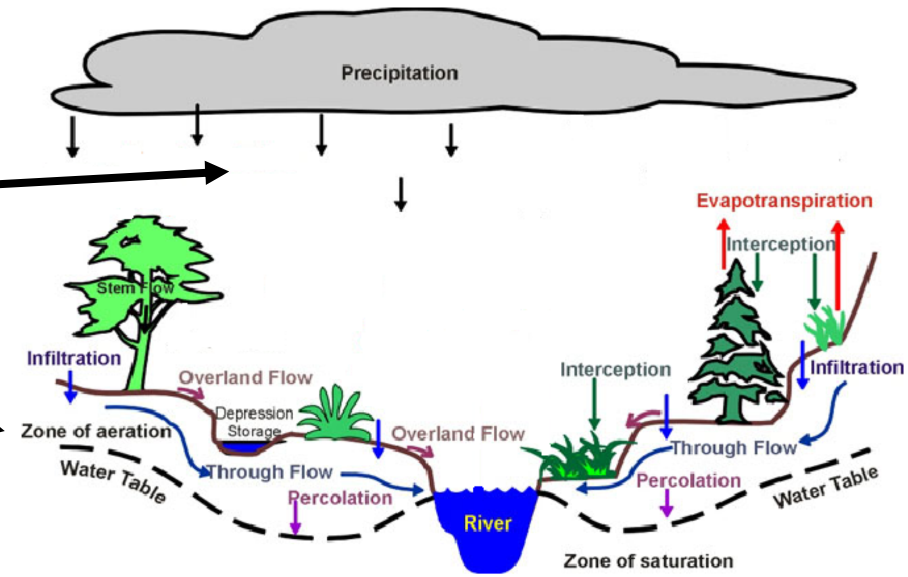
Complex landscape at various resolutions (from 100m to 100 km)

> Subgrid hydrology accounts for heterogenity in a cell

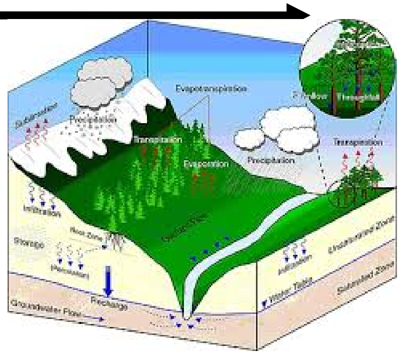
4 Parameterizations : hydrology

Spatial variability of hydrologic processes :

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



grid cell



1) Vertical transfers

- ***Exponential profile of k_{sat} with soil depth***
- ***Subgrid drainage***

2) Horizontal heteorogenity

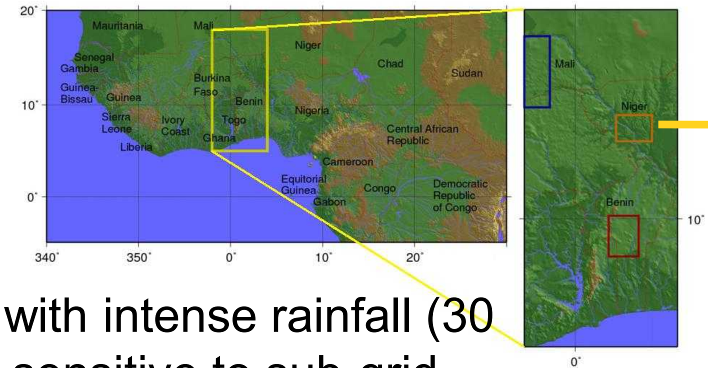
- ***Tiling***
- ***Subgrid precipitation and runoff (Horton and Dune) using PDFs***

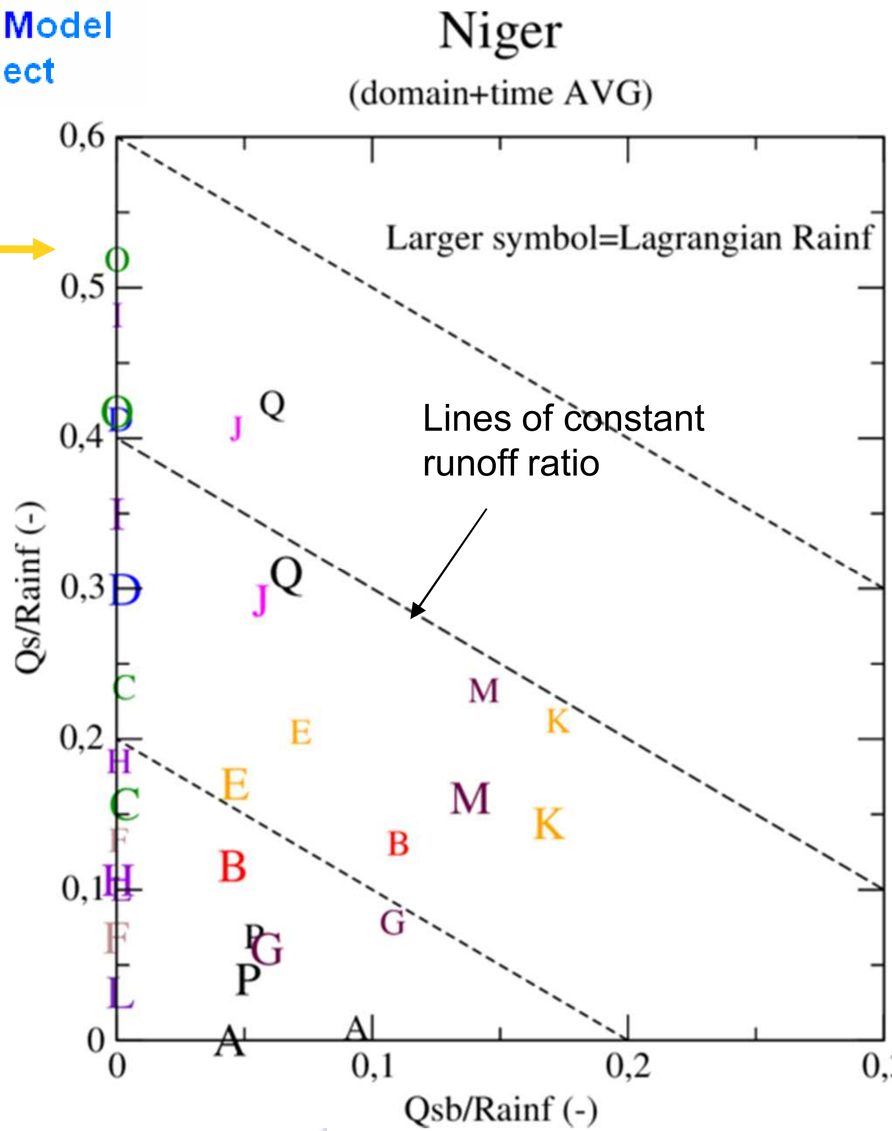
t.

Especially relevant for large (global) and/or regional applications

4 Parameterizations : hydrology

ALMIP AMMA Land Surface Model Intercomparison Project





Semi-arid with intense rainfall (30 min)- very sensitive to sub-grid parameteriation of runoff !

Distinction between *Qs* and *Qsb* is important :

Qs=fast (correlated with rainfall)

generally can't be recycled !

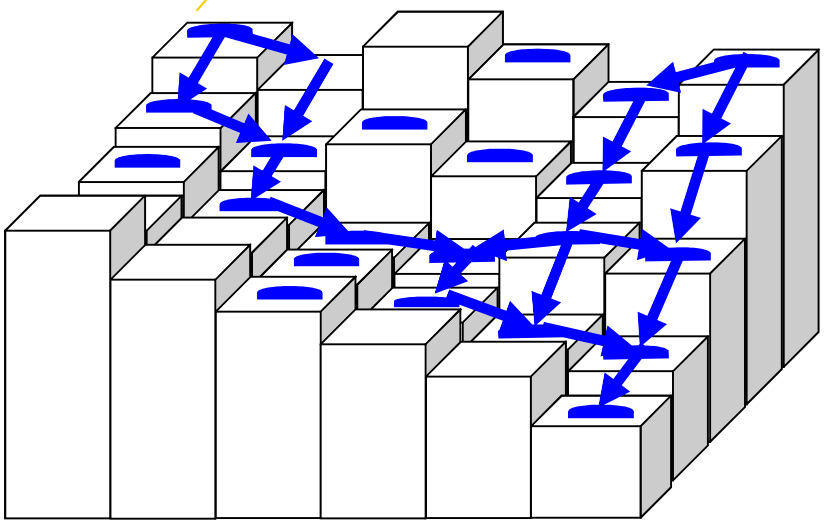
Qsb=slow

(after *Et* and *Eg* extraction, vertical flow...after recycling)

Overland Flow Processes in Noah-Router

(NCAR Tech Note: Gochis and Chen, 2003)

IF (Surface Head > Retention Depth) → Route Water as Overland Flow



2-Dimensional Diffusive Wave Overland Flow Routing Ogden, 1997

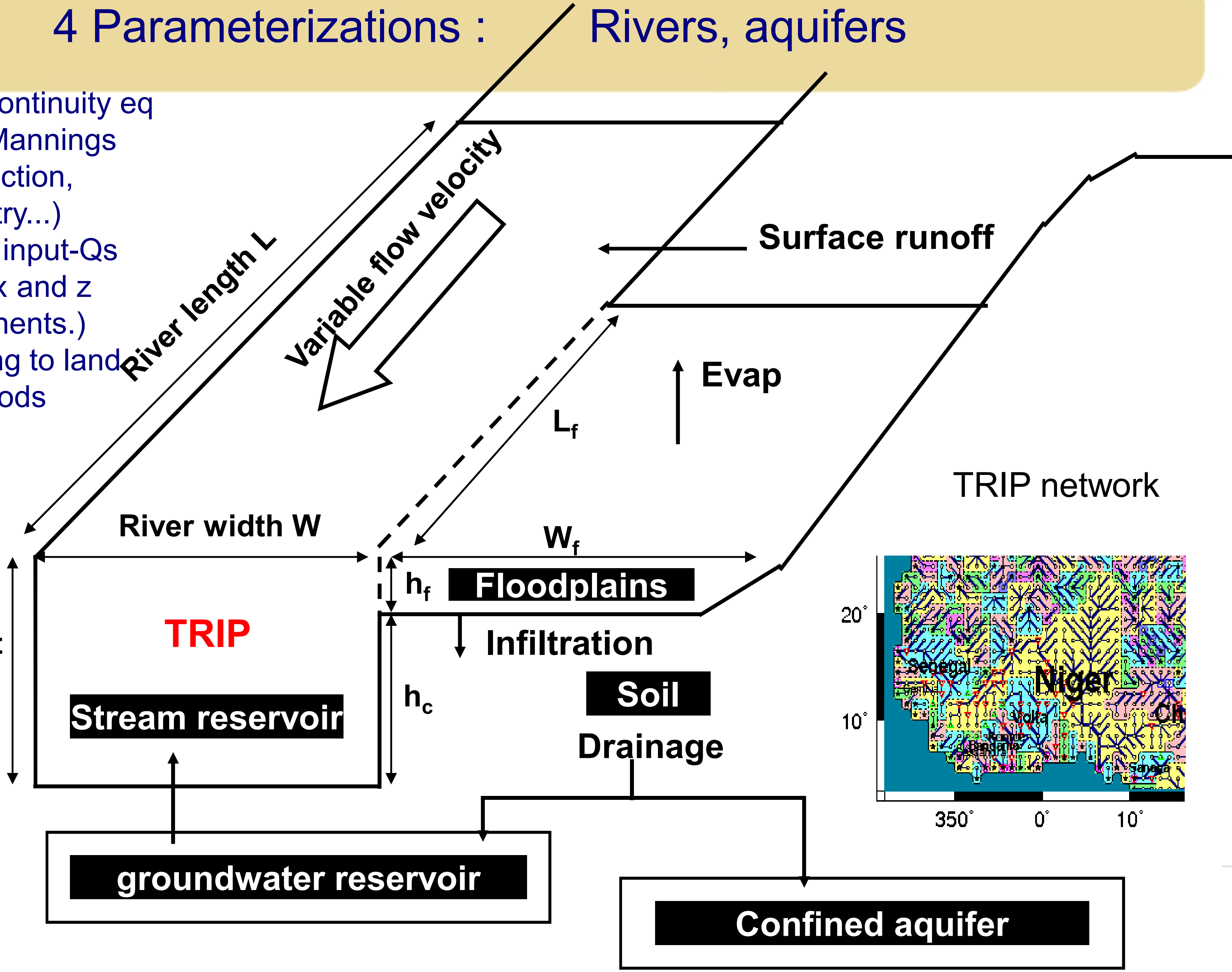
- **New Parameters: retention depth, surface roughness**
- **Ponded water in excess of retention depth subject to overland flow**
- **Overland flow: fully-unsteady, explicit, finite-difference, 2-dimensional diffusive wave (generally applicable to length scales < 1km)**

$$dhdx = (h_{i+1,j} - h_{i,j}) / gsize$$

$$sfx = SOX_{i,j} - dhdx + 1E-30 \rightarrow q_x = \frac{(sfx / ABS(sfx))\alpha h^{5/3} dt}{dx}$$

4 Parameterizations : Rivers, aquifers

- Mass continuity eq
- Flux : Mannings Law (friction, geometry...)
- Lateral input-Qs
- Qsb...(x and z components.)
- Coupling to land sfc via floods



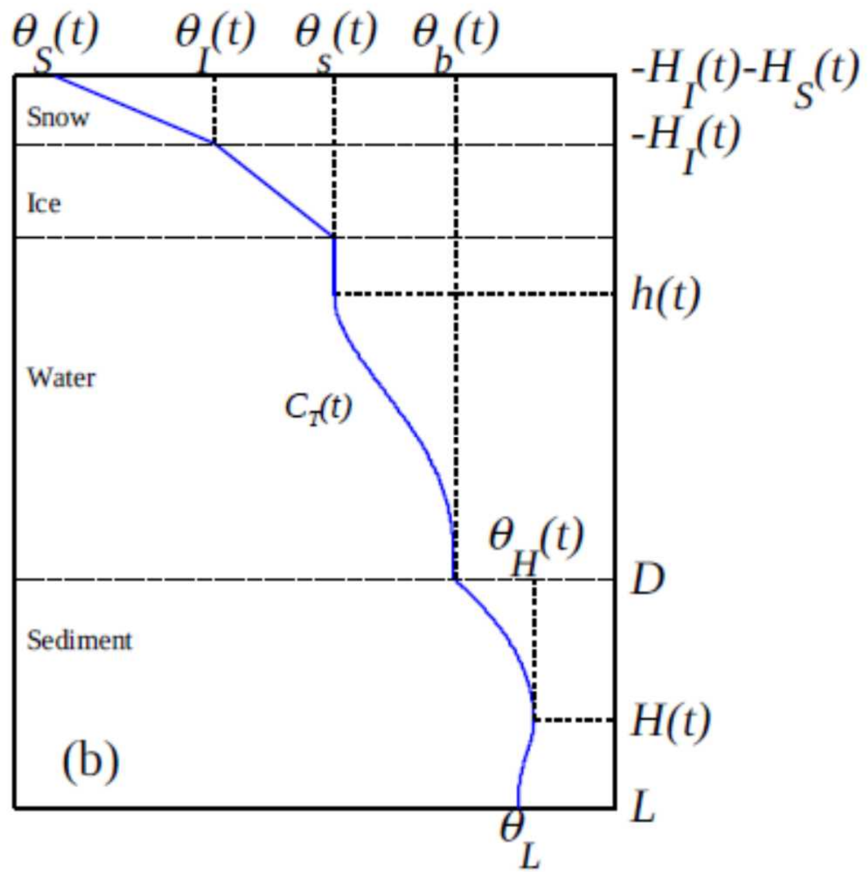
4 Parameterizations : lakes

Problem : Small to medium sized or shallow lakes can have significant diurnal Ts ranges, thus impacting the PBL on NWP timescales

Flake-a 2 layer model with a parameterized vertical T profile (ideal for NWP- used by DWD, ECMWF, HIRLAM...)

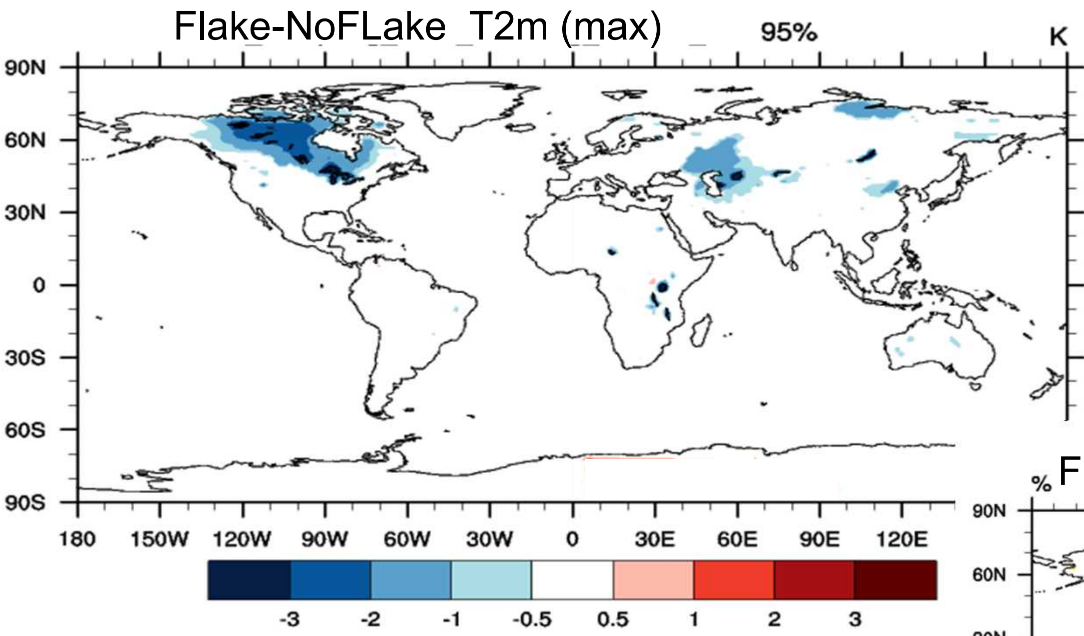
Issues/Challenges :
- lake fraction
- lake depth (critical, yet diffcult to determine)
- wind (fetch) issues – z0
- transmission (optical parameters), sediment layer

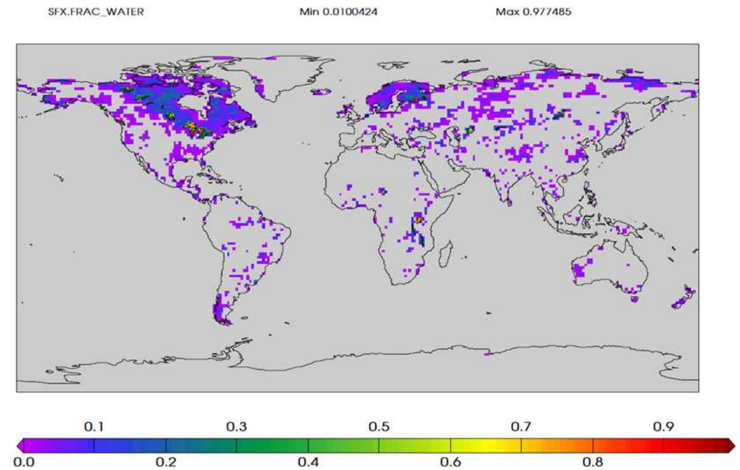
Flake (D. Mironov, 2003)

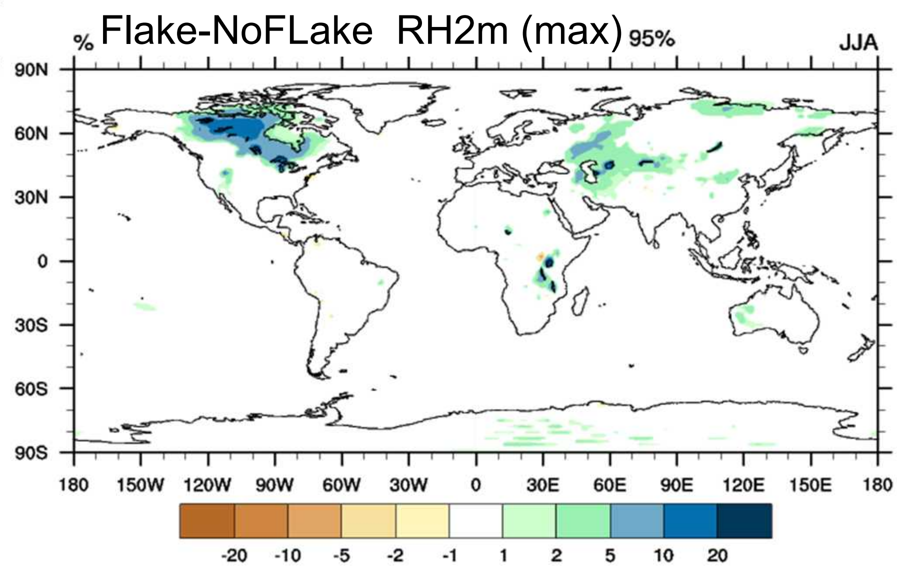


4 Parameterizations : lakes

Summertime cooling effect of lakes : JJA maximum T2M (ARPEGE-GCM)

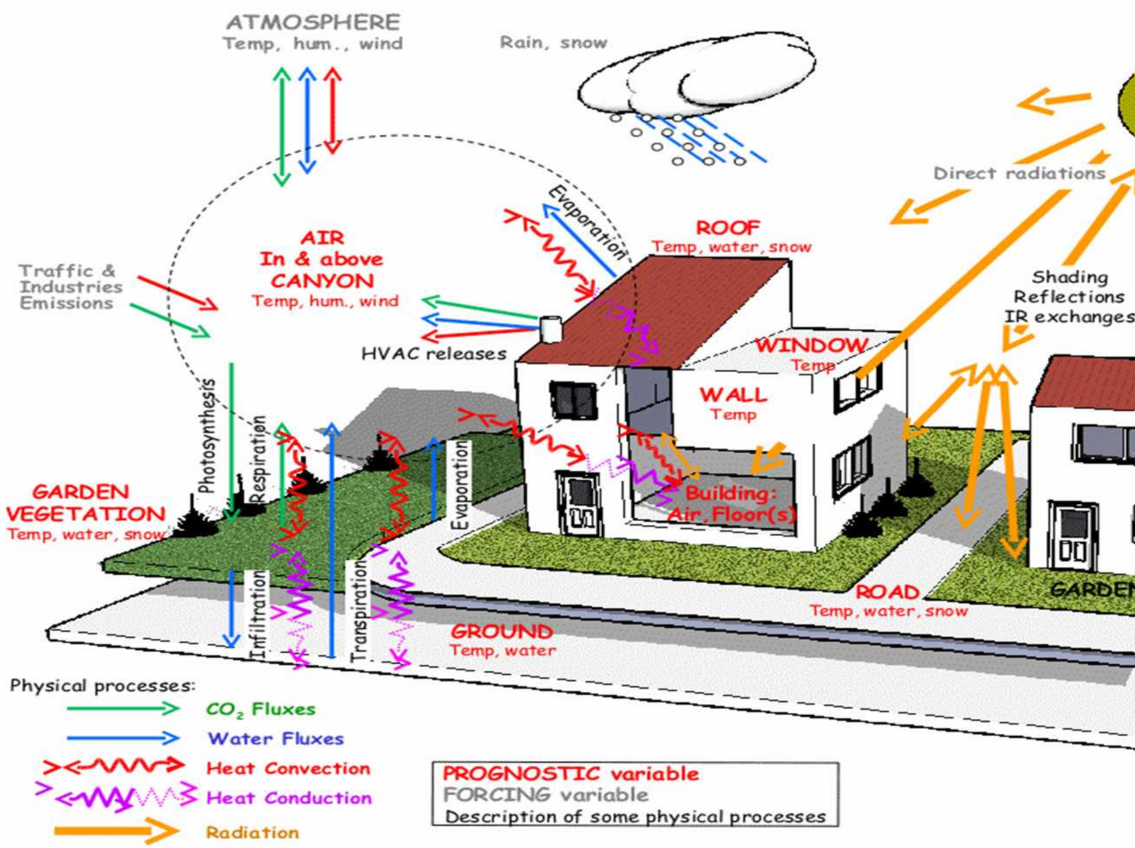


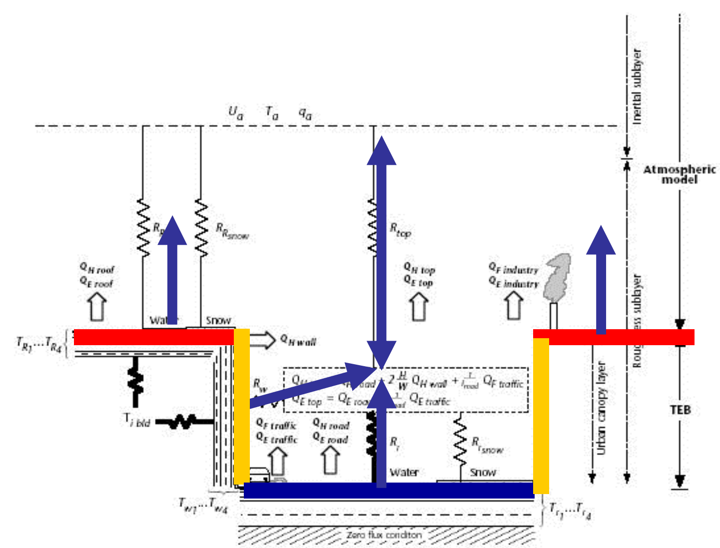




- 1971-2010 – T127 (1.5° at Eq.)
- 2 configs : without (old) & with FLake

4 Parameterizations : Urban areas





(example from TEB, Masson et al.,)

4 Parameterizations : Urban areas

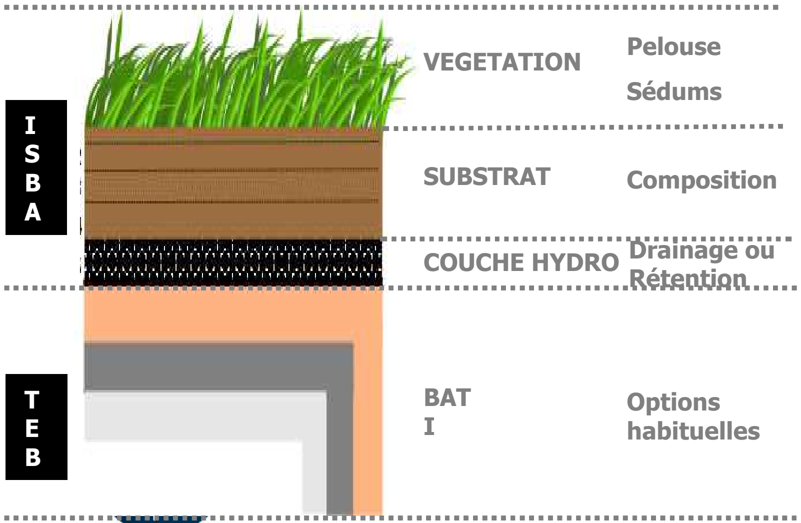
Urban vegetation

- 1) **Gardens** (Lemonsu et al 2012)
  - Radiative interactions between walls/gardens
  - Interactions with the micro-climate in the canyon

2) **Vegetated Rooftops** (De Munck et al 2013)
  - Climate change adaptation (urban areas)

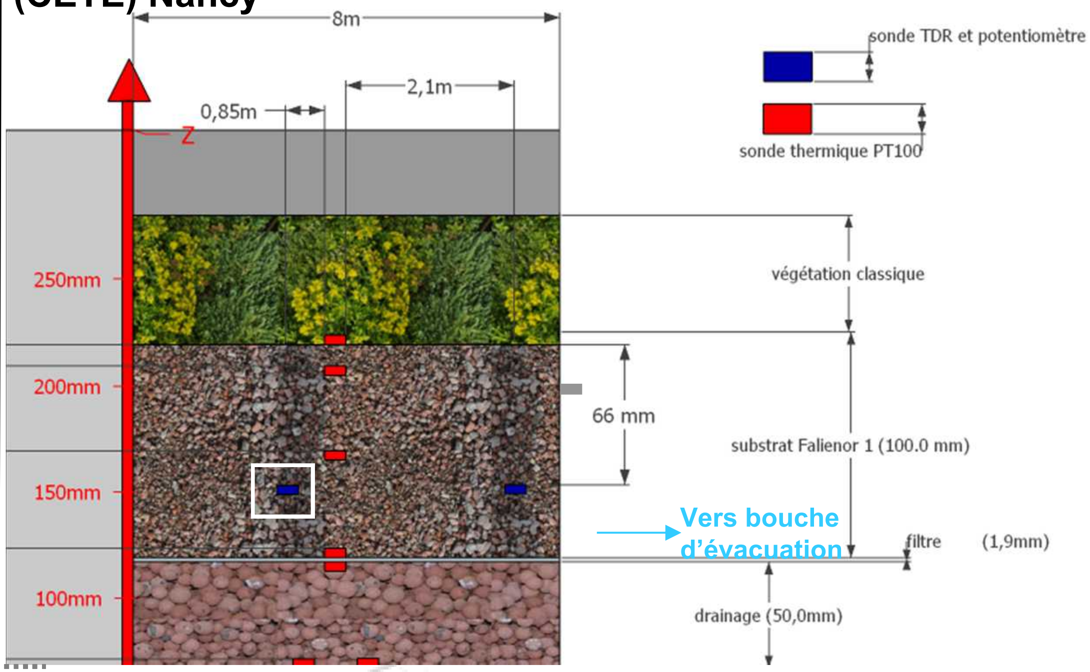
Implementation of ISBA on roofs of TEB

- Some articulier processes :
  sedum, substrate, sol de 10cm…



(CETE) Nancy

- water contents
- temperatures at different levels
- rooftop discharge



5 Summary : Issues and future work

Need for improved representation of Anthropization
Hydrology – dams, irrigation, reservoirs (lakes, but with volumes!) For a closed water balance, irrigation sources must be tracked (rivers, reservoirs, ground water)
Crops – harvest schedules, for different types

Not very consistent treatments yet :

- Aerosols
- Dynamic vegetation (PFT distributions)
- Biogeochemistry

Carbon dynamics
Photosynthesis (many parameters/degrees of freedom !)
Plant phenology, senesence (feedbacks possible, inter-model var)

Cryosphere
Snow fraction - Orography links ? Hysterysis (density or aging)
Coupling ? (ESM-SnowMIP)
Soil freezing (highly grid res dependent!). Permafrost (highly dynamic lakes, bogs in high latitudes, emissions…)
Extremely Stable surface layers (snow, but not exclusively)
Ice sheet hydrology (Greenland...)

Still serious issues with Bowen ratio (vegetation but mostly soil moisture)
Most problematic in semi-arid/stressed areas (most strongly coupled and social implications)

Moving to higher Resolution
Horizontal : More « scalable » parameterizations needed...lateral soil moisture, radiative effects…
Vertical : lowest atmospheric model layer conundrum (higher res, taller objects)

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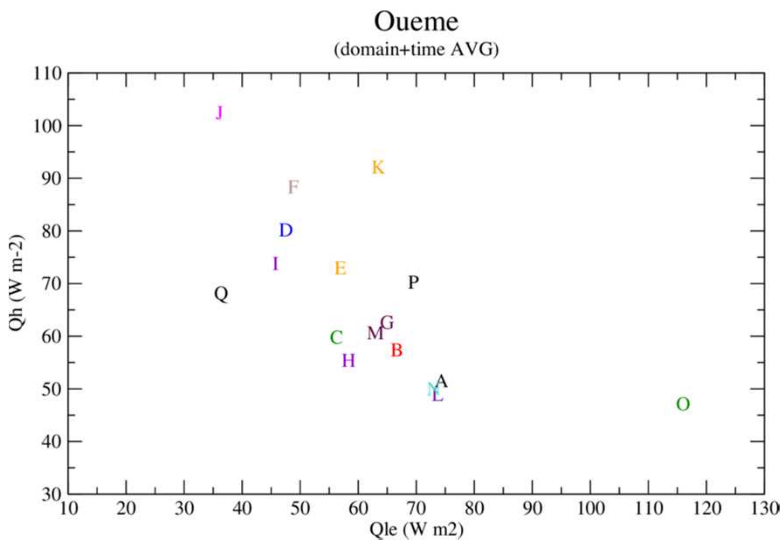

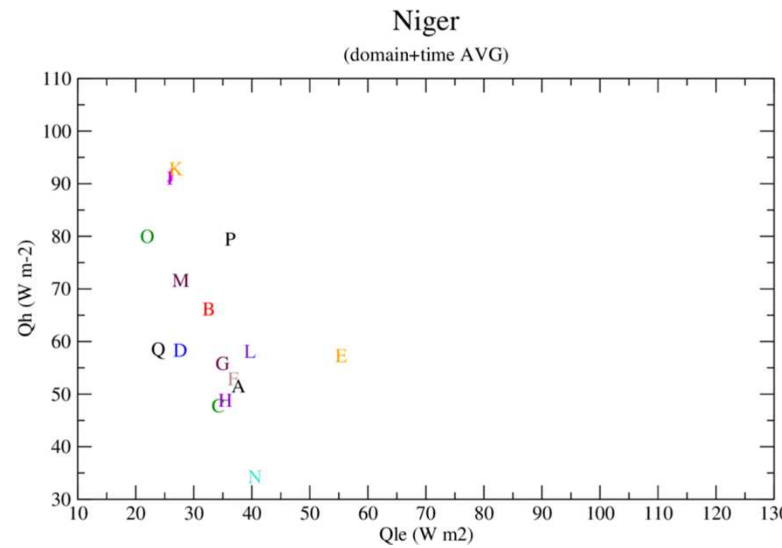

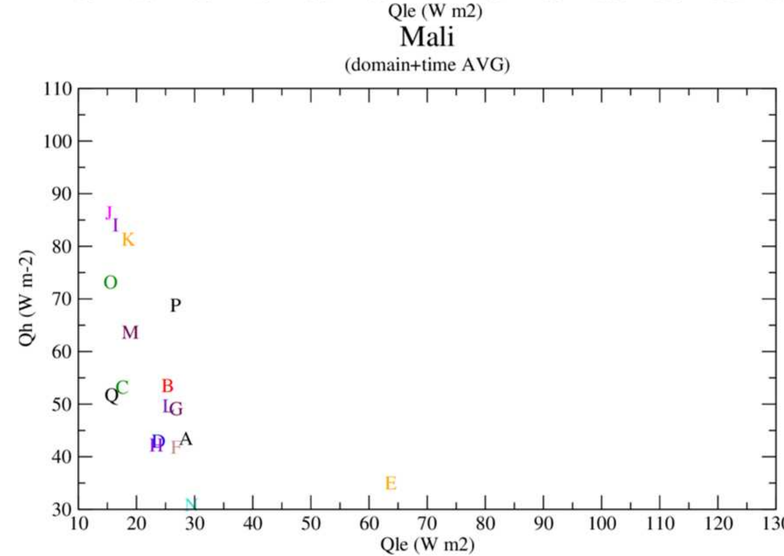

Rnet paritioning into Qh, Qle :

- Relatively large scatter, especially in terms of Qh

- Rnet decreases as move N, Qh ➔ Rnet as move N, but LSM relative position same, also inter model var > inter-annual var