surfex

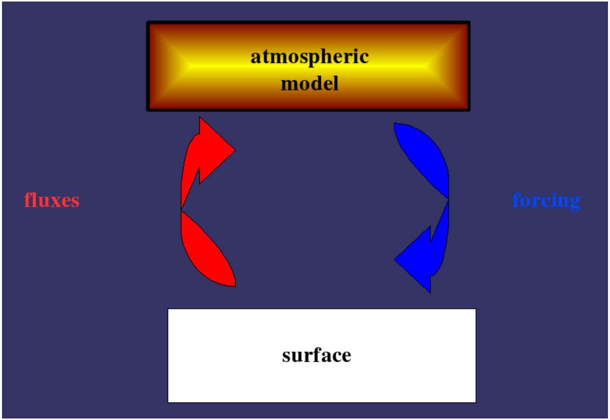
Arome training course

Marsh 2008

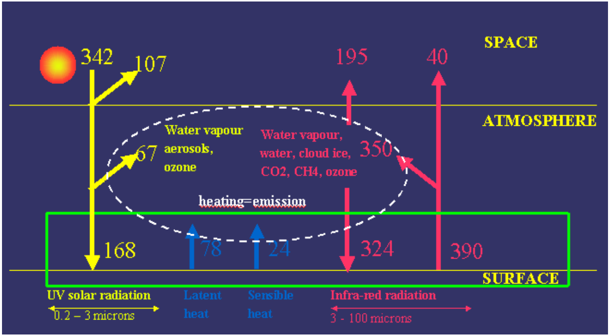
Surfex system

- surfex stands for surface externalisée ;
- externalized from meso-NH mesoscale model ;
- externalization allows use with various atmospheric models ;
- surfex gathers all surface developments ;
- lower boundary condition of atmospheric model ;
- its goal is to compute the exchanges of momentum, heat, water, CO2 concentration or chemical species. These exchanges are performed by mean of fluxes.

Surfex system



energy budget



IPCC, 2001 sources (Intergovernemental Panel for Climate Change)

Mean annual values (W/m^2)

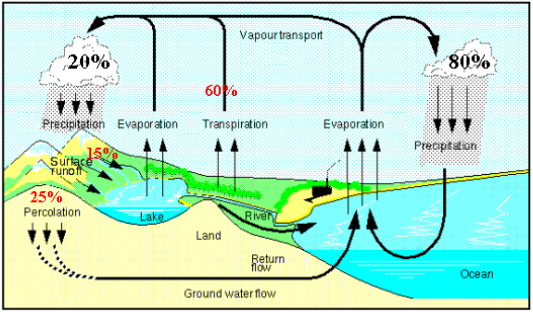
net radiation

$$F_{net} = S_w \downarrow - S_w \uparrow + L_w \downarrow - L_w \uparrow$$

$$F_{net} = (1 - \alpha) * S_w \downarrow + \epsilon (L_w \downarrow - \sigma {T_s}^4)$$

$$F_{net} = H + LE + G$$

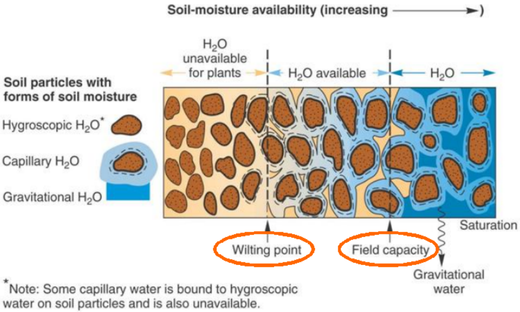
water cycle



water repartition

On the 20% of total precipitation falling on continent
60% evaporates, 25% infiltrates and 15% generates surface runoff

available water for plants



surfex content

global databases

- orography : GTOPO30, 1km
- soil texture : FAO, 10km
- land use : ECOCLIMAP, 1km
- bathymetry : ETOPO2, 4km

surfex content

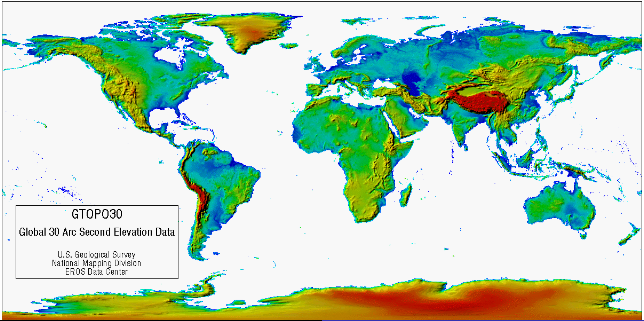
physical models

- ISBA : Interaction Soil Biosphere Atmosphere, *Noilhan, Planton, 1989*
- TEB : Town Energy Balance, *Masson 2000*
- FLAKE : *Mironov, 2005*
- SEAFLUX : *Gaspar, et al. 1990*

databases

orography

GTOPO30 is a global, digital elevation model (DEM), with a horizontal grid spacing of 30 arc seconds (approximately 1km)
http ://edc.usgs.gov/products/elevation/gtopo30/gtopo30.html



orography

envelope

$$z_s = \overline{z_s} + F_{env} * \sigma_{z_s}$$

$$F_{env} = 0 \qquad in\ Arome$$

Laplacian filtering

$${z_{s_n}}^f = z_{s_{n-1}} + \frac{1}{8} * \Delta(z_{s_{n-1}}) \qquad n \geq 1$$

$${z_s}^f = z_s + \frac{1}{8} * \Delta(z_s) \qquad in\ Arome$$

databases

soil texture

FAO information is used to construct a 10km global database for percentage of sand and clay, used in surfex to retrieve some model parameters.

http ://www.fao.org/ag/agl/agll/dsmw.htm

land use

ECOCLIMAP is a 1km global database for land use.

- parameters depending on soil
  - % sand
  - % clay
  - soil depth
- parameters depending on vegetation
  - fraction of vegetation veg
  - leaf area index LAI
  - minimal stomatal resistance R_{smin}
  - roughness length z_0
- parameters depending on soil and vegetation
  - albedo
  - emissivity

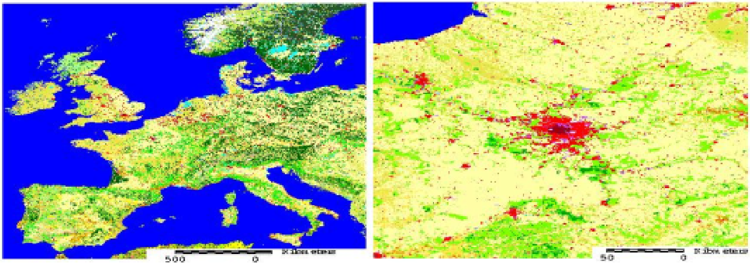
ecoclimap

definition of ecosystems/land covers

- climate map : Koeppe and de Lond 1958, 16 classes, 1km
- land cover maps :
  - University of Maryland, global, 15 classes, 1km
  - Corine land cover, Europe, 44 classes, 250m
- ndvi profiles

ecoclimap

Corine land cover, Europe, 44 classes, 250m



ecoclimap

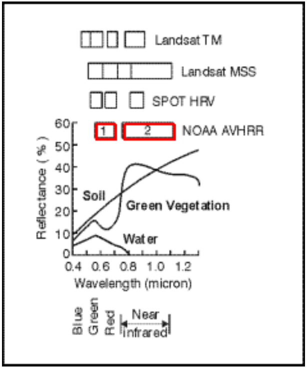
ndvi : normalized digital vegetation index

$$ndvi = \frac{R_{nir} - R_{vis}}{R_{nir} + R_{vis}}$$

$$0.725\mu \leq R_{nir} \leq 1.\mu$$

$$0.58\mu \leq R_{vis} \leq 0.68\mu$$

$$0.1 \leq ndvi \leq 0.6$$



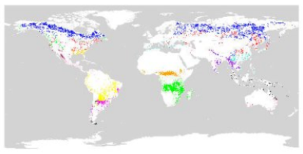
ecoclimap

each land cover is represented by a fraction of 12 vegetation types : *bare soil, rocks, permanent snow, evergreen broadleaf, deciduous broadleaf, needleleaf, C3 crops, C4 crops, irrigated crops, grassland, wetland, irrigated herbaceous*

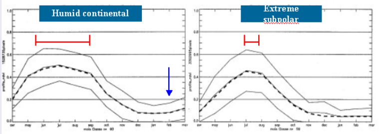
	bare soil: bare soil / rocks / permanent snow permanent snow	**woody vegetation:** evergreen brodaleaf / deciduous broadleaf / needleleaf	**herbaceous:** C3 / C4 / irr. crops / natural herbaceous / wetland and irr. herbaceous
any forest		100%	
woodland	0-10%	40-50%	50%
wooded grassland	0-20%	20-30%	50-70%
closed shrubland	20-30%	20%	50-60%
open shrubland	20-60%		40-80%
grassland			100%
crops			100%
bare soil; rock, permanent snow	90-100%		0-10%

ecoclimap

global repartition of woodland



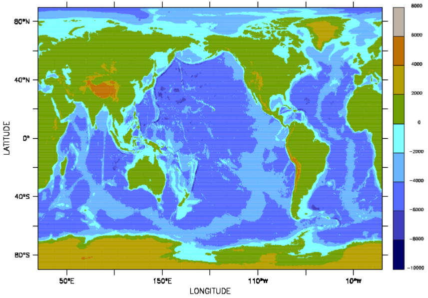
ndvi profiles of woodland



databases

bathymetry

ETOPO2 is a global database, with a horizontal grid spacing of 2 arc minutes (approximately 4km) .
http ://www.ngdc.noaa.gov/mgg/global/global.html



PGD tool

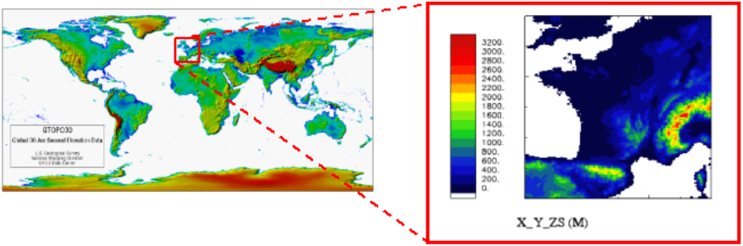
user has to define

- geographic area of interest
- projection
- grid

user has to select

- databases for vegetation, orography, soil texture and bathymetry

PGD tool



orography

Example of 10km orography computed from initial GTOPO30 database

PGD tool

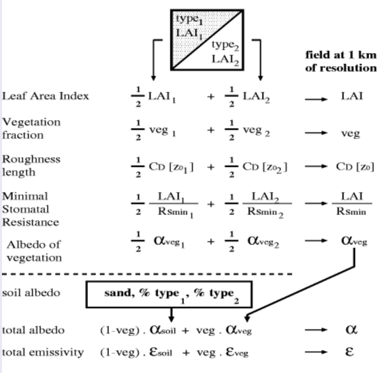
computation of surface parameters

$$LAI - LAI_{min} = (NDVI - NDVI_{min}) * \delta_{LAI} / \delta_{NDVI}$$

vegetation type	total vegetation fraction	roughness length (m)	albedo of vegetation	minimal stomatal resistance (sm^{-1})	emissivity of vegetation
bare soil	0	0.013			
rocks	0	0.13			
permanent snow and ice	0	0.0013			
C3 crops	$1 - e^{-0.6LAI}$	$0.13 \min(1, e^{\frac{LAI-3.5}{1.3}})$	0.20	40	0.97
C4 and irr. crops	$1 - e^{-0.6LAI}$	$0.13 \min(2.5, e^{\frac{LAI-3.5}{1.3}})$	0.20	40	0.97
natural herbaceous (tropics)	0.95	$0.13 \frac{LAI}{6}$	0.20	120	0.97
Other herbaceous	0.95	$0.13 \frac{LAI}{6}$	0.20	40	0.97
Needleleaf trees	0.95	$0.13\ h$	0.10	150	0.97
Evergreen broadleaf trees	0.99	$0.13\ h$	0.13	250	0.97
Deciduous broadleaf trees	0.95	$0.13\ h$	0.15	150	0.97

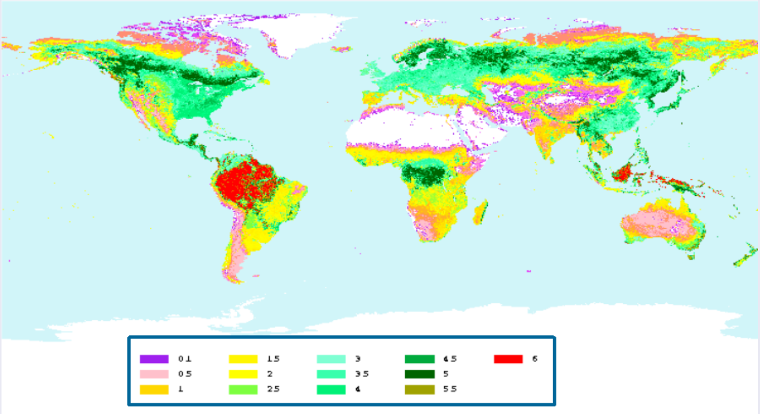
PGD tool

aggregation rules



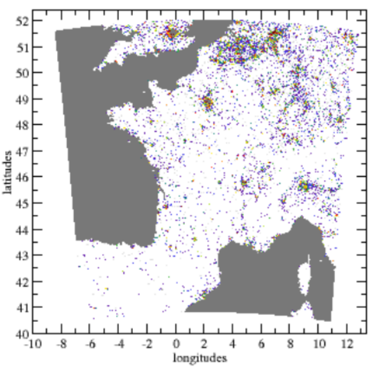
PGD tool

LAI for July



PGD tool

town fraction



PREP tool

$$\frac{\partial X}{\partial t} = \cdots \leftarrow \quad X(t=0)$$

from atmospheric model :
ECMWF, ARPEGE, ALADIN, MESO-NH, MOCAGE, MERCATOR

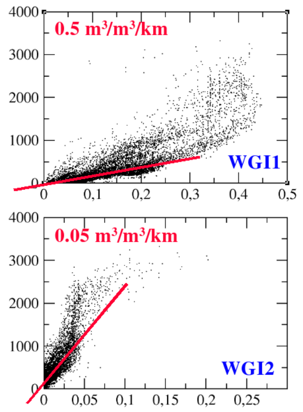
- vertical profiles for temperature, liquid water and ice
- interception water content
- temperatures of road, wall, roof
- sst, salinity
- snow water equivalent, albedo, ...

PREP tool

- reading of relevant surface fields in atmospheric file : Z_s, T, W_{liq}, W_{ice}, W_R, $snow$, SST (LAI)
- horizontal interpolation on target grid
- vertical interpolation on target soil
- vertical interpolation according to δ_{Z_s}
  - repartition of liquid water and ice

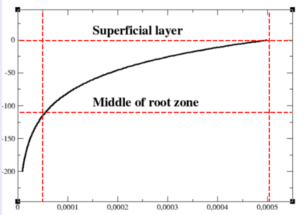
PREP tool

ice content with height



soil ice vertical gradient

$$\gamma(d) = \gamma_0 * e^{-\frac{d}{H_0}}$$



PREP tool

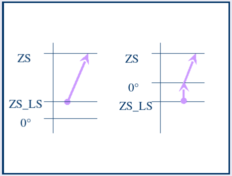
liquid water and ice content

$$w_l = w_l - \delta w$$

$$w_i = w_i + \delta w$$

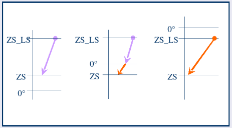
freezing

$$\delta w = \gamma(h) * \delta z$$



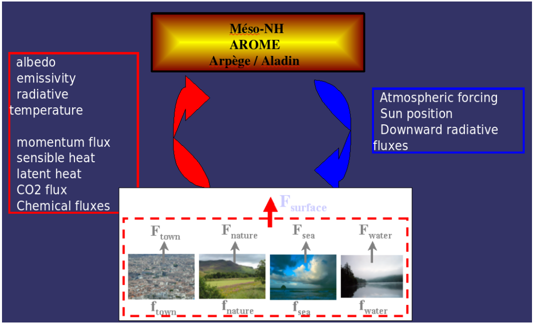
melting

$$\delta w = \gamma(h)\delta z_1 + \gamma(0) * \delta z_2$$



princip

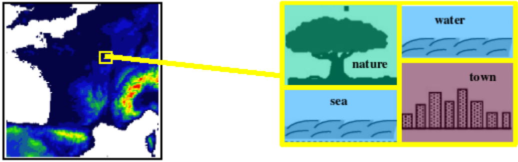
Surfex output as surface boundary conditions for atmospheric radiation and turbulent scheme



princip

tiling

one important feature of the externalized surface :
each grid cell is divided into 4 elementary units called tiles
according to the fraction of covers in the grid cell



princip

vegetation tiling

second level of tiling for vegetation : natural areas of each grid cell may be divided into several peaces called patches

1: bare ground
2: rocks
3: permanent snow
4: deciduous forest
5: conifer forest
6: evergreen broadleaf trees
7: C3 crops
8: C4 crops
9: irrigated crops
10: grassland
11: tropical grassland
12: garden and parks

setup

packing

- a mask is associated to each tile to select points of same kind
- physical parameterizations are done separately on each tile
- masks size is obtained by counting number of point which have a non-zero fraction of the tile in the domain

setup

initialization of masks

Particular case where each grid box is represented with only one tile (pure pixel, while in reality the 4 tiles may be present in the box)
The grid is composed of 12 grid cells organized as follows

1 NATURE	2 NATURE	3 TOWN	4 TOWN
5 WATER	6 NATURE	7 SEA	8 TOWN
9 NATURE	10 SEA	11 SEA	12 NATURE

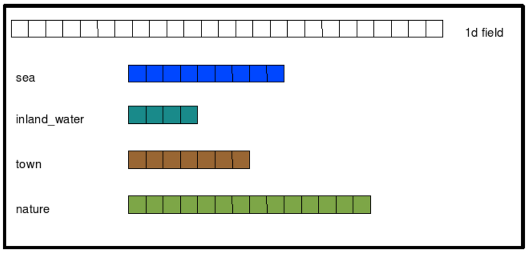
fraction of each tile

XNATURE = (1 1 0 0 0 1 0 0 1 0 0 1)
XTOWN = (0 0 1 1 0 0 0 1 0 0 0 0)
XSEA = (0 0 0 0 0 0 1 0 0 1 1 0)
XWATER = (0 0 0 0 1 0 0 0 0 0 0 0)
The dimensions of the masks are respectively 5, 3, 3 and 1

setup

Once the fraction and the size of the mask of each tile is computed, it becomes possible to pack the variables over each tile to deduce effective mask (1D vector)

associated masks



Input/Output

I/O belong to the model that calls SURFEX. Reading and writing orders are done using the same generic subroutine, called respectively read_surf and write_surf

According to the atmospheric model (AROME, Meso-NH, Aladin), specific subroutines are used

reading and writing orders are distributed over processors

fluxes

Monin Obukov characteristic scale parameters : u_*, q_*, θ_*

$$\|\vec{\tau}\| = \rho_a \overline{w' u'} = -\rho_a {u_*}^2$$

$$H = \rho_a c_{p_a} \overline{w' \theta'} = -\rho_a c_{p_a} u_* \theta_*$$

$$LE = \rho_a L_v \overline{w' q'} = -\rho_a L_v u_* q_*$$

fluxes

bulk formulation

$$\|\vec{\tau}\| = -\rho_a C_D U^2$$

$$H = \rho_a c_{p_a} C_H U(\theta_S - \theta_a)$$

$$LE = \rho_a L_v C_E U(q_S - q_a)$$

C_D, C_H and C_E are expressed as functions of atmospheric 1st layer height, stratification and roughness lengths

Intercation Soil Biosphere Atmosphere

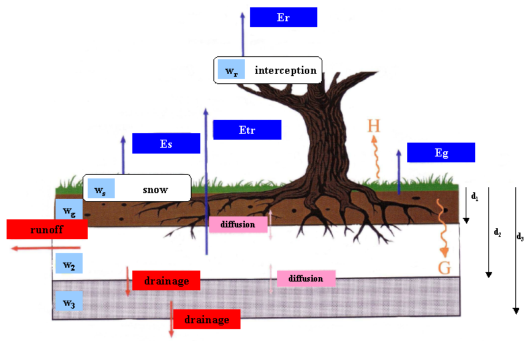
isba

2 options to treat soil transfer

- force restore method (Noilhan-Planton 1989)
  2 layers for temperature and 2 or 3 layers for water and ice contents
- diffusion method (Boone 1999)
  n-layers for temperature, water and ice contents

isba

Atmospheric forcing : T, q, u, P, S_w, L_w, rain, snow



basic equations

$$\frac{\partial T_s}{\partial t} = C_T(G) - \frac{2\pi}{\tau}(T_s - T_2)$$

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

C_T : thermal coefficient for continuum soil-vegetation-snow
G : ground flux

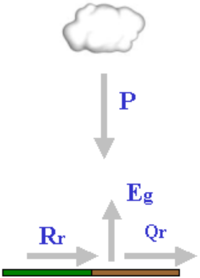
$$G = F_{net} - H - LE$$

basic equations

$$\frac{\partial w_g}{\partial t} = \frac{C_1}{\rho_w d_1}(P_g - E_g) - \frac{C_2}{\tau}(w_g - w_{g_{eq}})$$

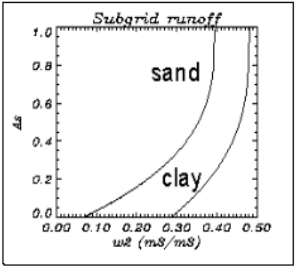
$$P_g = (1 - veg)P + R_r - Q_r$$

- P : total precipitation
- E_g : bare ground evaporation
- $w_{g_{eq}}$: balance water content (gravity/capillarity)
- R_r : interception runoff
- Q_r : surface runoff



surface runoff

saturated areas in a gridbox reduce infiltration and contribute to surface runoff.
Q_r depends on : soil texture, w_2 and a parameter b used to compute the saturated surface of the gridbox : Q_r increases with b

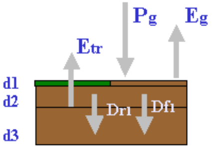


basic equations

$$\frac{\partial w_2}{\partial t} = \frac{1}{\rho_w d_2}(P_g - E_g - E_{tr}) - D_{r_1} - D_{f_1}$$

$$D_{f_1} = \frac{C_4}{\tau}(w_2 - w3)$$

- E_{tr} : evaoptranspiration
- D_{r_1} : root zone drainage
- D_{f_1} : diffusion of water term

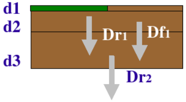


basic equations

$$\frac{\partial w_3}{\partial t} = \frac{d_2}{d_3 - d_2}(D_{r_1} + D_{f_1}) - D_{r_2}$$

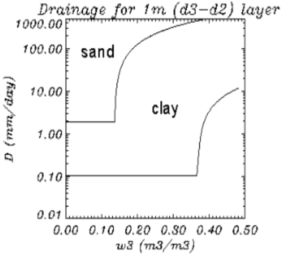
$$D_r = \frac{C_3}{\tau d}\left[e_b, w - w_{fc}\right]$$

- E_{tr} : evapotranspiration
- D_{r_1} : root zone drainage
- D_{f_1} : diffusion of water term



drainage

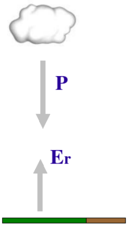
depends on soil texture and occurs from a given threshold



basic equations

$$\frac{\partial w_r}{\partial t} = veg(P) - E_r$$

- P : total precipitation
- E_r : evaporation of interception reservoir



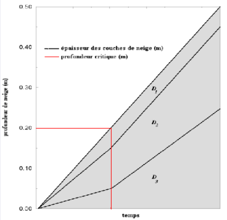
basic equations

$$\frac{\partial w_n}{\partial t} = P_n + p_n P_l - E_n - E_{melt}$$

$$D_s = P_n \frac{\Delta(t)}{\rho_{new}}$$

$$D_{s_1} = a_1 D_s + b_1$$

$$D_{s_2} = a_2 D_s + b_2$$



force restore equations

$$G = F_{net} - H - LE$$

$$F_{net} = (1 - \alpha) * S_w \downarrow + \epsilon (L_w \downarrow - \sigma {T_s}^4)$$

$$H = \frac{\rho_a c_{p_a}}{R_a}(\theta_s - \theta_a)$$

$$LE = L_v * E = L_v * (E_g + E_r + E_{tr} + E_n)$$

evaporation

bare ground evaporation

$$E_g = (1 - veg)\frac{\rho_a}{R_a}(h_u q_{sat}(T_s) - q_a)$$

h_u is the ground humidity

$$h_u q_{sat}(T_s) = q_s$$

evaporation

evaporation due to interception

$$E_r = veg\,\rho_a \frac{\delta}{R_a}(q_{sat}(T_s) - q_a)$$

δ is the fraction of foliage covered by water

$$\delta = (1 - f_{z_0})\delta_{low} + f_{z_0}\delta_{high}$$

evaporation

snow sublimation

$$E_n = p_n \frac{\rho_a}{R_a}(q_{sat}(T_s) - q_a)$$

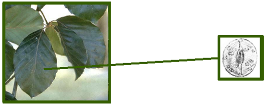
p_n : snow fraction

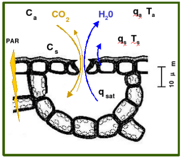
evaporation

evapotranspiration

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

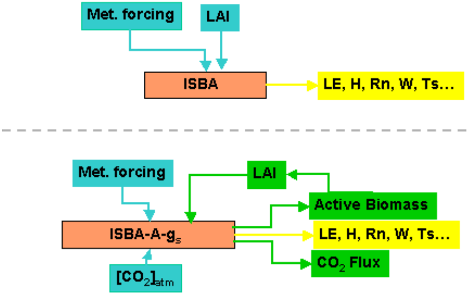
stomatal resistance R_s regulates evaporation of plants





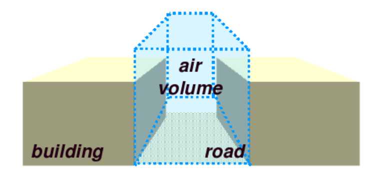
A-gs approach

The active biomass is a reservoir fed by the net CO2 uptake by leaves : net assimilation = photosynthesis - leaf respiration



Town Energy Balance

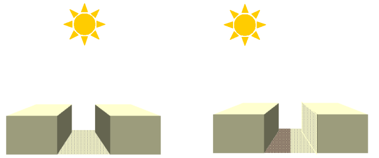
urban canyon concept



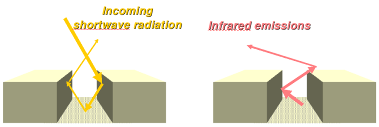
TEB

radiative perturbations

shading effect on walls and roads



radiative trapping inside the canyon



TEB

thermal perturbations

- specific properties of materials
- lot of available surfaces

$\Rightarrow$ strong heat storage

TEB

anthropogenic perturbations

- metabolism
- road traffic
- heating/cooling domestic systems
- industrial activity

TEB

hydrological perturbations

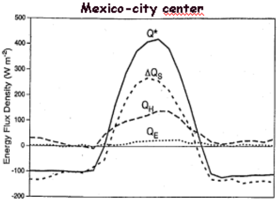
- sewer network
- waterproof surfaces

$\Rightarrow$ strong runoff and weak evaporation

TEB

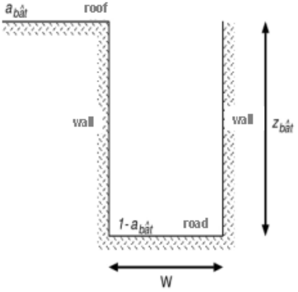
$$F_{net} + F_{ant} = H + LE + \Delta F_{sto} + \Delta F_{adv}$$

- F_{net} : net flux
- F_{ant} : anthopogenic flux
- H : sensible heat flux
- LE : latent heat flux
- F_{sto} : storage flux
- F_{adv} : advection flux



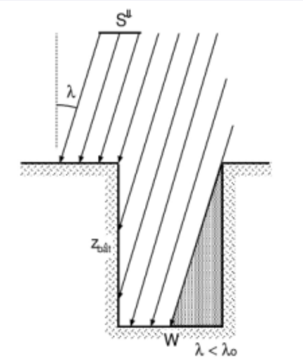
princip of TEB model

- urban canyon model : parameterization of exchanges of water and energy between canopy and atmosphere
- exclusive treatment of built surfaces
- idealized geometry
- 3 elementary surfaces

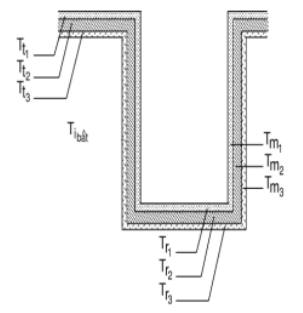


princip of TEB model

computation of energy budget of each surface

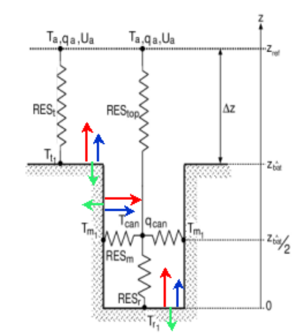


computation of temperature surface + materials

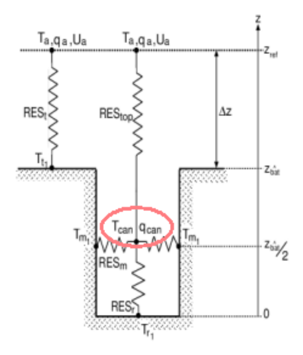


princip of TEB model

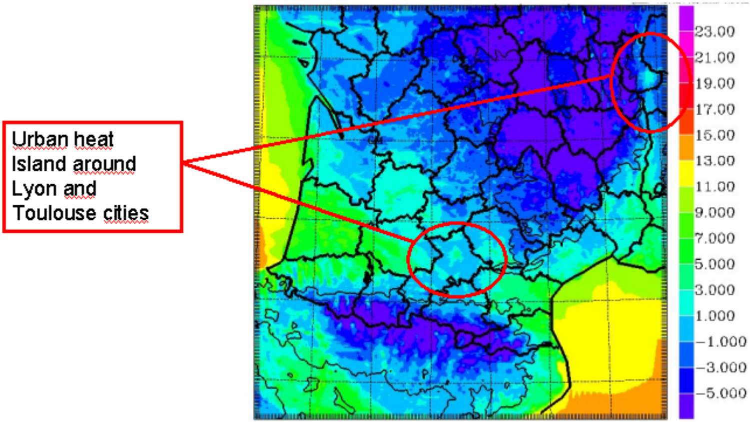
computation of exchanged energy with aerodynamical network



computation of air temperature and humidity inside the canyon



Arome forecast for the 18th November 2005 at 00UTC



sea flux parameterization

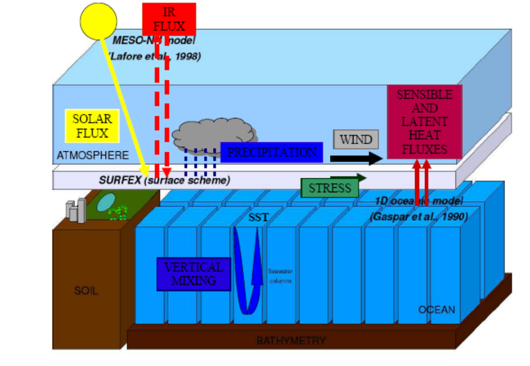
Charnock formulation

$$z_0 = 0.015 \frac{{u_*}^2}{G}$$

prescribed SST and Charnock's formulation allow to compute fluxes over sea

1d ocean boundary layer

pronostic SST, salinity and TKE

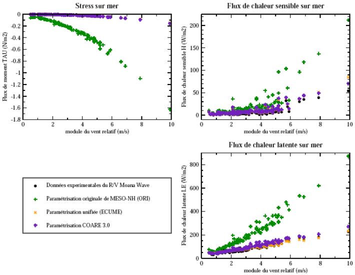


1d modele fluxes

$$\|\vec{\tau}\| = -\rho_a C_D U^2$$

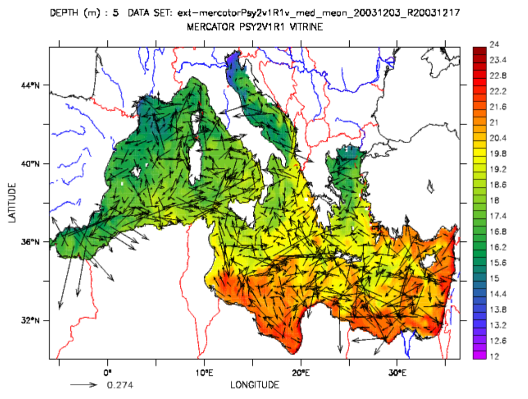
$$H = \rho_a c_{p_a} C_H U(\theta_S - \theta_a)$$

$$LE = \rho_a L_v C_E U(q_S - q_a)$$



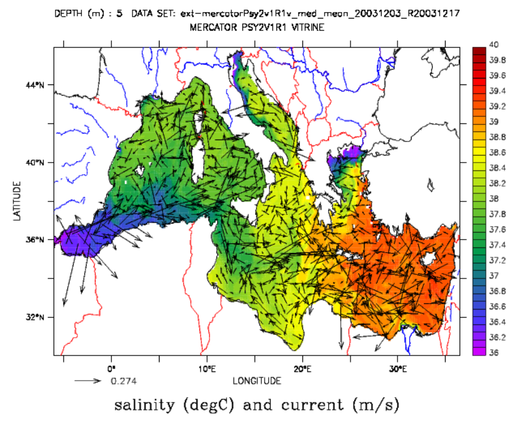
1d ocean boundary layer

sea surface temperature



1d ocean boundary layer

salinity



Flake model

Flake model is able to predict :

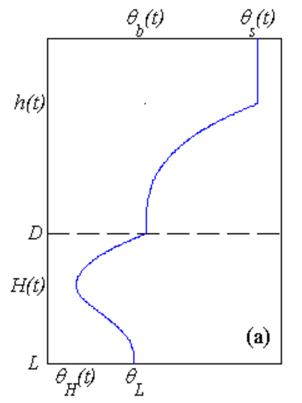
- vertical temperature structure
- mixing conditions in lakes of various depth
- for various time scales (few hours to several years)

- bulk model based on M.O. similarity theory : structure of turbulence in boundary layer entirely defined with turbulent scales u_* and θ_*
- includes a parameterization of sediments
- includes also a snow scheme since part of lake can freeze

variables

- $\theta_s(t)$ surface temperature
- $h(t)$ height of mixed layer
- $\theta_b(t)$ deep temperature
- $H(t)$ depth penetrated by thermal wave
- $\theta_H(t)$ temperature at depth $H(t)$

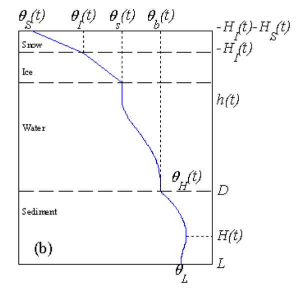
summer profile



variables

- $\theta_S(t)$ temperature at air-snow interface
- $\theta_I(t)$ temperature at ice-snow interface
- $H_S(t)$ snow thickness
- $H_I(t)$ ice thickness

winter profile



energy budget (mean and per tile/patch)

- LSURF_BUDGET, classical energy fluxes : F_{net}, H, LE, G
- LSURF_EVAP_BUDGET, evaporative components :
  - $L_v E_g$, $L_v E_r$, $L_v E_{tr}$, $L_s E_{gi}$, $L_s E_s$
  - total evaporative flux, drainage, runoff, snow melting rate
- LSURF_BUDGETC : accumulated fluxes from begining of simulation

inquiry mode

- LCOEF : turbulent exchange coefficients, roughness lengths
- LSURF_VARS : returns surface humidity q_s

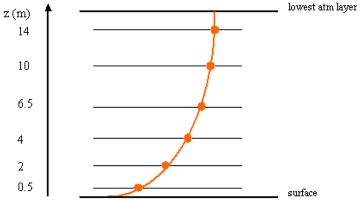
LPGD : returns surface parameters (LAI, veg, ...)

2 meters diagnostics

- N2M=1
  Paulson, 1970 : extrapolation from lowest atmospheric level using predefined stability functions
- N2M=2
  Geleyn, 1988 : interpolation between surface and lowest atmospheric level using exchange coefficients (used to compute fluxes)

SBL scheme : Masson, 2008

- 1d vertical prognostic scheme
- extra layers between lowest atmospheric level and surface
- takes into account large scale forcing, turbulence and drag due to canopy



2 meters variables are computed in a prognostic way