Boundary Conditions. Soil Atmosphere Interactions

CODE_BRIGHT SHORT COURSE

Department of Geotechnical Engineering and Geociences UPC

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Dept. of Geotechnical Engineering and Geosciences
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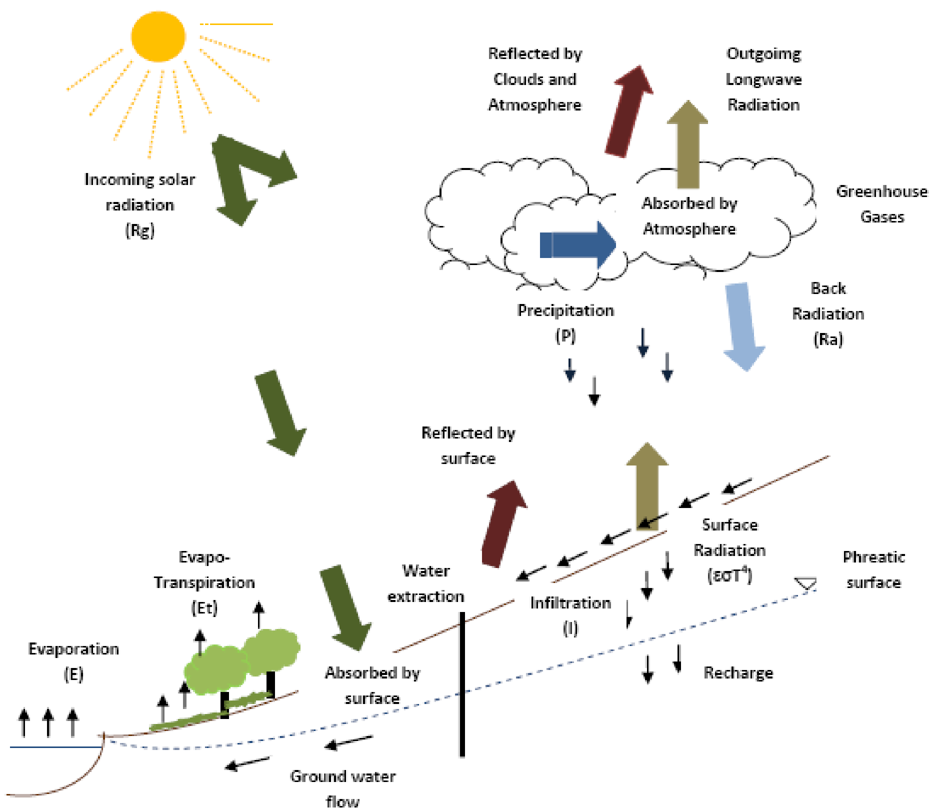
INTRODUCTION



- Short wave radiation
- Long wave radiation
- Surface radiation
- Surface reflection

Net radiation

- Sensible heat
- Heat convected by evaporation

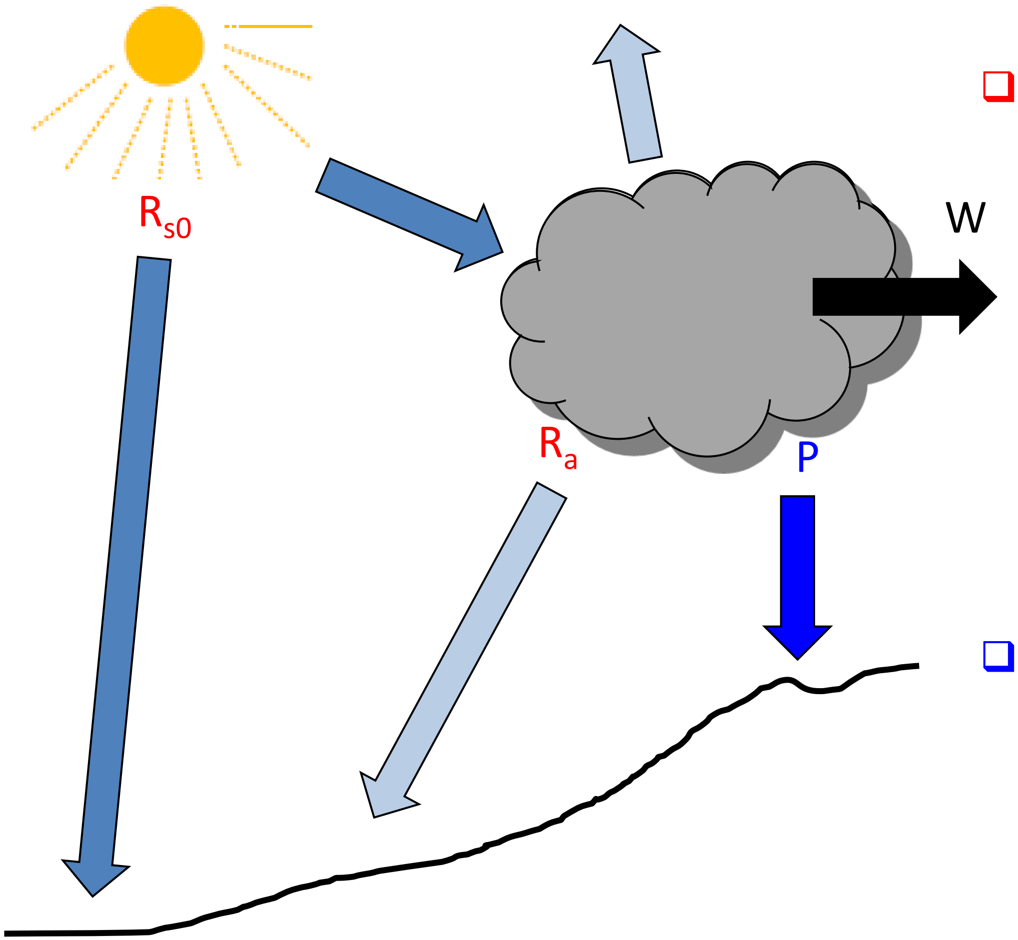
- Precipitation
- Run-off

Net infiltration

- Evapotranspiration
- Vapour convected by air motion

- Advective flow of air

RELEVANT ATMOSPHERIC DRIVING PROCESSES



❑ THERMAL PROCESS

- ✓ Direct solar radiation (short wave)
- ✓ Change of atmosphere temperature by radiation absorption
- ✓ Atmosphere radiation (long wave)

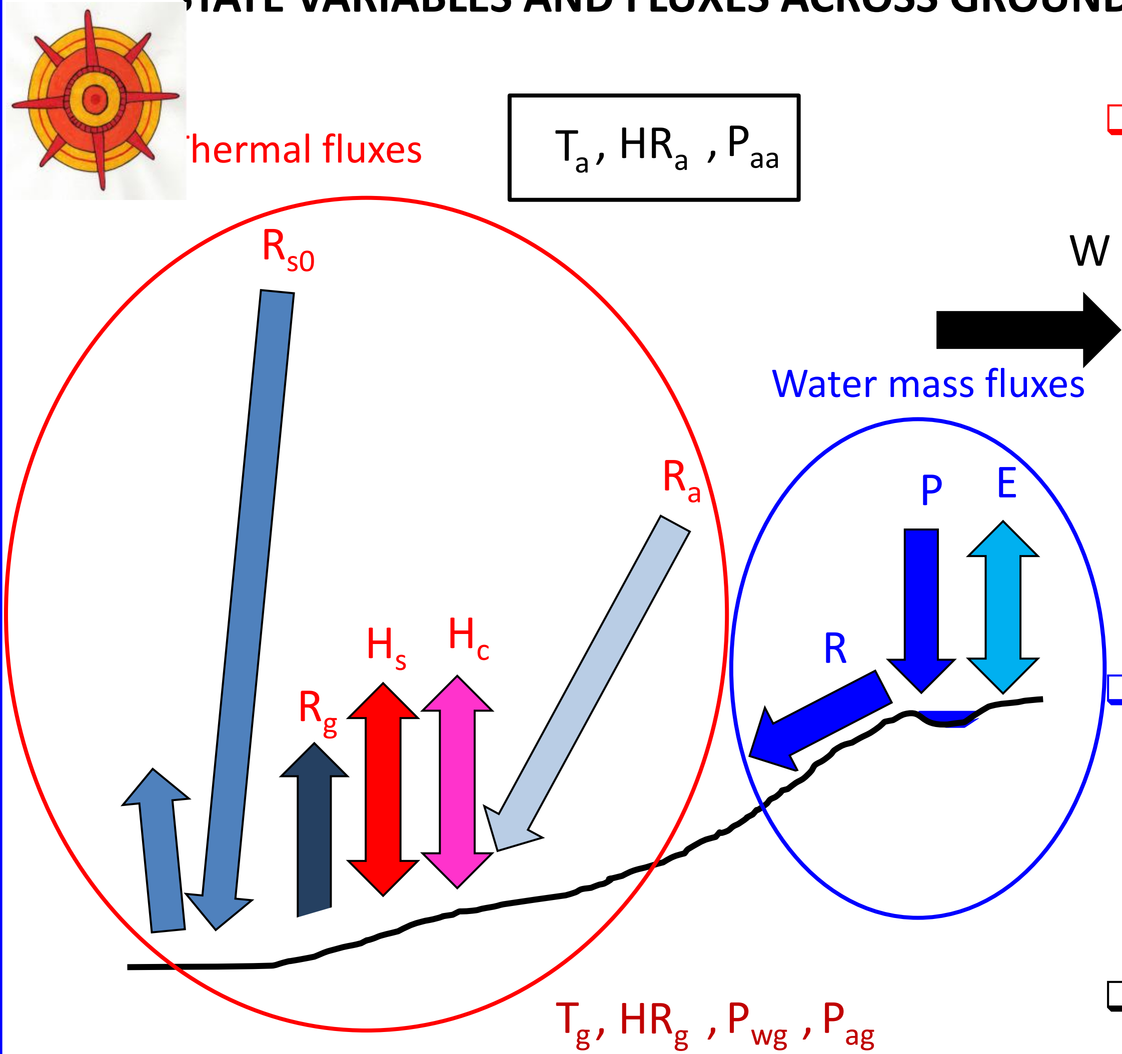
❑ MOISTURE PROCESS

- ✓ Cloud formation
- ✓ Precipitations

❑ AIR MASS MOTION

PROCESSES ARE COUPLED AND FORM COMPLEX, TURBULENT AND INSTABLE SYSTEMS

STATE VARIABLES AND FLUXES ACROSS GROUND SURFACE



- ❑ THERMAL PROCESS
  - ✓ Short wave ground reflection
  - ✓ Change of ground temperature by heat absorption
  - ✓ Ground radiation
  - ✓ Heat exchange due to ground-air temperature difference
  - ✓ Heat convected by water flow
- ❑ MOISTURE PROCESS
  - ✓ Run-off and ponding
  - ✓ Change in ground water content due to infiltration
  - ✓ Evaporation
- ❑ AIR MASS MOTION
  - ✓ Wind effect

(Noilhan & Planton, 1989; Blight, 1997)

FORMULATION OF FLUXES

THERMAL FLUX

$$j_e = \underbrace{(1-A_l)R_s + \varepsilon R_a - R_g}_{\text{Net radiation}} + \underbrace{H_s}_{\text{Sensible heat}} + \underbrace{H_c}_{\text{Heat convected by water}}$$

✓ **Net radiation**

Sun: $R_s = R_{s0} \times f(\text{time, latitude, cloudiness}), \quad R_{s0} = 1376\ \text{J.m}^{-2}.\text{s}^{-1}$

Atmosphere: $R_a = \varepsilon_a \sigma T_a^4, \quad \varepsilon_a = f(HR_a, T_a, p_a)$ ← Atmosphere emissivity

Ground : $R_g = \varepsilon_g \sigma T_g^4, \quad \varepsilon_g = f(\text{ground saturation})$ ← Ground emissivity

$A_l = f(\text{ground saturation})$ ← Ground albedo

✓ **Sensible heat**

$H_s = r_a \rho_a C_a (T_a - T_g) \qquad r_a = f(\text{wind velocity})$ ← Aerodynamic resistance of ground/atmosphere interface

✓ **Heat convected by mass fluxes**

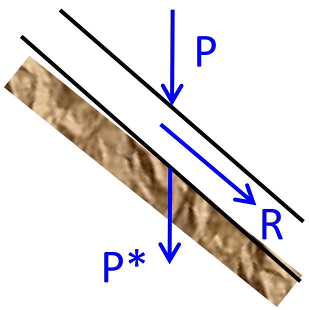
$H_c = e_w(P^* - R) + e_v(E + j_g^w) + e_a q_g^a \qquad e_v = e_{v0} + C_v(T - T_0)$

FORMULATION OF FLUXES

❑ WATER FLUX

$$j_w = \underbrace{P^* - R}_{\text{Net infiltration}} + \underbrace{E}_{\text{Evaporation}} + \underbrace{j_g^w}_{\text{Vapour convected by gas flow}}$$

✓ Net infiltration and ponding

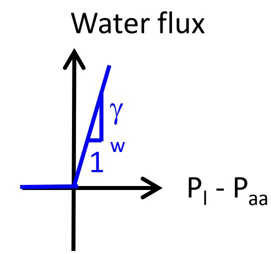


Runoff: modelled by mean of a continuum layer with porosity 1

Precipitation and ponding:

$$P^* = P + \gamma_w (P_l - P_{aa})$$

← Leakage coefficient



✓ Evaporation

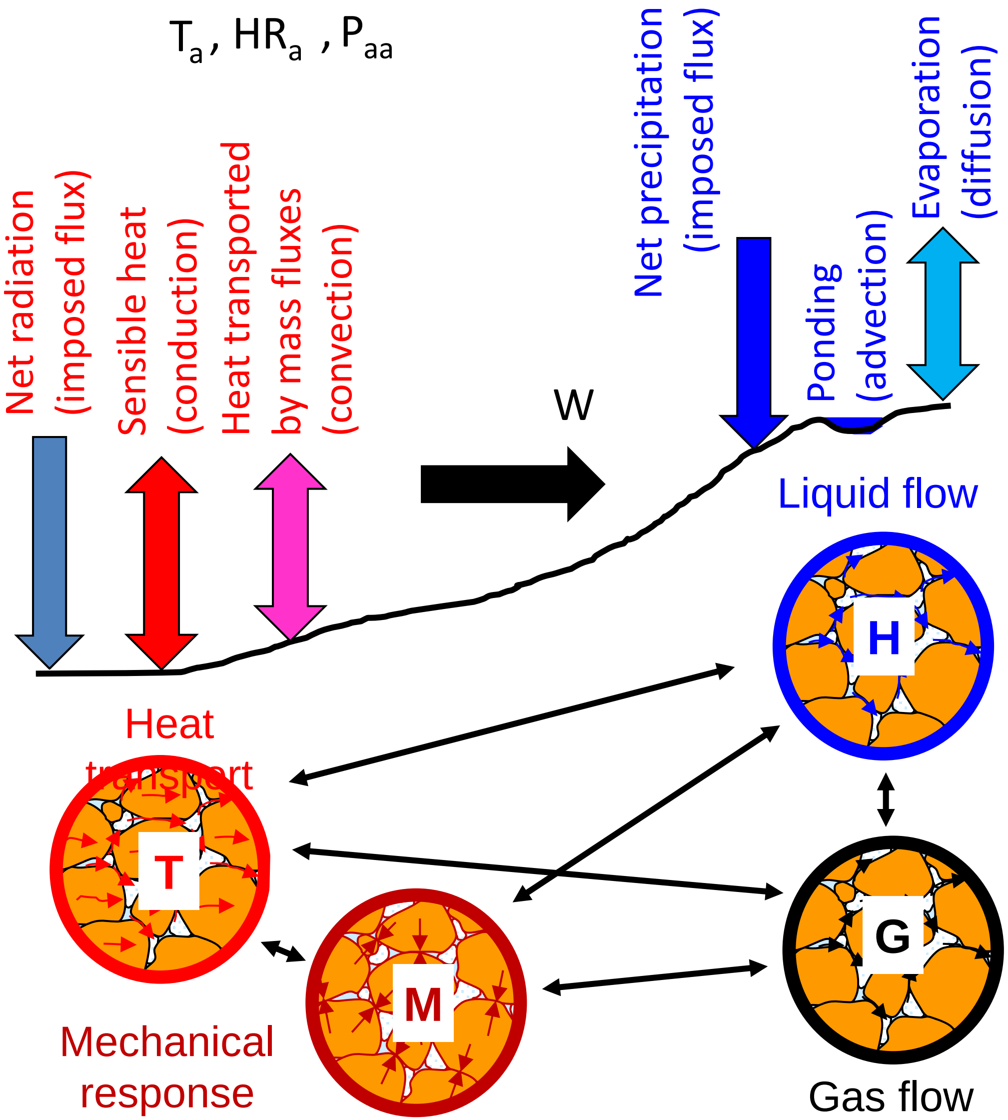
$$E = r_a \left(\theta_{ga}^w - \theta_{gg}^w \right)$$

← Aerodynamic resistance of ground/atmosphere interface

✓ Vapour convected by gas flow

$$j_g^w = \omega_g^w q_g$$

COUPLED THERMO-HYDRO (PNEUMO)-MECHANICAL PHENOMENA



❑ THERMAL PROCESS

- ✓ Heat convection
- ✓ Heat advection
- ✓ Phase changes

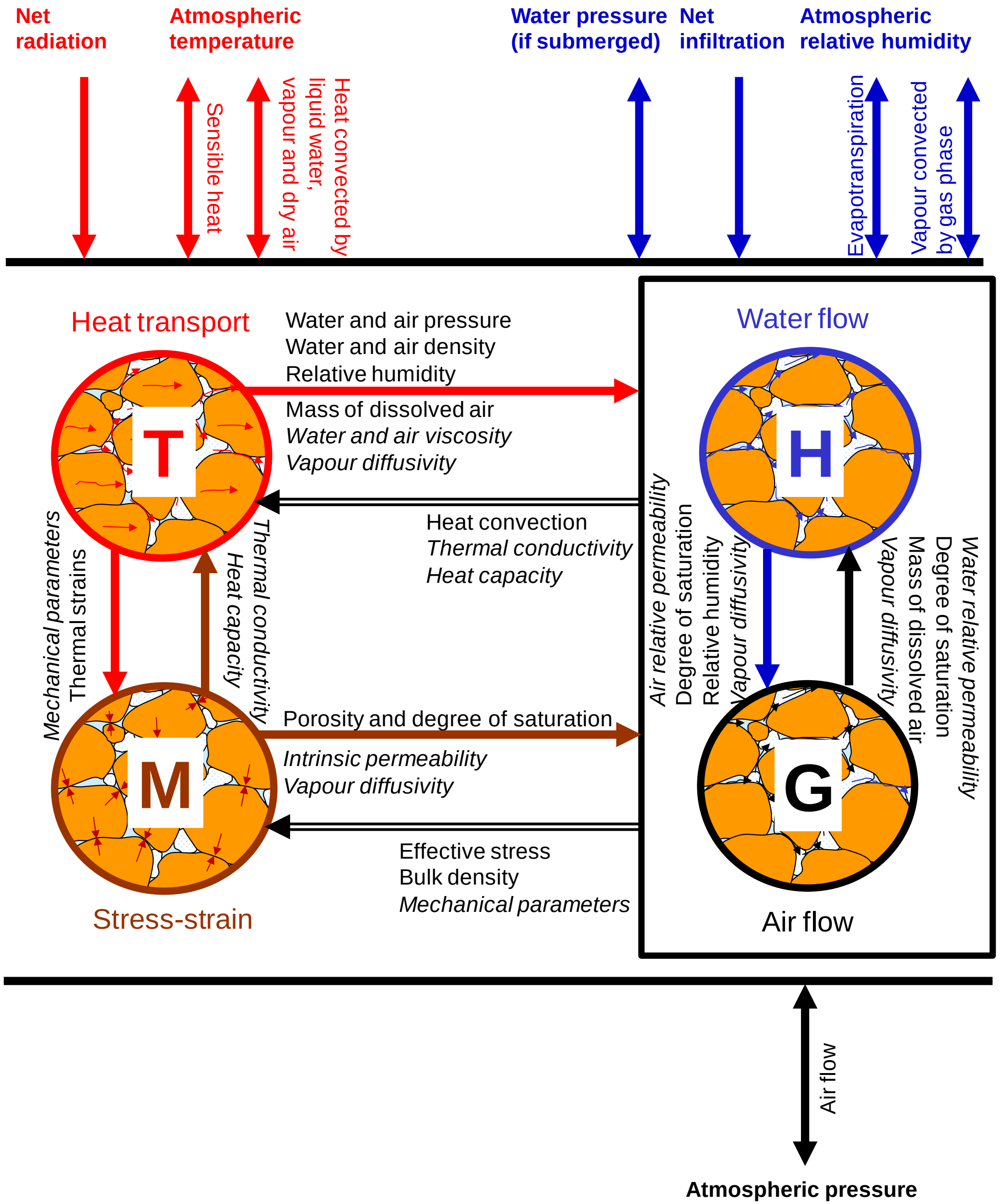
❑ HYDRAULIC (PNEUMATIC) PROCESS

- ✓ Liquid flow
- ✓ Gas flow
- ✓ Vapour diffusion
- ✓ Air dissolution in water
- ✓ Air diffusion in water

❑ MECHANICAL EFFECT

- ✓ Deformation of material under stresses, pore pressures and temperature changes

THM FORMULATION AND GENERAL BOUNDARY CONDITIONS



THM FORMULATION AND GENERAL BOUNDARY CONDITIONS

MASS BALANCE OF SOLID

$$\frac{\partial}{\partial t}(1-\phi)\rho_S + \nabla\cdot\left(\mathbf{j}^s\right) = f^s$$

MASS BALANCE OF WATER

$$\frac{\partial}{\partial t}\left(\theta_l^w S_l \phi + \theta_g^w S_g \phi\right) + \nabla\cdot\left(\mathbf{j}_l^w + \mathbf{j}_g^w\right) = f^w$$

MASS BALANCE OF AIR

$$\frac{\partial}{\partial t}\left(\theta_l^a S_l \phi + \theta_g^a S_g \phi\right) + \nabla\cdot\left(\mathbf{j}_l^a + \mathbf{j}_g^a\right) = f^a$$

INTERNAL ENERGY BALANCE FOR THE MEDIUM

$$\frac{\partial}{\partial t}\left(E_s\rho_s(1-\phi) + E_l\rho_l S_l\phi + E_g\rho_g S_g\phi\right) + \nabla\cdot(\mathbf{i}_c + \mathbf{j}_{Es} + \mathbf{j}_{El} + \mathbf{j}_{Eg}) = f^Q$$

MOMENTUM BALANCE FOR THE MEDIUM

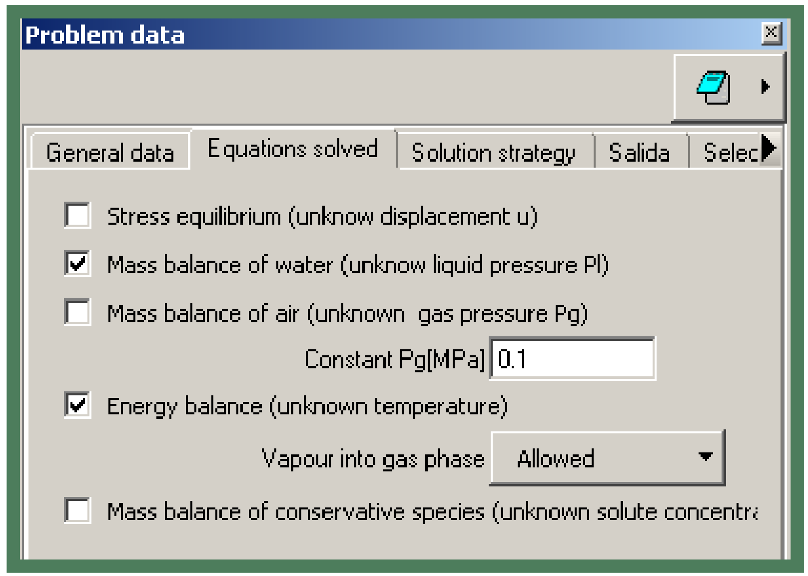
$$\nabla\cdot\boldsymbol{\sigma} + \mathbf{b} = \mathbf{0}$$

THM FORMULATION AND GENERAL BOUNDARY CONDITIONS

Fluxes	Within the soil or rock		Prescribed flux at the boundary
	Governing law	Theoretical expression	
Liquid phase (volume)	Darcy's law	$q_l = -\frac{K_i K_{rl}}{\mu_l}\left(\nabla p_l + \rho_l \nabla z\right)$	$\bar{q}_l = \bar{q}_{l0} + \bar{\gamma}_l\left(p_l - \bar{p}_{l0}\right)$
Gas phase (volume)	Generalized Darcy's law	$q_g = -\frac{K_i K_{rg}}{\mu_g}\left(\nabla p_g + \rho_g \nabla z\right)$	$\bar{q}_g = \bar{q}_{g0} + \bar{\gamma}_g\left(p_g - \bar{p}_{g0}\right)$
Liquid water (mass)	Convection by liquid phase	$q_w = \rho_l \omega_l q_l$ $\left(\omega_l = 1\right)$	$\bar{q}_w = \bar{\rho}_{l0}\bar{q}_l$ if $\bar{q}_l$ inflow $\bar{q}_w = \rho_l \bar{q}_l$ if $\bar{q}_l$ outflow
Vapour (mass)	Convection by gas phase +	$q_v = \rho_g \omega_v q_{g_v}$	$\bar{q}_v = \bar{\rho}_{g0}\bar{\omega}_{v0}\bar{q}_g$ if $\bar{q}_g$ inflow $\bar{q}_v = \rho_g \omega_v \bar{q}_g$ if $\bar{q}_g$ outflow
	Diffusion in gas phase	$i_v = -\rho_g D_v \nabla \omega_g$	$\bar{i}_v = \bar{\beta}_v\left(\rho_g \omega_v - \bar{\rho}_{g0}\bar{\omega}_{v0}\right)$
Dry air (mass)	Convection by gas phase +	$q_a = \rho_g \omega_a q_g$ $\left(\omega_a = 1 - \omega_v\right)$	$\bar{q}_a = \bar{\rho}_{g0}\bar{\omega}_{a0}\bar{q}_g$ if $\bar{q}_g$ inflow $\bar{q}_a = \rho_g \omega_a \bar{q}_g$ if $\bar{q}_g$ outflow
	Diffusion in gas phase	$i_a = -\rho_g D_a \nabla \omega_a$	$\bar{i}_a = \bar{\beta}_g\left(\rho_g \omega_a - \bar{\rho}_{g0}\bar{\omega}_{a0}\right)$
Dissolved air (mass)	Convection by liquid phase +	$q_a = \rho_l \omega_{da} q_l$	$\bar{q}_{da} = \bar{\rho}_{l0}\bar{\omega}_{da0}\bar{q}_l$ if $\bar{q}_l$ inflow $\bar{q}_{da} = \rho_l \omega_{da} \bar{q}_l$ if $\bar{q}_l$ outflow
	Diffusion in liquid phase	$i_{da} = -\rho_l D_{da} \nabla \omega_{da}$	$\bar{i}_{da} = \bar{\beta}_l\left(\rho_l \omega_{da} - \bar{\rho}_{l0}\bar{\omega}_{da0}\right)$
Heat	Convection by liquid water +	$j_{ew} = \rho_l q_l C_w T$	$\bar{j}_{ev} = \bar{\rho}_{l0}\bar{q}_l C_w \bar{T}_0$ if $\bar{q}_l$ inflow $\bar{j}_{ev} = \rho_l \bar{q}_l C_w T$ if $\bar{q}_l$ outflow
	Convection by dry air +	$j_{ea} = \omega_a \rho_g q_g C_a T$	$\bar{j}_{ea} = \bar{\omega}_{a0}\bar{\rho}_{g0}\bar{q}_g C_a \bar{T}_0$ if $\bar{q}_g$ inflow $\bar{j}_{ea} = \omega_a \rho_g \bar{q}_g C_a T$ if $\bar{q}_g$ outflow
	Convection by vapour +	$j_{ev} = \omega_v \rho_g q_g\left(C_v T + e_{v0}\right)$	$\bar{j}_{ev} = \bar{\omega}_{v0}\bar{\rho}_{g0}\bar{q}_g\left(C_v \bar{T}_0 + e_{v0}\right)$if $\bar{q}_g$ inflow $\bar{j}_{ev} = \omega_v \rho_g \bar{q}_g\left(C_v T + e_{v0}\right)$if $\bar{q}_g$ outflow
	Conduction	$i_c = -\lambda \nabla T$	$\bar{i}_c = \bar{q}_{T0} + \bar{\gamma}_T\left(T - \bar{T}_0\right)$

PRACTICAL INTRODUCTION OF DATA

❑ These Conditions only exists if any balance (water, air, energy flow) is solved.



❑ It is precisely the case of **ATMOSPHERIC** and **VEGETATION** conditions

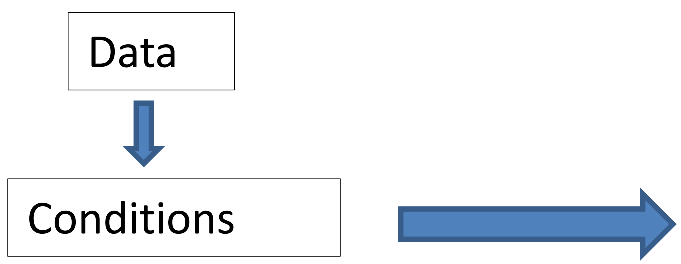
Introduce as **FLUX B.C.** :

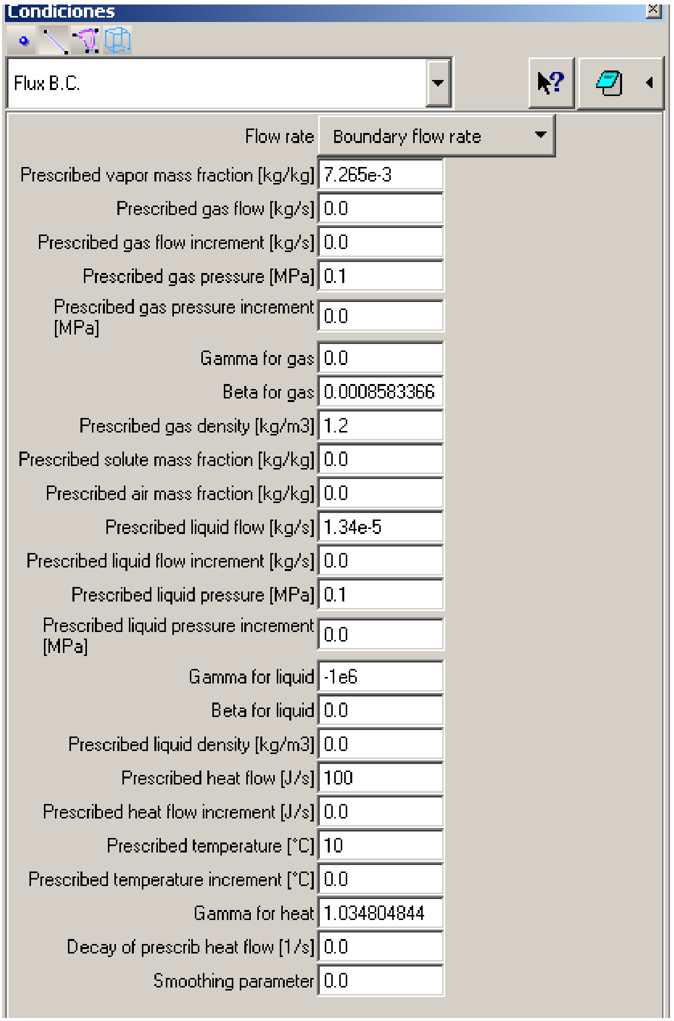
- **Water**
- **Air**
- **Energy**

PRACTICAL INTRODUCTION OF DATA

- Usually the boundary condition is incorporated by adding a flux,

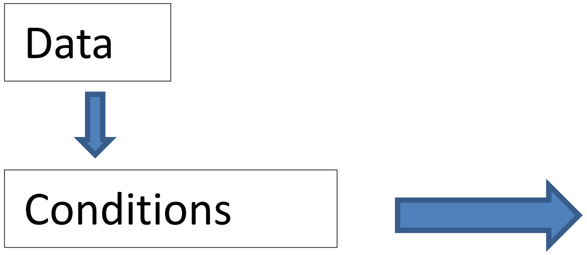
$$j_g^w = \left(\omega_g^w\right)^0 j_g^0 + \left(\omega_g^w\right)^0 \gamma_g \left(P_g^0 - P_g\right) + \beta_g \left[\left(\rho_g \omega_g^w\right)^0 - \left(\rho_g \omega_g^w\right)\right]$$

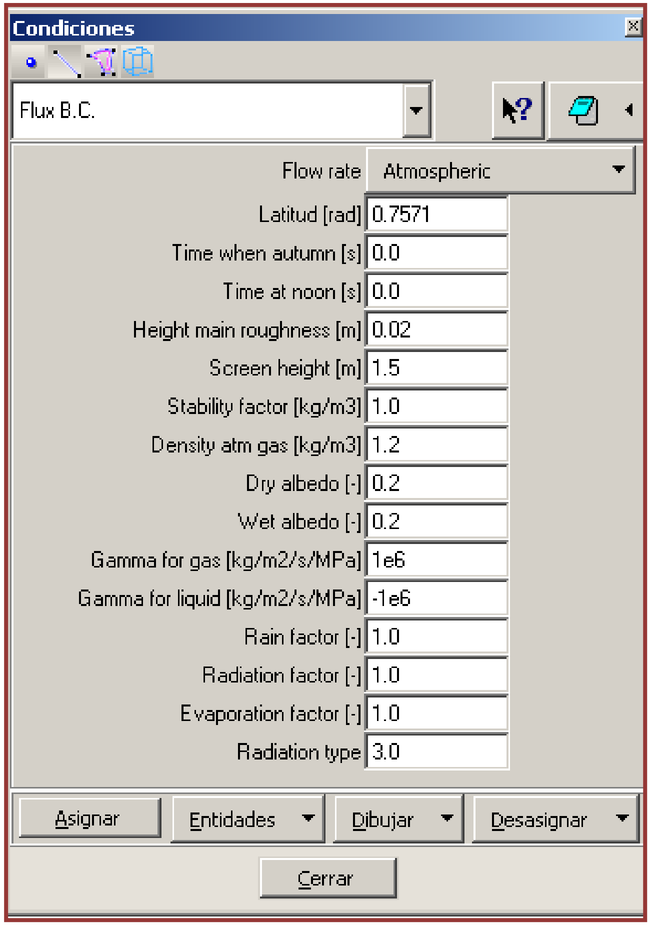




PRACTICAL INTRODUCTION OF DATA

- Parameters to be enter when **atmospheric boundary conditions** are considered





PRACTICAL INTRODUCTION OF DATA

- Time varying atmospheric data is read from the file **root_atm.dat**

	T_a		P_{ga}		H_r		R_n		I_n		P		v_a	
Flag	**1**	0	**1**	0	**1**	0	**1**	0	**1**	0	**1**	0	**1**	0
Annual mean	0	x_am	0	x_am	0	x_am	0	x_am	0	x_am	0	x_am	0	x_am
Annual ampl	0	x_aa	0	x_aa	0	x_aa	0	x_aa	0	x_aa	0	x_aa	0	x_aa
Annual gap (s)	0	x_ag	0	x_ag	0	x_ag	0	x_ag	0	x_ag	0	x_ag	0	x_ag
Daily ampl	0	x_da	0	x_da	0	x_da	0	x_da	0	x_da	0	x_da	0	x_da
Daily gap (s)	0	x_dg	0	x_dg	0	x_dg	0	x_dg	0	x_dg	0	x_dg	0	x_dg
Unused	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Measures…	ti	xi	ti	xi	ti	xi	ti	xi	ti	xi	ti	xi	ti	Xi
Measures…	ti	xi	ti	xi	ti	xi	ti	xi	ti	xi	ti	xi	ti	Xi
Measures…	ti	xi	ti	xi	ti	xi	ti	xi	ti	xi	ti	xi	ti	Xi
Measures…	ti	xi	ti	xi	ti	xi	ti	xi	ti	xi	ti	xi	ti	Xi
Measures…	ti	xi	ti	xi	ti	xi	ti	xi	ti	xi	ti	xi	ti	Xi
Measures…	ti	xi	ti	xi	ti	xi	ti	xi	ti	xi	ti	xi	ti	Xi
Measures…	…	…	…	…	…	…	…	…	…	…	…	…	…	…

- **ProjectATM.gid** → **Root.dat**
ProjectATM_gen.dat
ProjectATM_gri.dat
ProjectATM_atm.dat

CONCLUDING REMARKS

✓ The atmospheric boundary Condition allows for accounting for most of meteorological data:

- solar radiation
- temperature
- infiltration
- relative humidity
- wind effect
- vegetation

✓ It is consistently implemented in CODE_BRIGHT THM formulation

✓ It has been validated on several cases

- Le Fauga (water mass and heat flux in a vegetalized horizontal ground)
- Carmaux embankment (water mass and heat flux in a bare inclined ground)
- La Roque Gageac (solar radiation and deformation in a vertical cliff)
- Slope in Tremp area (run-off, validation in course)