

# Boundary Conditions. Soil Atmosphere Interactions

**CODE\_BRIGHT SHORT COURSE**

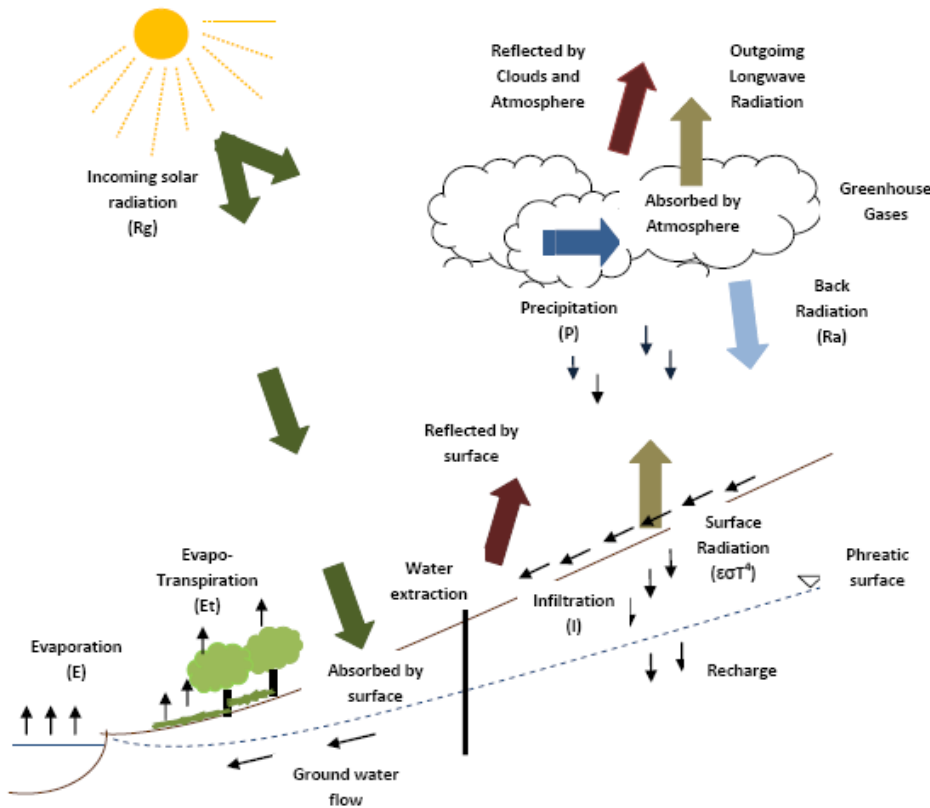
*Department of Geotechnical Engineering and Geosciences UPC*

**Barcelona, 8th to 10th june 2016**



Dept. of Geotechnical Engineering and Geosciences  
UNIVERSITAT POLITÈCNICA DE CATALUNYA

# INTRODUCTION

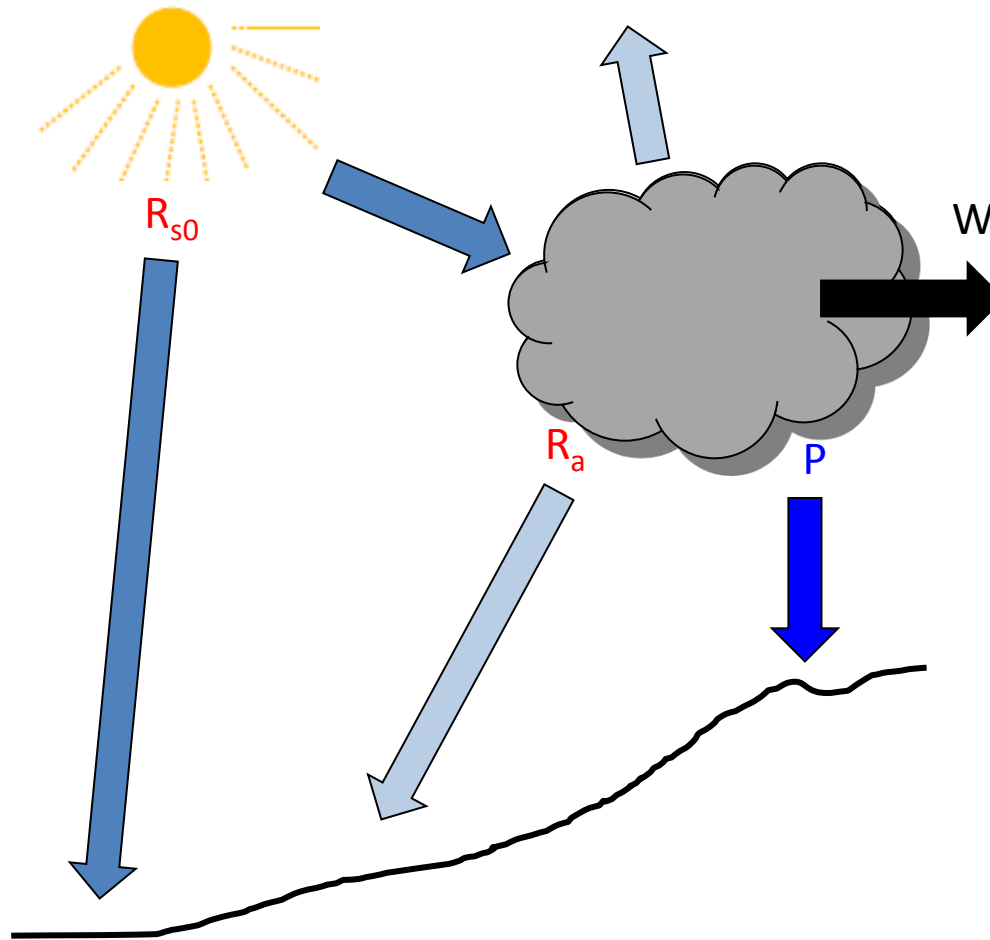


- Short wave radiation
  - Long wave radiation
  - Surface radiation
  - Surface reflection
  - Sensible heat
  - Heat convected by evaporation
- Net radiation

- Precipitation
  - Run-off
  - Evapotranspiration
  - Vapour convected by air motion
- Net infiltration

- 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

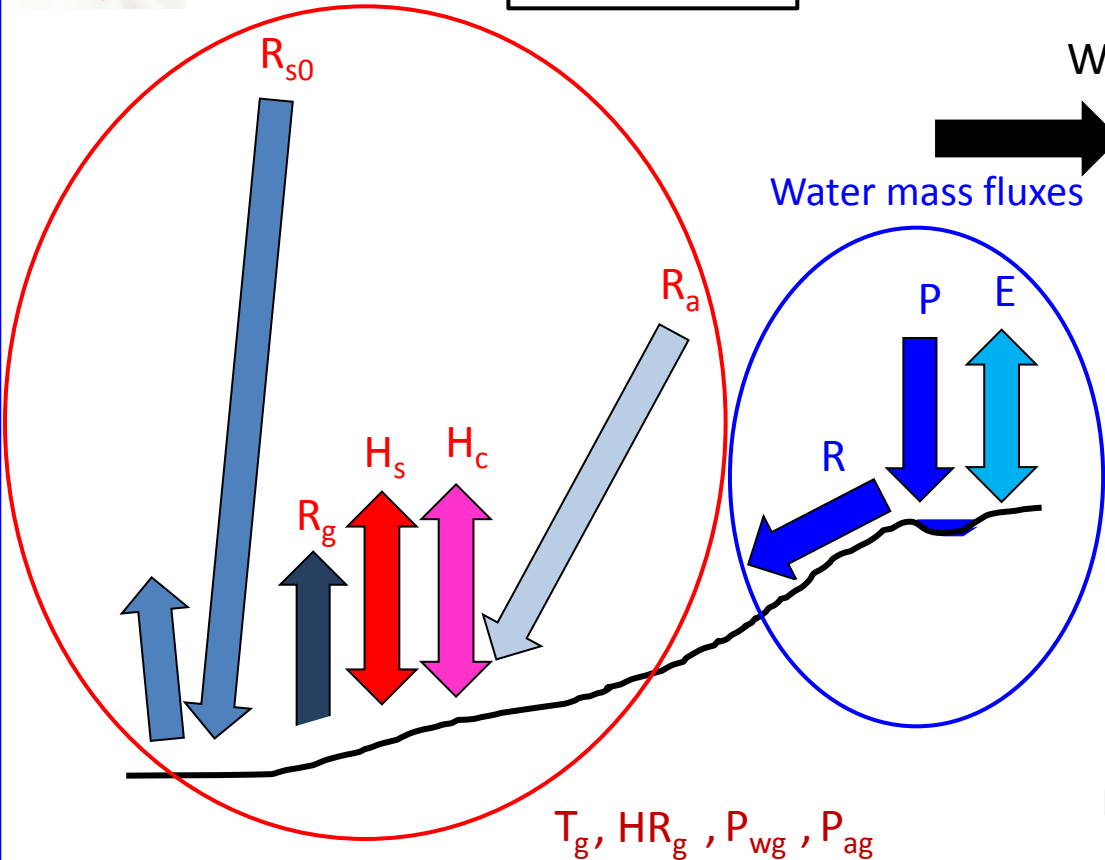
PROCESSES ARE COUPLED AND FORM COMPLEX, TURBULENT AND INSTABLE SYSTEMS

# STATE VARIABLES AND FLUXES ACROSS GROUND SURFACE



Thermal fluxes

$$T_a, HR_a, P_{aa}$$



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

Atmosphere:  $R_a = \varepsilon_a \sigma T_a^4, \varepsilon_a = f(HR_a, T_a, p_a) \leftarrow \text{Atmosphere emissivity}$

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

:

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

#### ✓ Sensible heat

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

#### ✓ Heat convected by mass fluxes

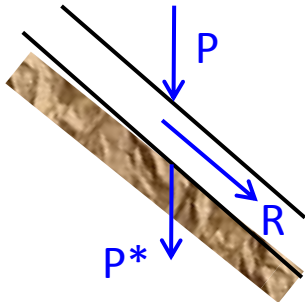
$$H_c = e_w (P^* - R) + e_v (E + j_g^w) + e_a q_a^a \quad e_v = e_{v0} + C_v (T - T_0)$$

# 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

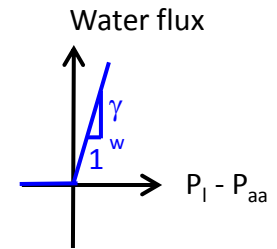


Runoff: modelled by mean of a continuum layer with porosity 1

Precipitation and ponding:

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

← Leakage coefficient



### ✓ Evaporation

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

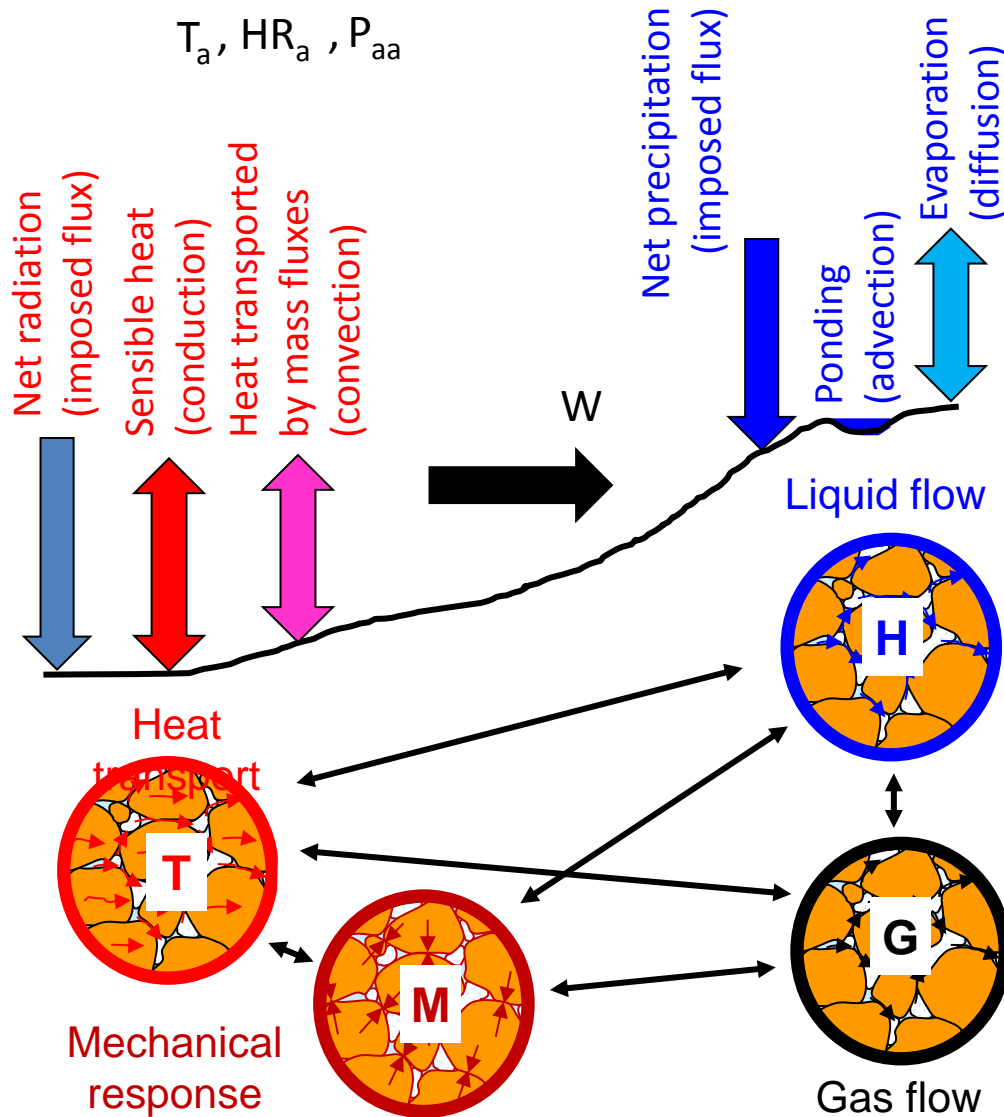
← Aerodynamic resistance of ground/atmosphere interface

### ✓ Vapour convected by gas flow

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

# COUPLED THERMO-HYDRO (PNEUMO)-MECHANICAL PHENOMENA

$T_a, HR_a, P_{aa}$



## ☐ THERMAL PROCESS

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

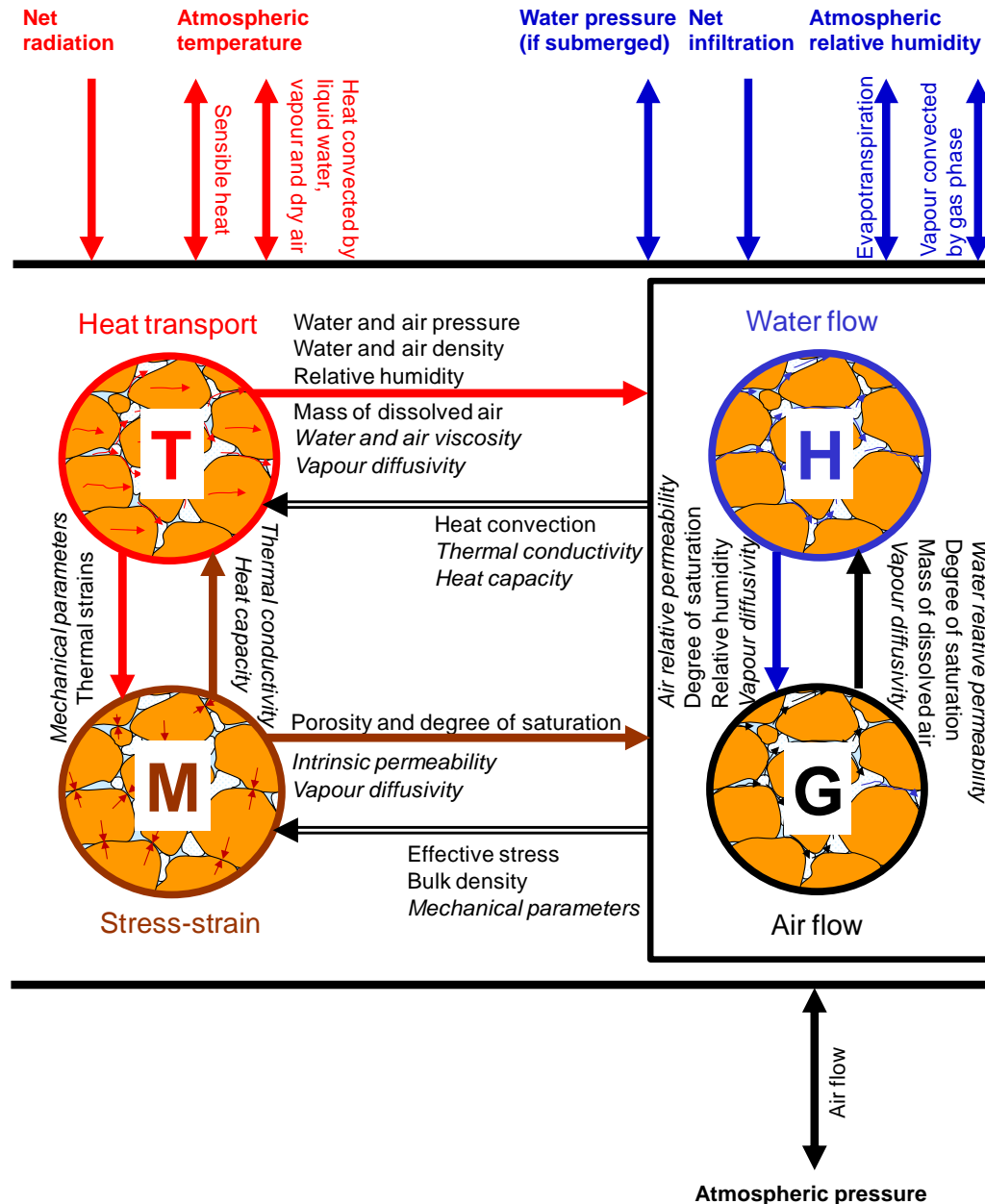
## ☐ HYDRAULIC (PNEUMATIC) PROCESS

- ✓ 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

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

## MASS BALANCE OF WATER

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

## MASS BALANCE OF AIR

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

## INTERNAL ENERGY BALANCE FOR THE MEDIUM

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

## MOMENTUM BALANCE FOR THE MEDIUM

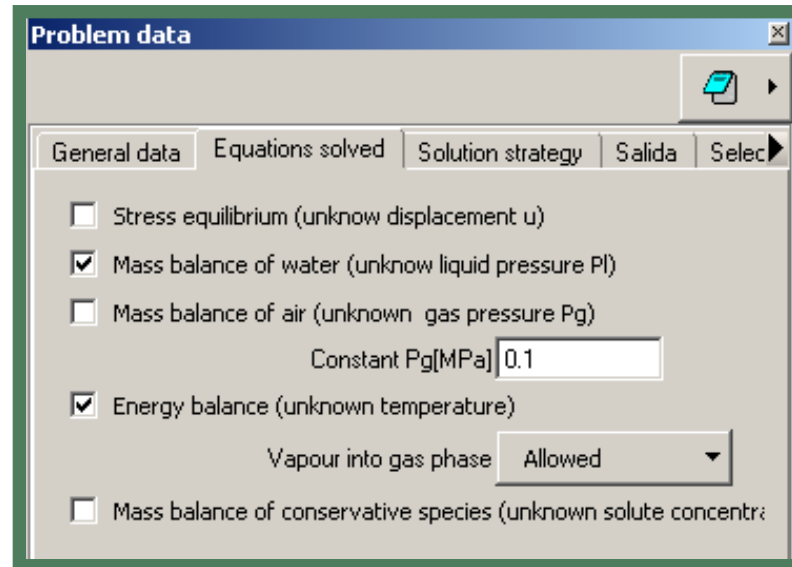
$$\nabla \cdot \boldsymbol{\sigma} + \mathbf{b} = \mathbf{0}$$

# 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	$q_l = -\frac{K_l K_{rl}}{\mu_l} (\nabla p_l + \rho_l \nabla z)$	$\bar{q}_l = \bar{q}_{l0} + \bar{\gamma}_l (p_l - \bar{p}_{l0})$
Gas phase (volume)	Generalized Darcy's law	$q_g = -\frac{K_l K_{rg}}{\mu_a} (\nabla p_g + \rho_g \nabla z)$	$\bar{q}_g = \bar{q}_{g0} + \bar{\gamma}_g (p_g - \bar{p}_{g0})$
Liquid water (mass)	Convection by liquid phase	$q_w = \rho_l \omega_l q_l$ ( $\omega_l = 1$ )	$\bar{q}_w = \bar{\rho}_{l0} \bar{q}_l$ if $\bar{q}_l$ inflow $\bar{q}_w = \rho_l \bar{q}_l$ if $\bar{q}_l$ outflow
Vapour (mass)	Convection by gas phase +	$q_v = \rho_g \omega_v q_g$	$\bar{q}_v = \bar{\rho}_{g0} \bar{\omega}_{v0} \bar{q}_g$ if $\bar{q}_g$ inflow $\bar{q}_v = \rho_g \omega_v \bar{q}_g$ if $\bar{q}_g$ outflow
	Diffusion in gas phase	$i_v = -\rho_g D_v \nabla \omega_g$	$\bar{i}_v = \bar{\beta}_v (\rho_g \omega_v - \bar{\rho}_{g0} \bar{\omega}_{v0})$
Dry air (mass)	Convection by gas phase +	$q_a = \rho_g \omega_a q_g$ ( $\omega_a = 1 - \omega_v$ )	$\bar{q}_a = \bar{\rho}_{g0} \bar{\omega}_{a0} \bar{q}_g$ if $\bar{q}_g$ inflow $\bar{q}_a = \rho_g \omega_a \bar{q}_g$ if $\bar{q}_g$ outflow
	Diffusion in gas phase	$i_a = -\rho_g D_a \nabla \omega_a$	$\bar{i}_a = \bar{\beta}_g (\rho_g \omega_a - \bar{\rho}_{g0} \bar{\omega}_{a0})$
Dissolved air (mass)	Convection by liquid phase +	$q_{da} = \rho_l \omega_{da} q_l$	$\bar{q}_{da} = \bar{\rho}_{l0} \bar{\omega}_{da0} \bar{q}_l$ if $\bar{q}_l$ inflow $\bar{q}_{da} = \rho_l \omega_{da} \bar{q}_l$ if $\bar{q}_l$ outflow
	Diffusion in liquid phase	$i_{da} = -\rho_l D_{da} \nabla \omega_{da}$	$\bar{i}_{da} = \bar{\beta}_l (\rho_l \omega_{da} - \bar{\rho}_{l0} \bar{\omega}_{da0})$
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 +	$j_{ev} = \omega_v \rho_g q_g (C_v T + e_{v0})$	$\bar{j}_{ev} = \bar{\omega}_{v0} \bar{\rho}_{g0} \bar{q}_g (C_v \bar{T}_0 + e_{v0})$ if $\bar{q}_g$ inflow $\bar{j}_{ev} = \omega_v \rho_g \bar{q}_g (C_v T + e_{v0})$ if $\bar{q}_g$ outflow
	Conduction	$i_c = -\lambda \nabla T$	$\bar{i}_c = \bar{q}_{T0} + \bar{\gamma}_T (T - \bar{T}_0)$

# 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,

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



Condicion

Flux B.C.

Flow rate	Boundary flow rate
Prescribed vapor mass fraction [kg/kg]	7.265e-3
Prescribed gas flow [kg/s]	0.0
Prescribed gas flow increment [kg/s]	0.0
Prescribed gas pressure [MPa]	0.1
Prescribed gas pressure increment [MPa]	0.0
Gamma for gas	0.0
Beta for gas	0.0008583366
Prescribed gas density [kg/m3]	1.2
Prescribed solute mass fraction [kg/kg]	0.0
Prescribed air mass fraction [kg/kg]	0.0
Prescribed liquid flow [kg/s]	1.34e-5
Prescribed liquid flow increment [kg/s]	0.0
Prescribed liquid pressure [MPa]	0.1
Prescribed liquid pressure increment [MPa]	0.0
Gamma for liquid	-1e6
Beta for liquid	0.0
Prescribed liquid density [kg/m3]	0.0
Prescribed heat flow [J/s]	100
Prescribed heat flow increment [J/s]	0.0
Prescribed temperature [°C]	10
Prescribed temperature increment [°C]	0.0
Gamma for heat	1.034804844
Decay of prescrib heat flow [1/s]	0.0
Smoothing parameter	0.0

# PRACTICAL INTRODUCTION OF DATA

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



The screenshot shows a software window titled 'Condiciones'. At the top, there is a dropdown menu set to 'Flux B.C.' and a 'Flow rate' dropdown set to 'Atmospheric'. Below this is a list of parameters with their corresponding values in input fields:

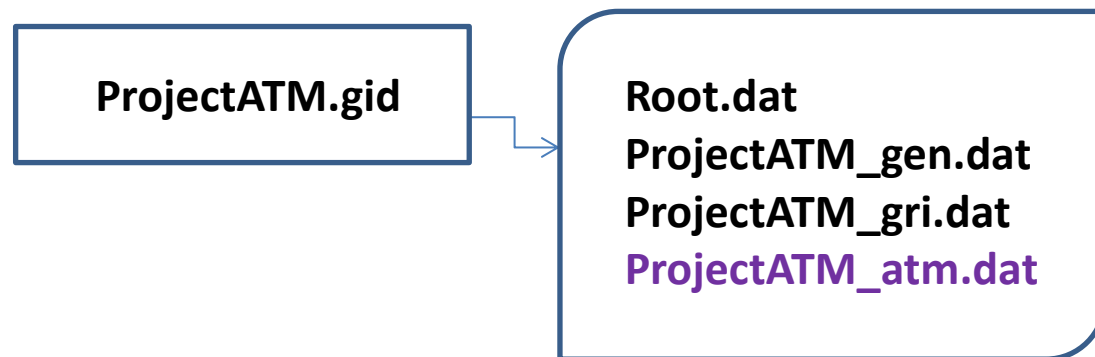
Parameter	Value
Latitud [rad]	0.7571
Time when autumn [s]	0.0
Time at noon [s]	0.0
Height main roughness [m]	0.02
Screen height [m]	1.5
Stability factor [kg/m3]	1.0
Density atm gas [kg/m3]	1.2
Dry albedo [-]	0.2
Wet albedo [-]	0.2
Gamma for gas [kg/m2/s/MPa]	1e6
Gamma for liquid [kg/m2/s/MPa]	-1e6
Rain factor [-]	1.0
Radiation factor [-]	1.0
Evaporation factor [-]	1.0
Radiation type	3.0

At the bottom of the window, there are buttons for 'Asignar', 'Entidades', 'Dibujar', 'Desasignar', and 'Cerrar'.

# 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	<b>1</b>	0	<b>1</b>	0	<b>1</b>	0	<b>1</b>	0	<b>1</b>	0	<b>1</b>	0	<b>1</b>	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...	...	...	...	...	...	...	...	...	...	...	...	...	...	...



# CONCLUDING REMARKS

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- ✓ **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 Tresp area (run-off, validation in course)**