Modeling the hydraulic transfers inside the soil-plant-atmosphere continuum in ORCHIDEE

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1. Context and aim of the study

Context of the study

Work started from ORCHIDEE_trunk (version from May 2020) with N. Vuichard and A. Tuzet.

→Two ways to model transpiration:

- → Historical model based on « humrel »
- → First hydraulic architecture

Aim of our study:
Introduce the hydraulic architecture of Tuzet et al. (2017) in ORCHIDEE in order to better model transpiration (and have a more process-based model).

→ Completely new model introduced in the hydrol module.

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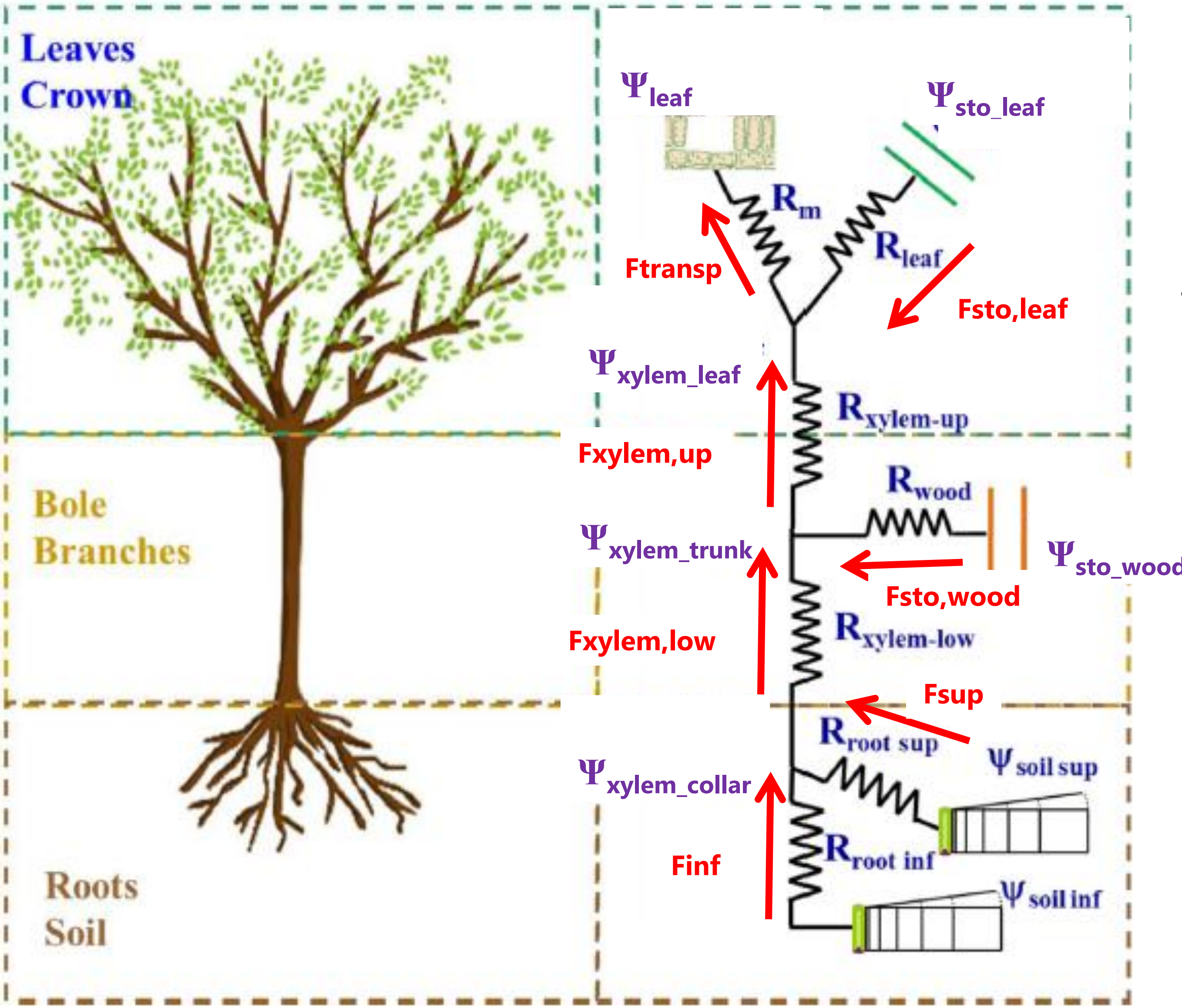
2. General principle of the model

Overall scheme



→ Scheme based on the calculation of the water potential all along the circuit.

→ Fluxes are calculated first and potentials at the end.

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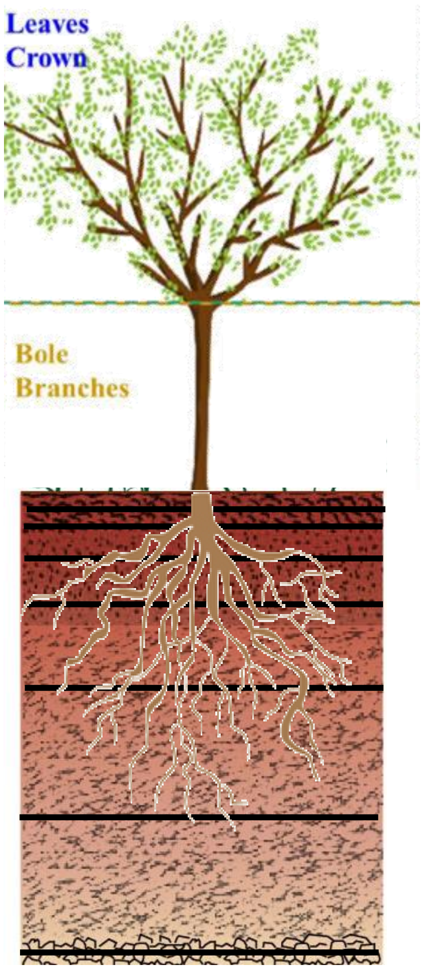
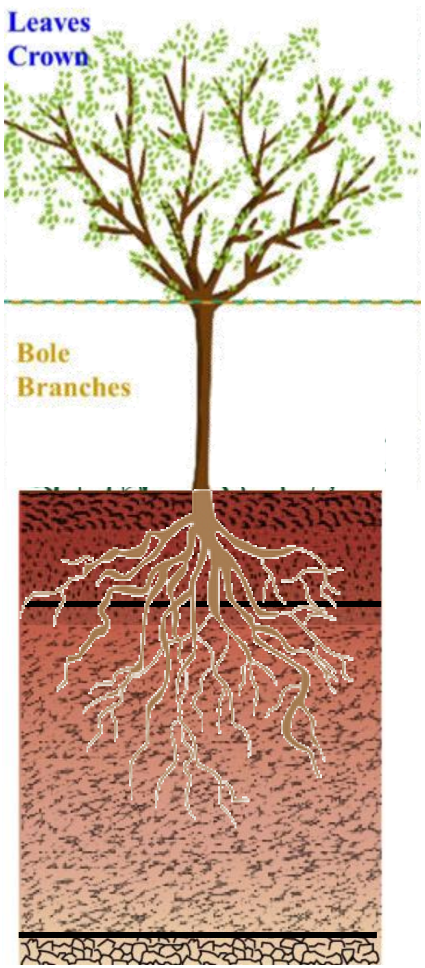
3. Model details

Root absorption



ORCHIDEE



Passage to 2 soil horizons

Soil is divided into two soil layers (0.5m and 1.5m)

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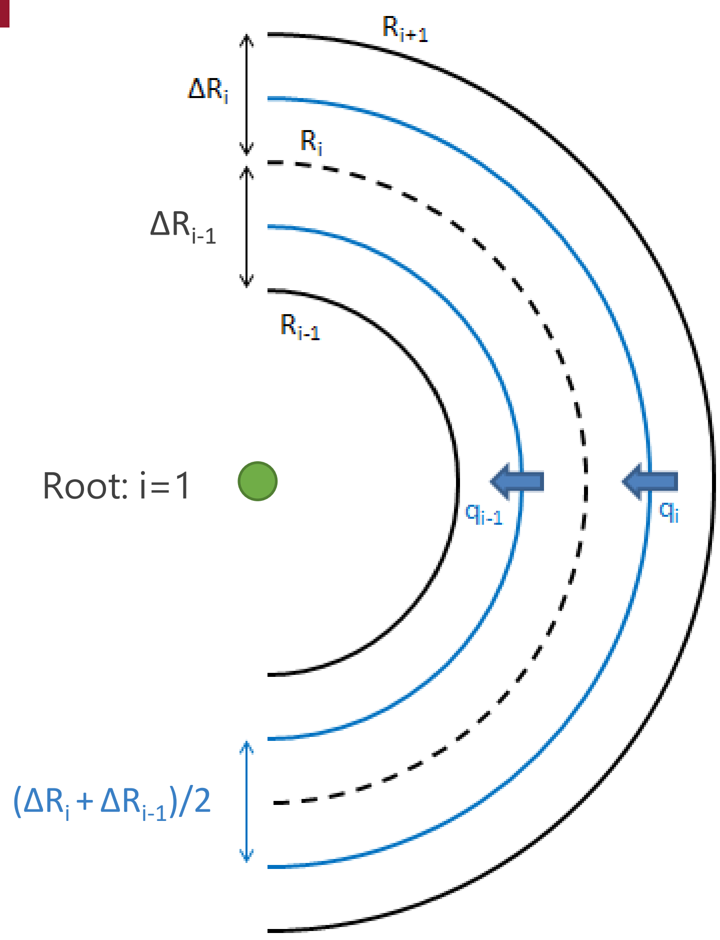
Root absorption



Diffusion equation:

$$\frac{\partial \theta}{\partial t} = \frac{1}{r}\frac{\partial}{\partial r}(rD(\theta)\frac{\partial \theta}{\partial r})$$

(θ : soil water content)

- Semi implicit resolution scheme
- Discretization of the equation and solving of the corresponding tridiagonal system

→ Same resolution as Patricia de Rosnay's thesis, but, in cylindrical coordinates

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Transport through the vegetation

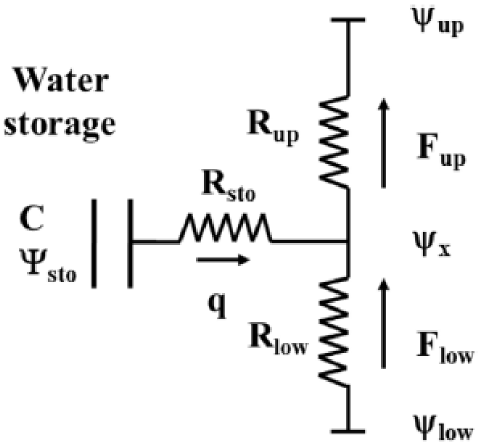
Resistances

Hydraulic resistances are parameterized thanks to Tuzet et al. (2017) model.

$$\Psi_x = \Psi_{low} - F_{low} . R_{low}$$

→ Fixed values
→ Possible to introduce dynamic resistances: need to discuss about it

Water storage



Capacitance values depend on the amount of water inside the storage (and then storage water potential).

$$C = \frac{dV}{d\psi} = \lambda \frac{(AV_{max} - V_r(A-1)) - V}{A}\left(\frac{V - V_r}{V_{max} - V_r}\right) \quad with \quad A = 1 + \exp(\lambda\psi_0)$$

$$\frac{V - V_r}{V_{max} - V_r} = \frac{1 + \exp(\lambda\psi_0)}{1 + \exp(\lambda(-\psi + \psi_0))}$$

Water potential answers to the following differential equation:

$$\frac{d\psi_{sto}}{dt} + \frac{1}{C(R_{low} + R_{sto})}\psi_{sto} - \frac{1}{C(R_{low} + R_{sto})}\left(\psi_{low} - R_{low}F_{up}\right) = 0$$

Tuzet et al. (2017)

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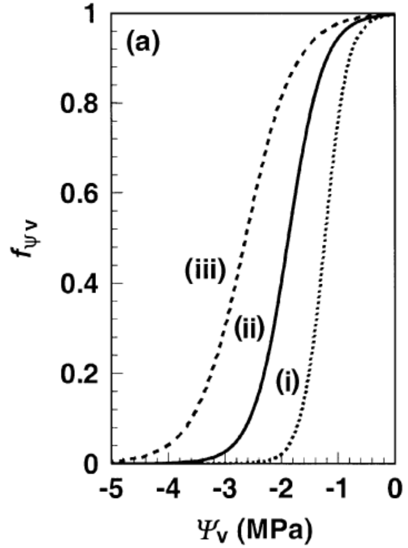
Stomatal conductance

In Tuzet et al. (2017): Stomatal conductance directly linked to the leaf water potential thanks to a sigmoidal function.

$$g_{CO_2} = g_0 + \frac{aA}{c_i - c_{i*}} f_{\Psi_{leaf}}$$

$$f_{\Psi_{leaf}} = \frac{1 + \exp(s_f . \Psi_{ref})}{1 + \exp(s_f . (\Psi_{ref} - \Psi_{leaf}))}$$



In the new model: Exactly the same function except that g0 is multiplied by the function. Without multiplication, too strong transpiration over Hesse in dry periods.

→Was done in ORCHIDEE before

→ Needs to be discussed: too strong g0?

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4. Mathematical choices

Mathematical choices

The scheme needs to be implicit, whereas: instability when soil is stressed.

In the previous version: correction scheme when the soil is stressed. Which leads to iterations in the multi-layer energy budget.

→**We want to avoid iterations**

For differential equations (ex: storage potentials)

Estimation of the values at t+1 thanks to a predictor corrector scheme (Runge-Kutta 2 or Adams-Moulton order 3)

For non-differential equations (ex: stomatal conductance)

Estimation of the new value thanks to an empirical method:

- Lagrange polynomials → necessitate to store a lot of previous time steps
- Mean of the two previous time steps : currently used, good results
- Custom function : harder to find, I have a few leads

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5. Technical implementation

Technical implementation

Completely replace the previous hydraulic architecture

Controls:

- ok_hydrol_arch: activates the scheme or not
- ok_muff: activates the muff absorption scheme (if not: classical Bonan dynamic resistance)
- ok_storage: activates the storage or not
- (ok_dyn_resist: if implemented, activates the dynamic water resistances)

New functions:

Everything is implemented in hydrol.f90

- Subroutine hydraulic_arch_calc
- If ok_muff= FALSE :
    - Subroutine hydraulic_arch_resist
- If ok_muff= TRUE :
    - Subroutine hydraulic_arch_muff
    - Subroutine muff_radial_coef_setup
    - Subroutine muff_radial_resolution

Saved variables:

- Classic scheme: around 6 variables added
- Muff scheme: around 5 more variables
- Storage scheme: around 5 more variables
- Dynamic resistances (for now): 5 more variables

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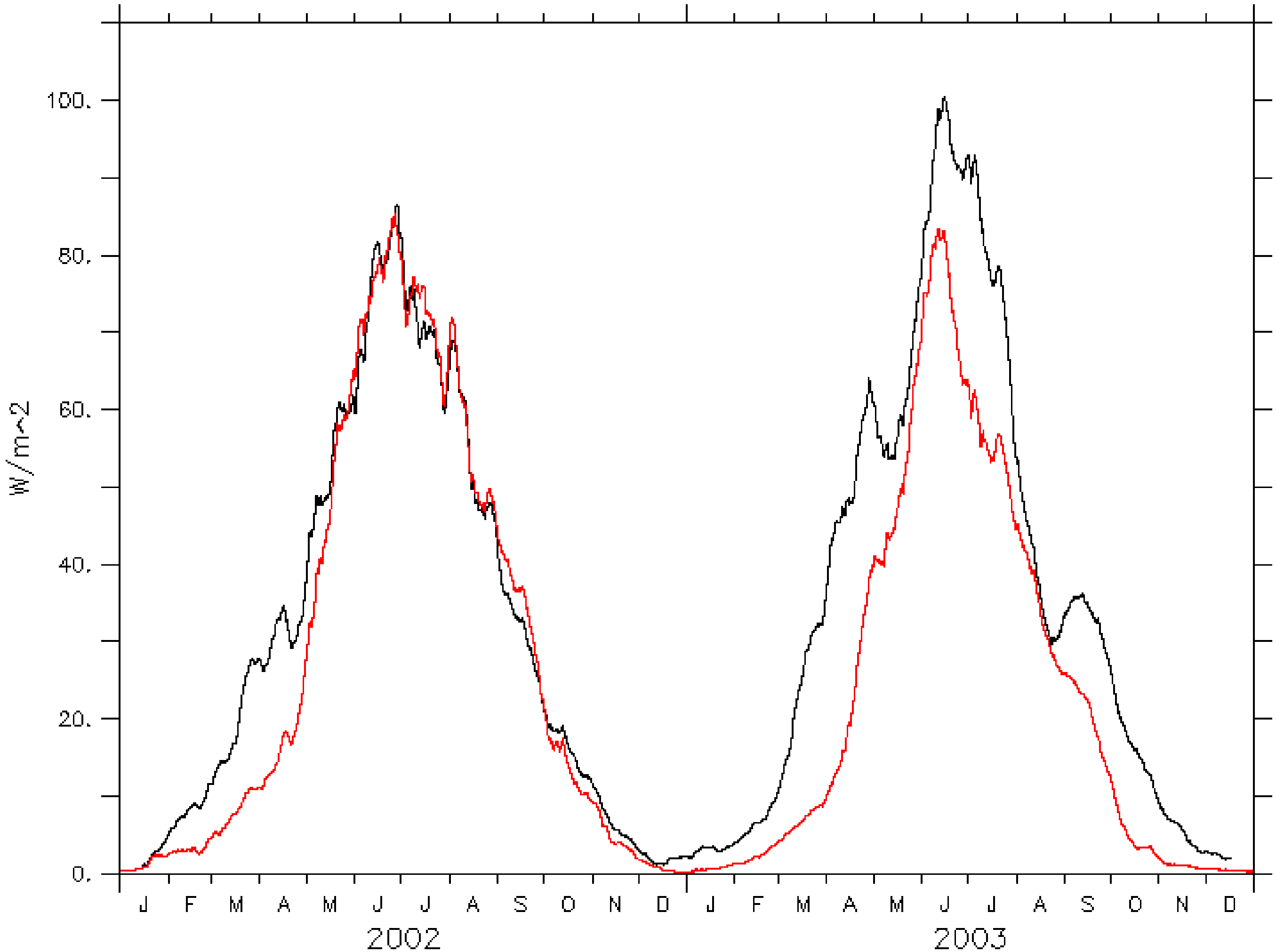
6. Results

Hesse – Latent heat flux



Model a bit adapted to match the on-site values:
- g0 limitation by f_vpd
- Different soil properties for above and below ground (following Tuzet et al. (2017))

(Results can be even better if water cannot be absorbed by the last soil layer)

Observations (Hesse Forest, Nancy, PFT6)
Model

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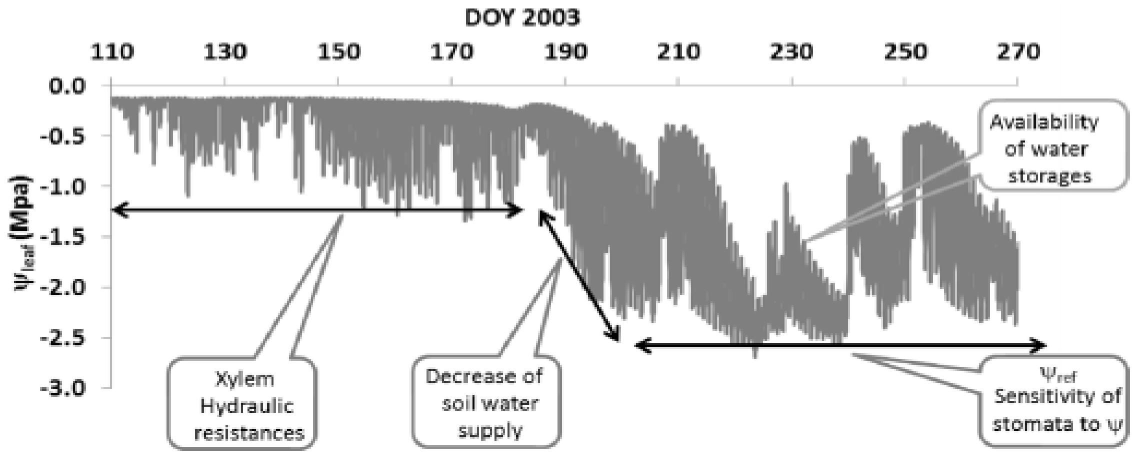
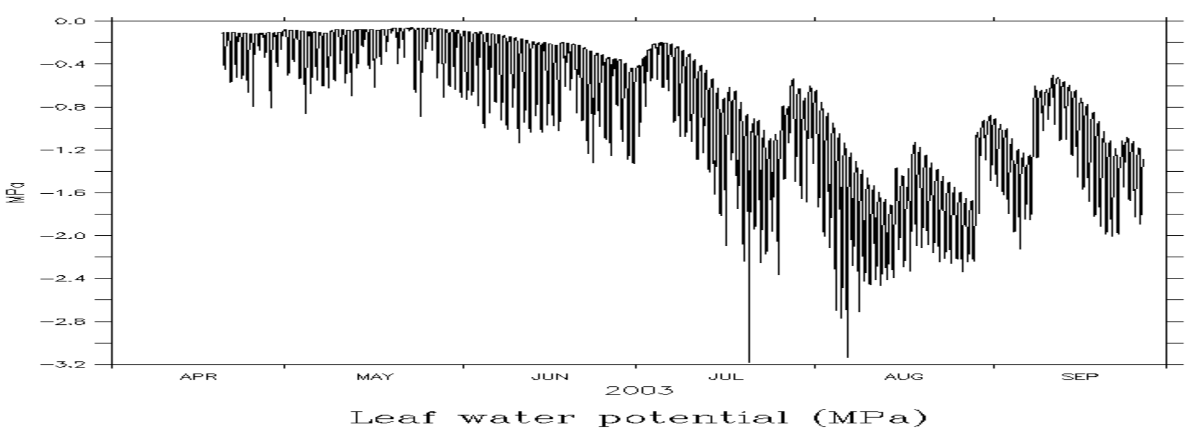
Hesse – Leaf water potential

Tuzet et al. (2017)



Model

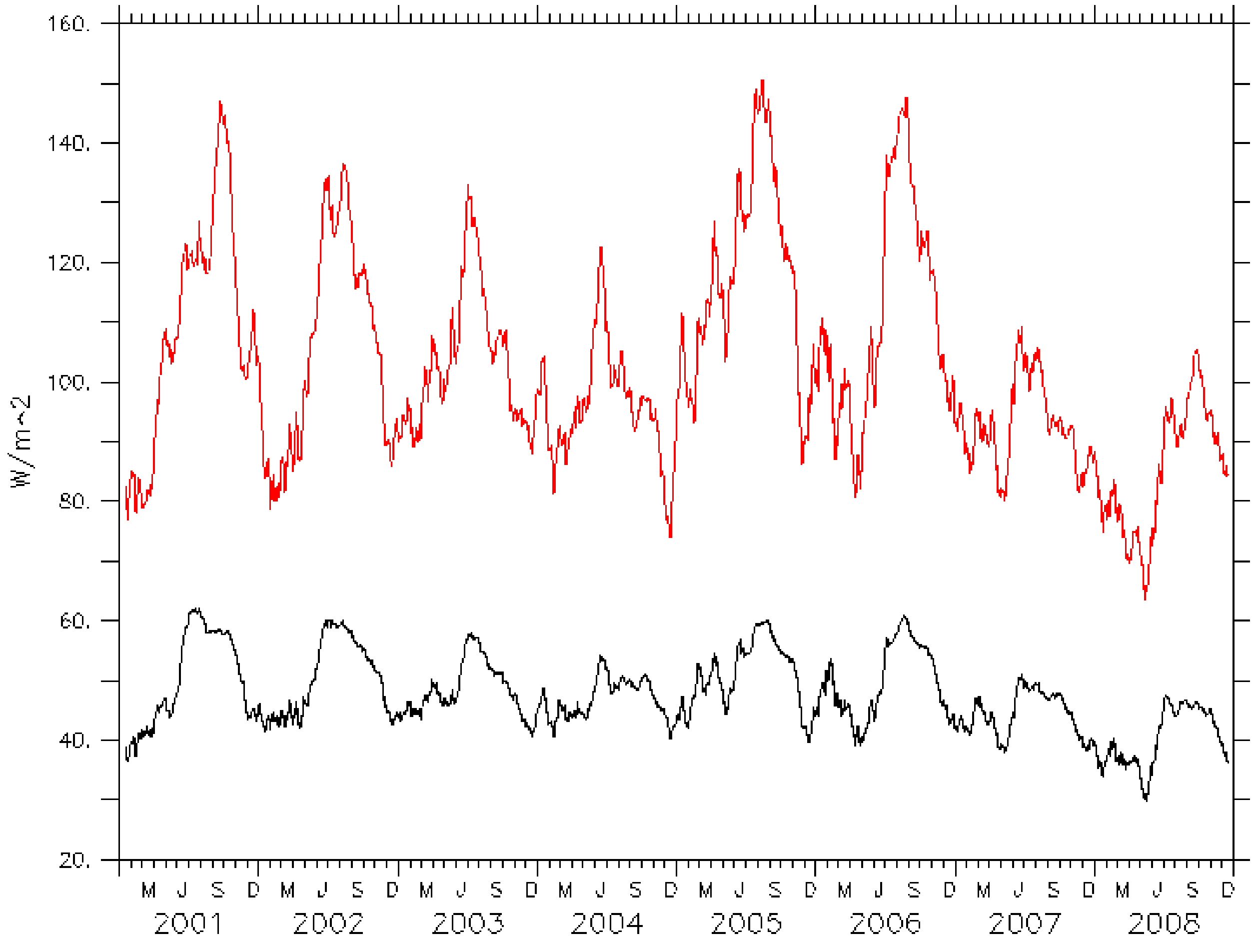


Period of simulation:

20/04/2003 – 27/09/2003

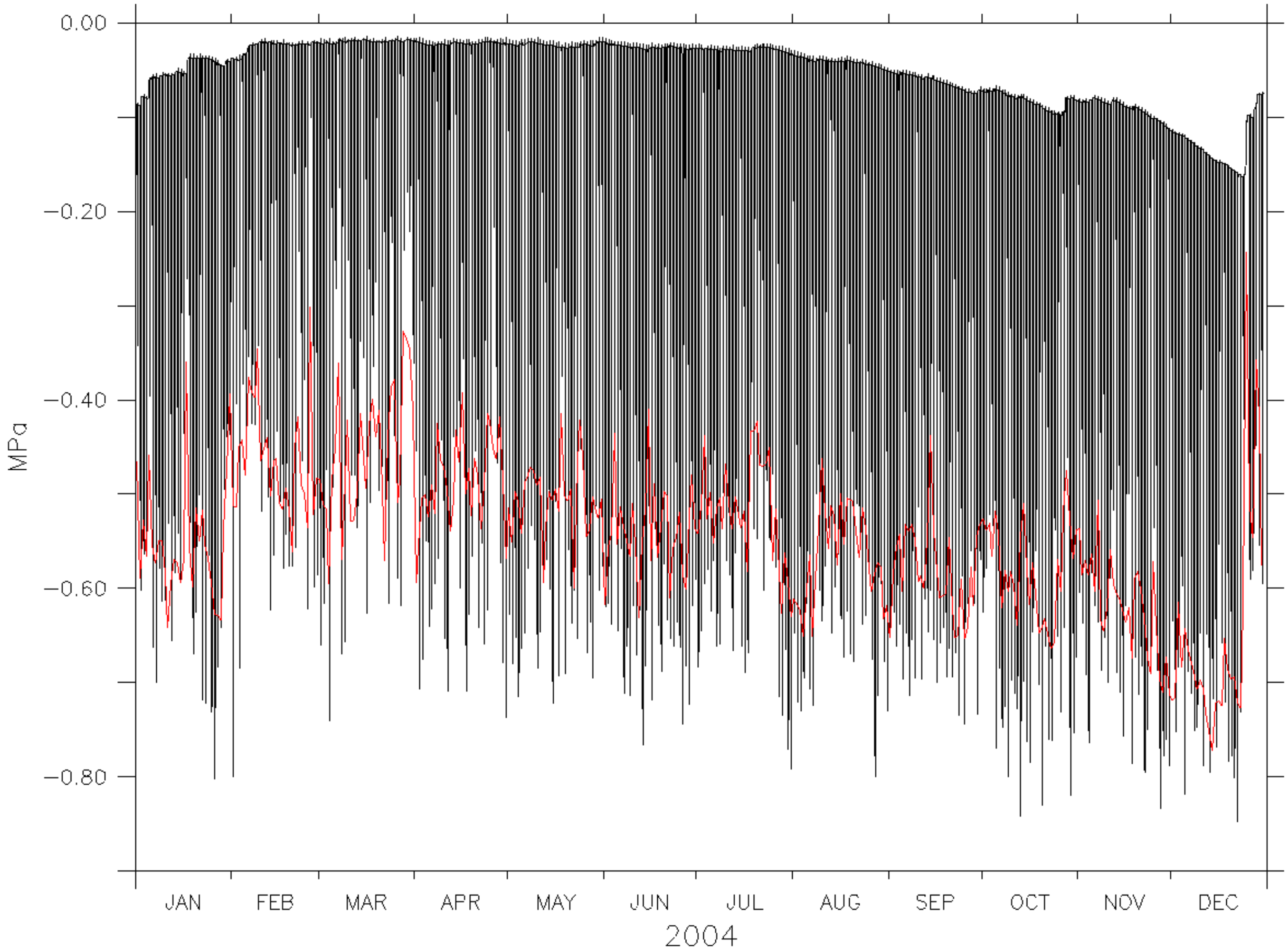
Summer 2003 (drought in France)

Caxiuana – Latent heat flux CTL



Yitong's model
My model

Caxiuana – Leaf water potential (2004)



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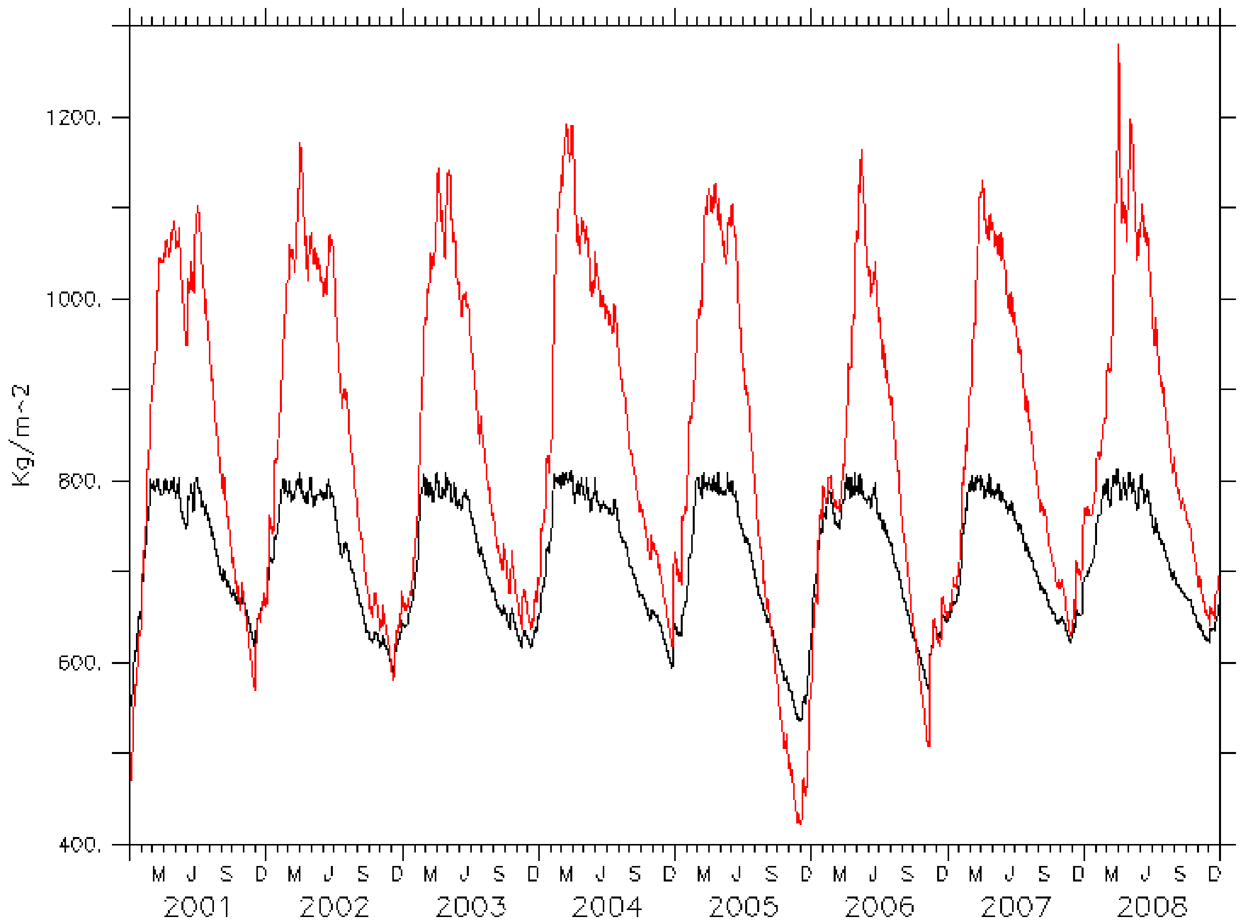

Yitong's model
My model

Thanks for your attention.
Questions ?

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