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81. Green roof set-up analysis: Monitoring and simulation of water and thermal transfer using HYDRUS-1D



Ryad BOUZOUIDJA^{1,2*}, Maeva SABRE³⁺, David RAMIER⁴, Patrice CANNAVO¹, Rémy CLAVERIE⁵

¹EPH, AGROCAMPUS OUEST, IRSTV, 49042, Angers, France

²Université de Nantes, UMR 6112 LPG-Nantes (Laboratoire de Planétologie et Géodynamique de Nantes)

³CAPE, Centre Scientifique et Technique du Bâtiment, Nantes, France

⁴Cerema Dter IdF, Trappes, France

⁵CEREMA Dter Est, Tomblaine, France

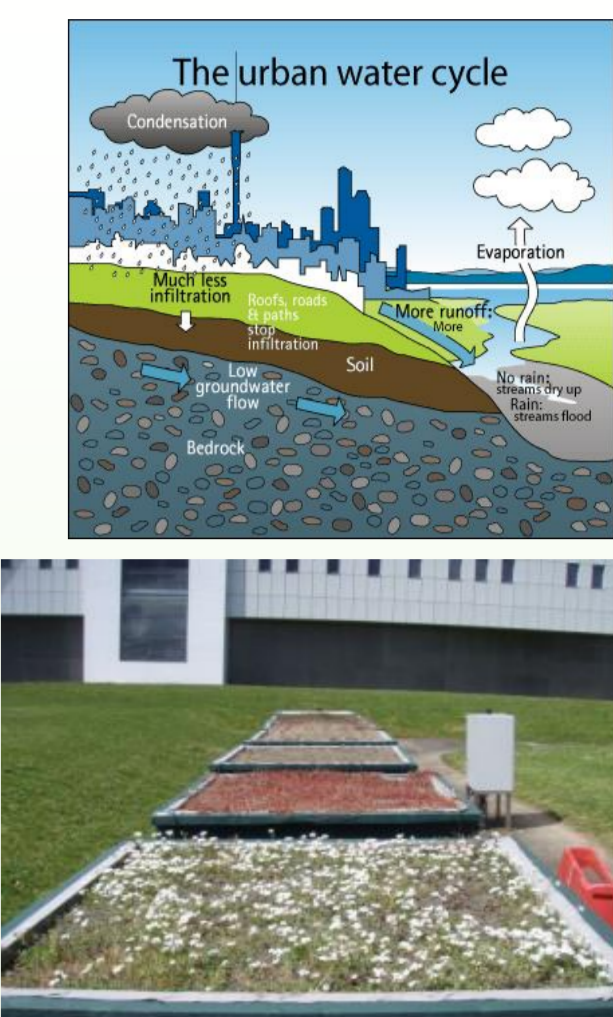
INTRODUCTION

Urbanization = sealed surfaces poorly covered by vegetation → **Increasing water runoff 55% in urban area vs 10% in natural area. Urban Heat Island (UHI) = Man's modification** of the atmospheric environment → the temperature increase may reach up to **10°C. Green roofs (GR) = part of the solution for urban water and thermal management** because they can:

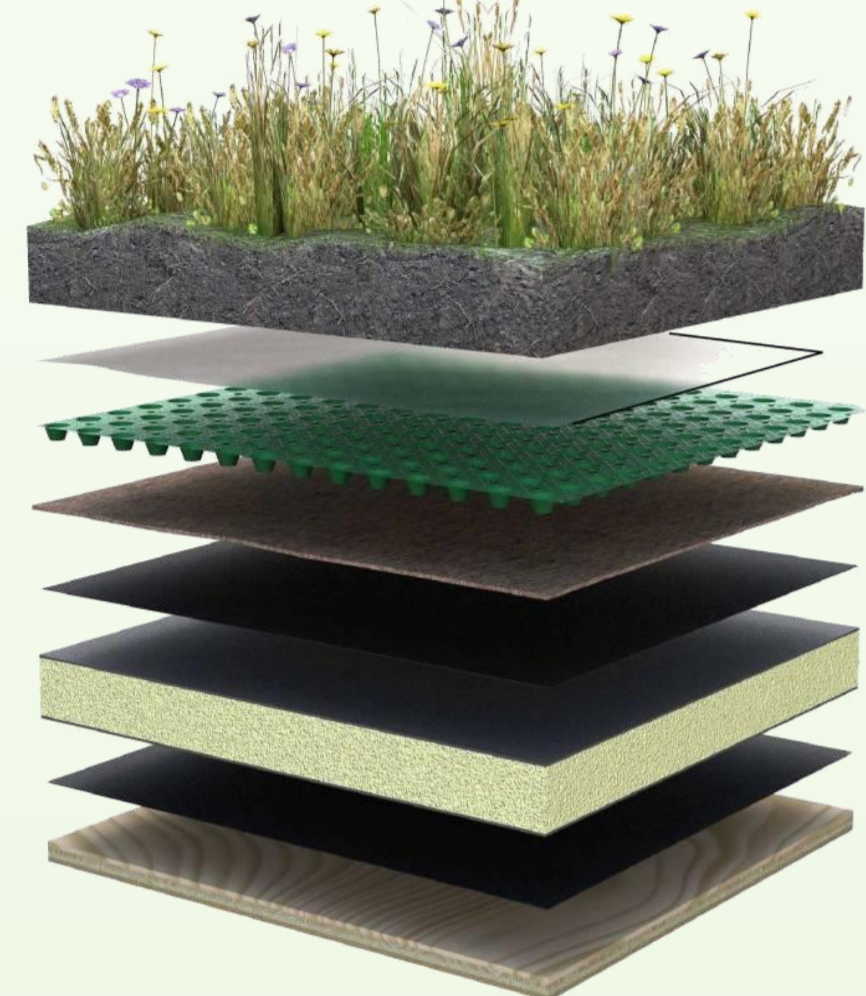
- **Store and release water with a delay.** Storage capacity = 40 to 80% of the total annual rainfall volume depending on the substrates properties (*i.e.* thickness, characteristics and proportion of its organic and mineral components) but also on type of plants and vegetation (*Bengtsson et al., 2005*).
- **Reduce urban air temperatures by 1.4°C on average 3.2°C at best**, which may lead to a reduction in UHI amplitude (*Jaffal et al., 2012*).

But GR are also **living systems** that are submitted to a significant **evolution with time capability to retain water and refresh the climate.**

The **influence of GR aging on their thermal and hydrologic performances was yet poorly addressed.**

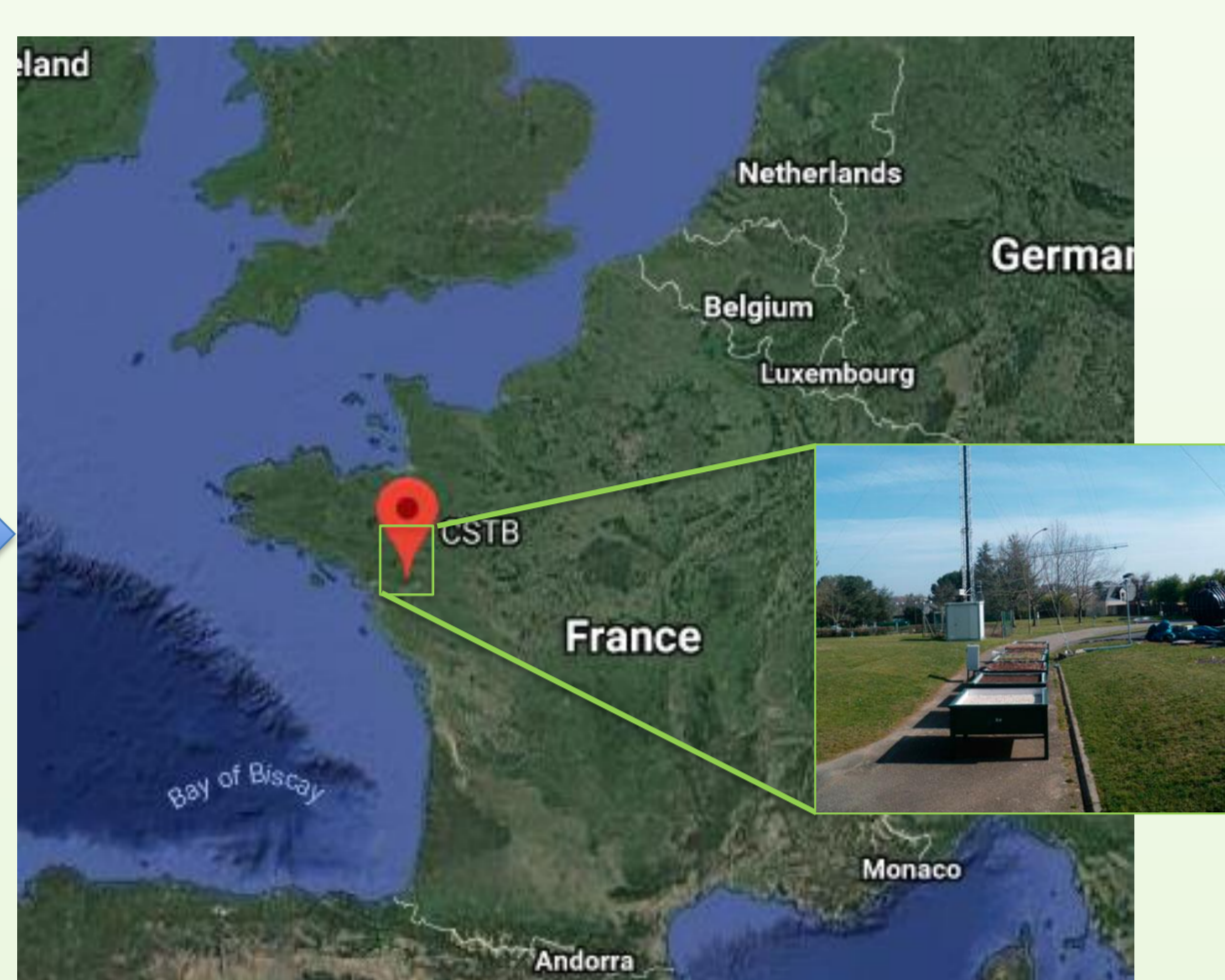


GREEN ROOF SOLUTION



IN SITU EXPERIMENTAL GR

7 x 2.3 M² OF EXPERIMENTAL PLOTS
Located in Nantes (47°15'17"N, 1°33'18.8"O) temperate oceanic climate Implemented in April 2011



Data used

- Soil moisture,
- Air and soil temperature,
- Relative humidity,
- Wind speed,
- Global radiation,
- Rainfall



RESOLUTION

The soil water content θ is modeled using the van Genuchten-Mualem (VGM) model (simple porosity model) (*Mualem, 1976; van Genuchten, 1980*)

$$\theta(h) = \begin{cases} \theta_r + \frac{\theta_s - \theta_r}{[1 + |\alpha h|^n]^m}, & h < 0 \\ \theta_s & h \geq 0 \end{cases}$$

Upper boundary condition: Met. Data
Lower boundary condition: (drainage condition)

EVALUATION OF GR PERFORMANCES

HYDRUS-1D

In this study the HYDRUS-1D model is used to simulate the thermal behavior and water movement in the GR. The model is capable of simulating the water movement in unsaturated, partly saturated or fully saturated porous media (*Simunek et al., 2008*).

$$\frac{\partial \theta(h)}{\partial t} = \frac{\partial}{\partial z} \left[K(h) \left\{ \frac{\partial h}{\partial z} + 1 \right\} \right] \pm S$$

$$C_p(\theta) \frac{\partial T}{\partial t} = \frac{\partial}{\partial x} \left[\lambda(\theta) \frac{\partial T}{\partial x} \right] - C_w q \frac{\partial T}{\partial x}$$

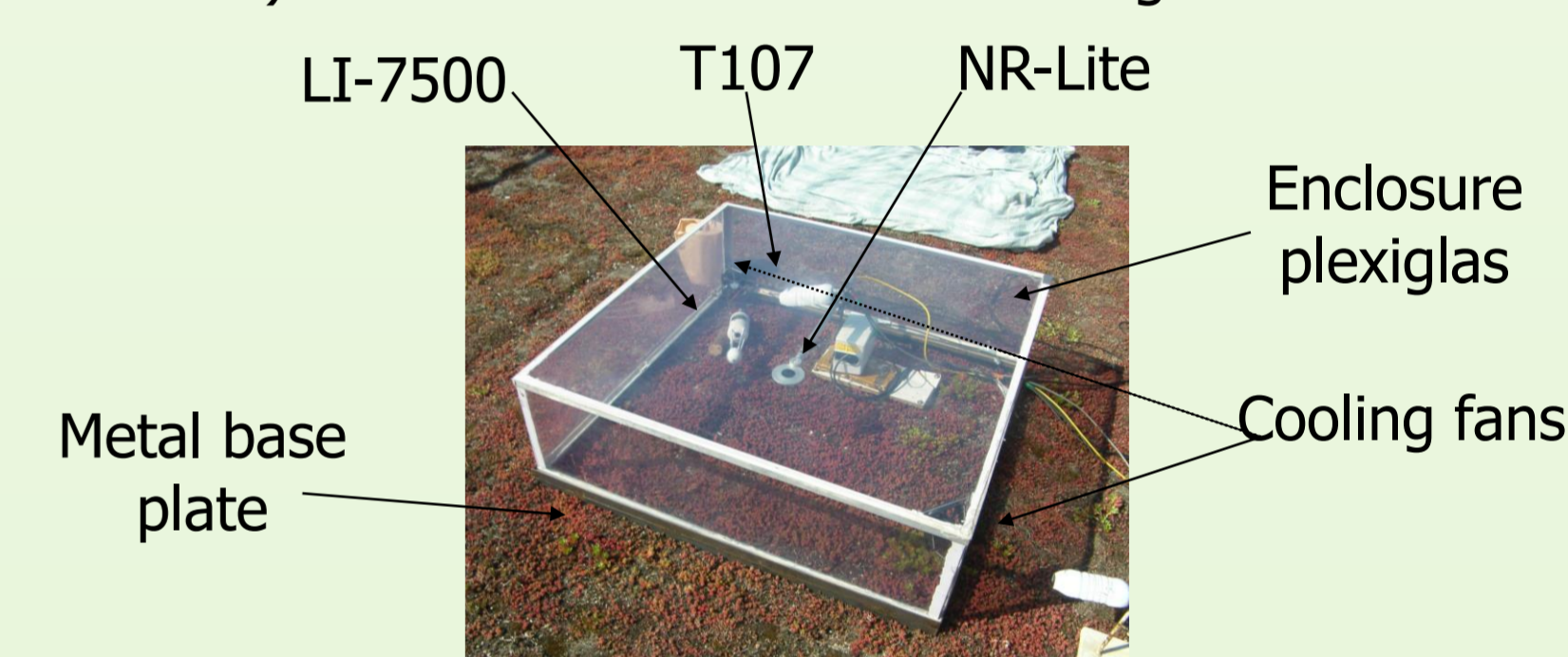
θ volumetric water content [m³ m⁻³]; h soil pressure head [m]; t time [hour]; z spatial coordinate [m]; positive downward; $K(h)$ unsaturated hydraulic conductivity [m h⁻¹]; S sink term, accounting for plant water; C_p and C_w volumetric heat capacity of the solid and liquid phases [J m⁻³ °C⁻¹]; T temperature [°C]; $\lambda(\theta)$ heat conductivity [W m⁻¹ °C⁻¹]; q total water flux density [m s⁻¹]; θ_s and θ_r saturated and residual water content [m³ m⁻³]; K_s saturated hydraulic conductivity [m h⁻¹]; α [m⁻¹], n [-] and m are adjustable parameters; ET evapotranspiration [mm]; R Rainfall [mm]; Q_{out} drainage outflow [mm].

WATER BALANCE (WB) AND EVAPOTRANSPIRATION (ET) CALCULATION

The water balance of GR can be written as below:

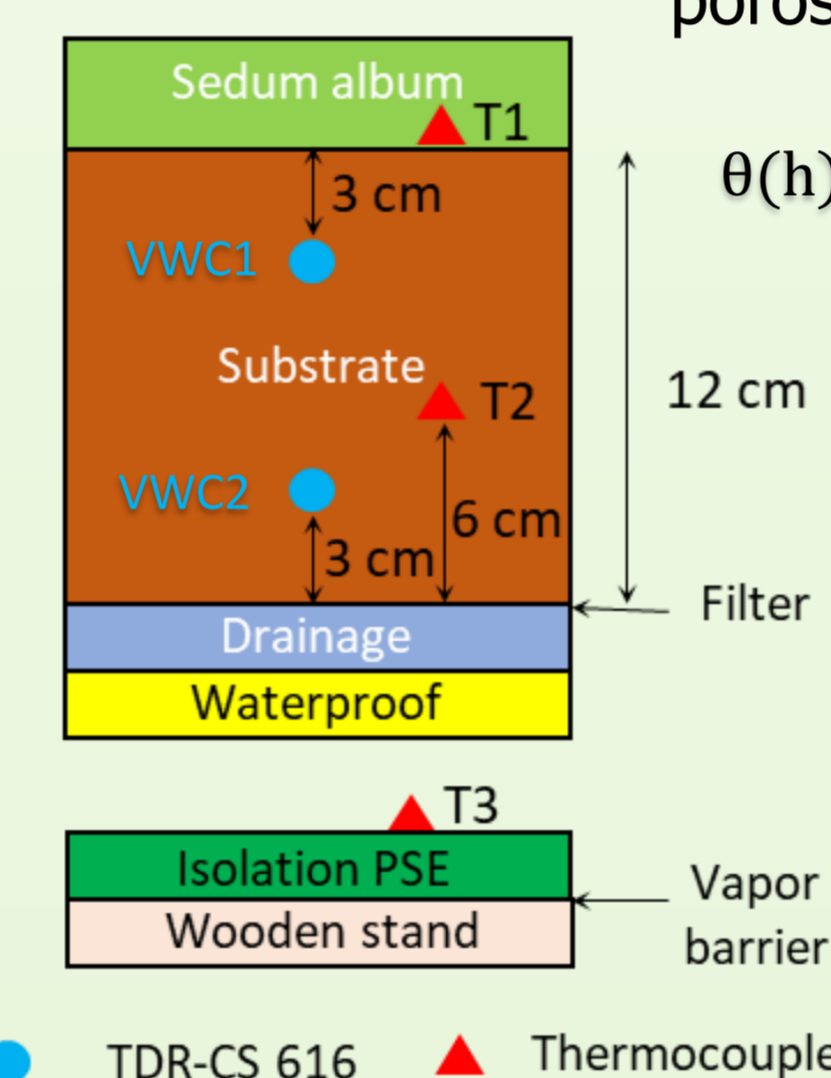
$$ET = R - Q_{out} \pm S$$

Measurement with a evapotranspiration chamber developed at Cerema (Figure below) with an area of 1 m² and a height of 30 cm:



BEHAVIOR ANALYSIS

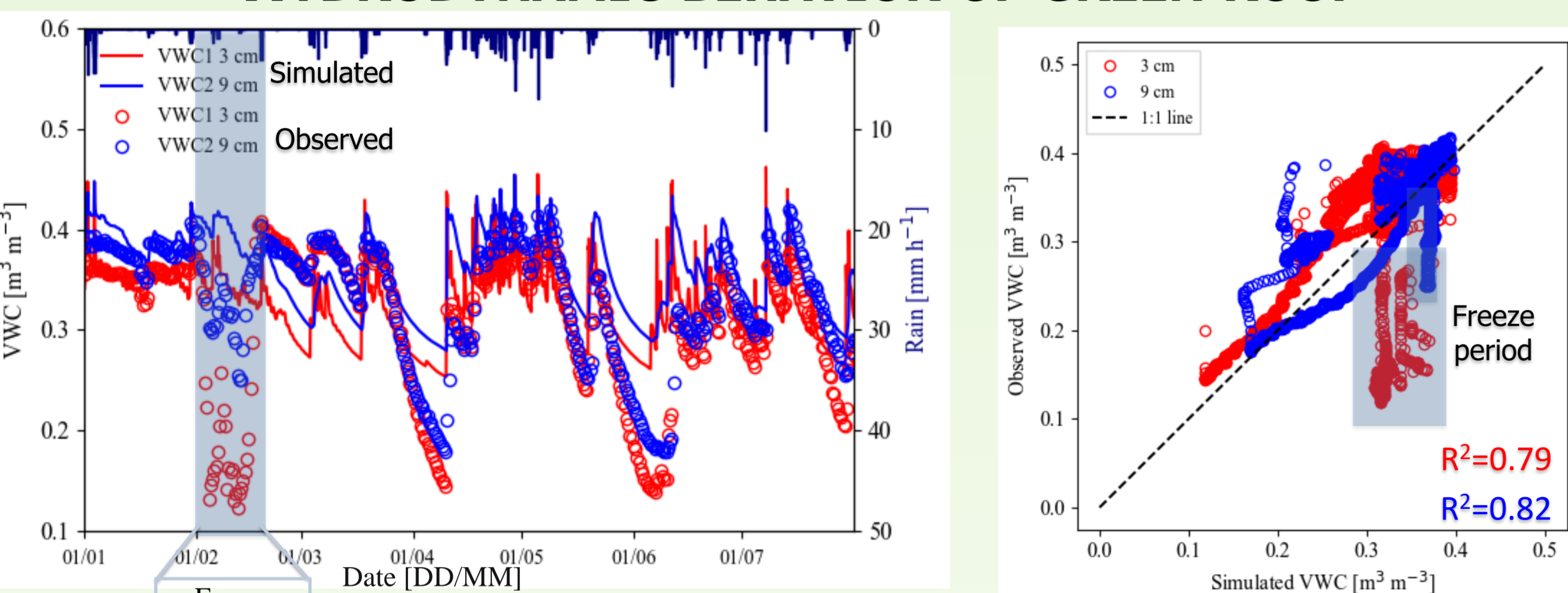
Comparison of GR water and thermal performances under different land covers: i) bare soil, ii) sedum album, iii) Festuca glauca and iv) Dianthus deltoides.



THE GR SYSTEM CAN:

- Reduce storm water runoff
- Provide additional roof insulation and extend the underlying membrane life
- Facilitate the implantation of vegetated roofs by homeowners
- Enhance heat island mitigation and carbon sequestration

HYDRODYNAMIC BEHAVIOR OF GREEN ROOF

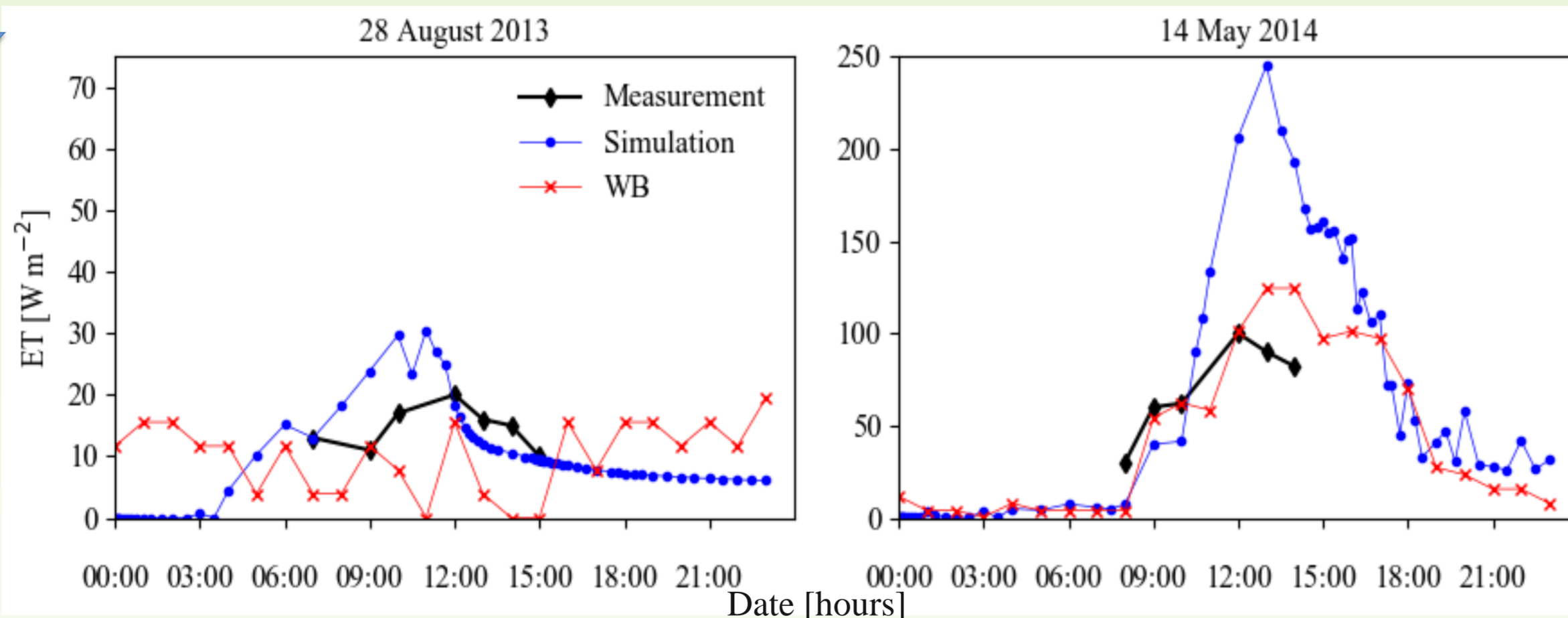


VARIATION OF HYDROLOGIC PERFORMANCES

- The corresponding simulated data (using HYDRUS-1D simulation tool) and measured hydrographs for 401 l m⁻² of cumulated rainfall (January to July 2012) show that the simulated soil water content value of the simulated water content is in quite good agreement with the experimental data
- The figure shows that the model correctly calculates the internal state of the substrate. The water content increases over time during rainfall, and decreases during dry periods.

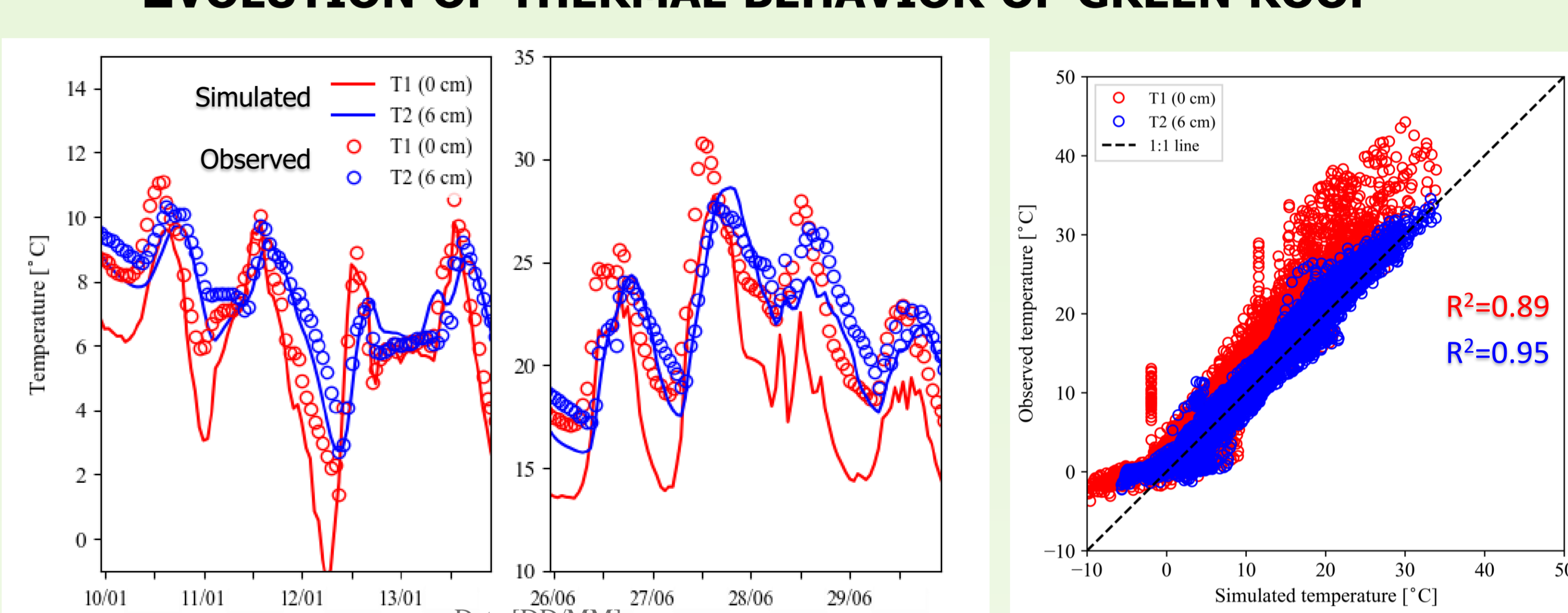
ET EVALUATION

The ET calculated as residual of the water balance shows the total ET of 0.4 mm in 24 hours. Measured ET for the same period is comparable to WB.



The ET simulated by Hydrus is overestimated and higher than the measured ET (Evapotranspiration chamber). It suggest that the water content should be simulated more accurately.

EVOLUTION OF THERMAL BEHAVIOR OF GREEN ROOF



INFLUENCE OF LAND SURFACE

- Regarding the variation of water content during time illustrates the variably temperature conditions inside the substrate. The model **slightly overestimates** (+6°C) the surface temperature and soil temperature at 6 cm depth (+0.5°C) during the warm period. During the cold period, the model underestimates the surface temperature during nighttime (-2°C) and perfectly simulates the temperature during daytime.
- It suggest that the presence of water and modification of land surface affect the temperature and should be calculated more accurately.



January 2012 March 2012 July 2012

SUMMARY

- We conduct observations and simulations of temperature and hydraulic behaviour of green roof in Nantes city, France.
- Our work provide a **better understanding** of the coupled **thermal and hydrological processes** in green roof technology.
- **Our simulations** showed that the **green roofs** has an **original behavior**: (i) **great variations** in hot and cold **thermal performance**, (ii) a strong impact of water inside GR opposite the thermal behavior and (iii) the daily variability of the ET is well observed. The measurement with the evapotranspiration chamber also makes it possible to apprehend the seasonal variability.
- Further simulation of actual evapotranspiration will be performed using Hydrus-1D, incorporating the impact of rock present in the soil using double porosity models.



*Contact: Ryad BOUZOUIDJA
ryad.bouzouidja@gmail.com



*Contact: Maeva SABRE
Maeva.sabre@cstb.fr



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