How do the soil, the vegetation and the weather affect the water content of a green roof?

Axelle Hego, Floriane Collin, Hugues Garnier, Rémy Claverie

GdR MASCOTNum 2022

How do the soil, the vegetation and the weather affect the water content of a green roof ?

Axelle HEGO[1], Floriane COLLIN[1], Hugues GARNIER[1], Rémy CLAVERIE[2]

[1]Université de Lorraine, CRAN, CNRS UMR 7039, [2]Cerema Est, Team research group, F-54510, Tomblaine, France

Figure 1 – Green roof located in Tomblaine (France)

Context

Urban imperviousness is a major urban issue during rainfall

Solution → Green Roofs

- lower the peak flow rate in water system by 22% to 93%
- delay the peak flow by 0 to 30 min

Collaboration

Cerema: Green Roofs experts
CRAN: Model Analysis skills
Collaboration between Cerema and CRAN for a better understanding of the GR behavior

Green Roofs hydrological modeling

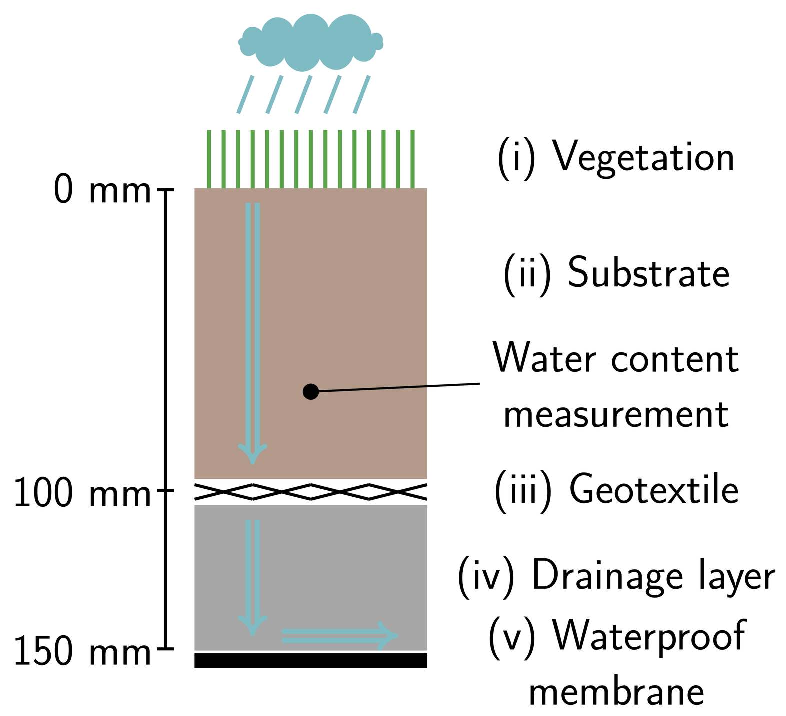


Figure 2 – Profile view of a green roof

- Meteorological data and real water content measured in a green roof of the CEREMA of Nancy
- Simulation of the water infiltration into the layers using Hydrus-1D© software where these equations are implemented:

$$\underbrace{\frac{\partial \theta(h)}{\partial t}}_{\text{water content}} = \underbrace{\frac{\partial}{\partial x} K(\theta)\left[\frac{\partial h}{\partial x} - 1\right]}_{\text{water infiltration in the soil (1)}} - \underbrace{S(h)}_{\text{plant effect (2)}}$$

(1) Richards equation which describes water inflitration in the soil
(2) combination of Feddes function and Penman-Monteith equation which describe plants effect

Problem statement

- Input: Rainfall;
- Output: Volumetric water content $\theta(t)$ or VWC in the substrate (ii) (Fig. 2);
- 6 soil parameters: θ_s, θ_r, K_s, l, n and α;
- 5 meteorological variables: temperatures T_{max}, T_{min}, radiation R_n, air moisture, wind speed;
- 4 vegetation parameters: crop height, LAI, albedo and root depth.

→ 5 parameters are considered uncertain: θ_s, n, α, LAI and $R_n(t)$

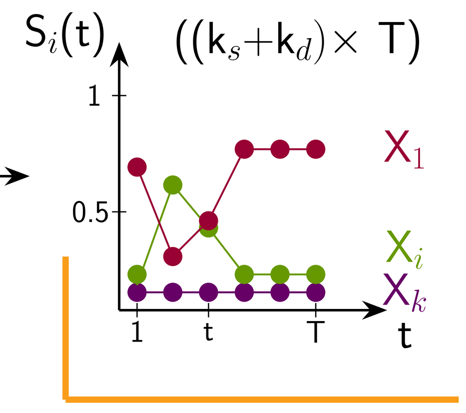
What parameters affect the water content (model output) ?

Methods: Generation of uncertain dynamic input for GSA

Aim of Global Sensitivity Analysis (GSA) : Better understand the model behavior

Definition of the uncertain paramaters X_i → Generation of N samples → Computation of the output Y(ω,t) (Fig. 4) → Computation of the sensitivity index S_i(t) (Fig. 5)

Input U(t)
Uncertain static param. $X_{i_s}(\omega)$ $i_s=1,\dots,k_s$ (N×1)
Uncertain dynamic param. $X_{i_d}(\omega,t)$ $i_d=1,\dots,k_d$ and $t=1,\dots,T$ (N×T)
→ Model → Output Y(ω,t) (N×T) →



Challenge 1: How to generate dynamic input ?

(1) Each dynamic param. can be defined as:

$$X_{i_d}(\omega,t) = \overline{X}(t) + \varepsilon(\omega,t)$$

with ω the randomness, $\overline{X}(t)$ the time mean and $\varepsilon(\omega,t)$ a stochastic variable defined by a correlation function $C_{ii}(t,t')$ and a distribution $h(t)$ for each instant.

(2) Extraction of the statistical information from a data set:

Observed data (N_{obs}×T) = Time mean $\overline{X}(t)$ (1×T) + Time variation (N_{obs}×T) → Time distribution $h(t)$; Time correlation $C_{ii}(t,t')$ (T×T)

(3) Generation of dynamic param. using Iman and Conover procedure (1982):

Time correlation $C_{ii}(t,t')$ (T×T) → Cholesky decomp. → Tranformation matrix P (T×T)
Independant samples following $h(t)$ (N×T) + Tranformation matrix P → Time correlated samples ε (N×T)

(4) Results: net radiation for a typical month of June in Fig. 3

Challenge 2: How to compute sensitivity indices ?

- For each instant, parameters are independant
- Computation of the indices for each instant
- Method: Sobol' indices estimated using samples permutation
- Results presented in Fig. 5

Conclusion and Prospect

- 2 samples of 5000 samples (LHS) generated and corresponding outputs computed
- Sensitivity indices are consistent with previous results (bootstrap in progress)

Prospects:

- How to generate uncertain dynamic input for non-stationary period ?
- Other estimator for sensitivity indices ?

Results

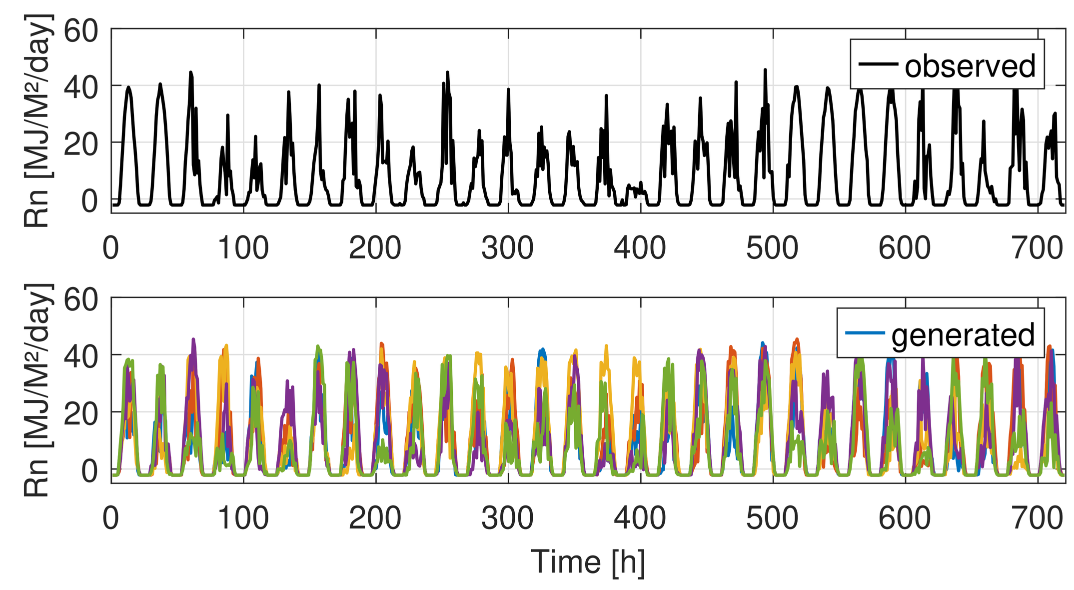


Figure 3 – Observed net radiation $R_n(t)$ of June 2020 and some generated samples.

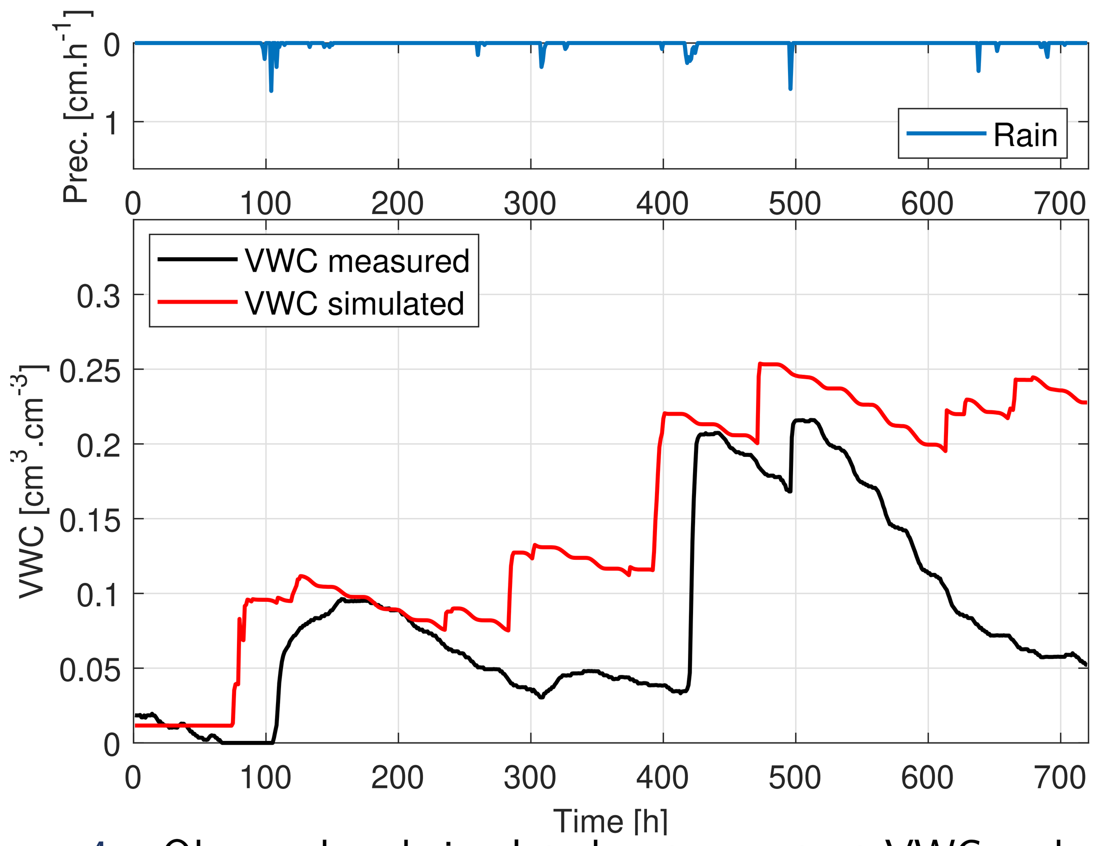


Figure 4 – Observed and simulated water content VWC and rainfall of June 2020

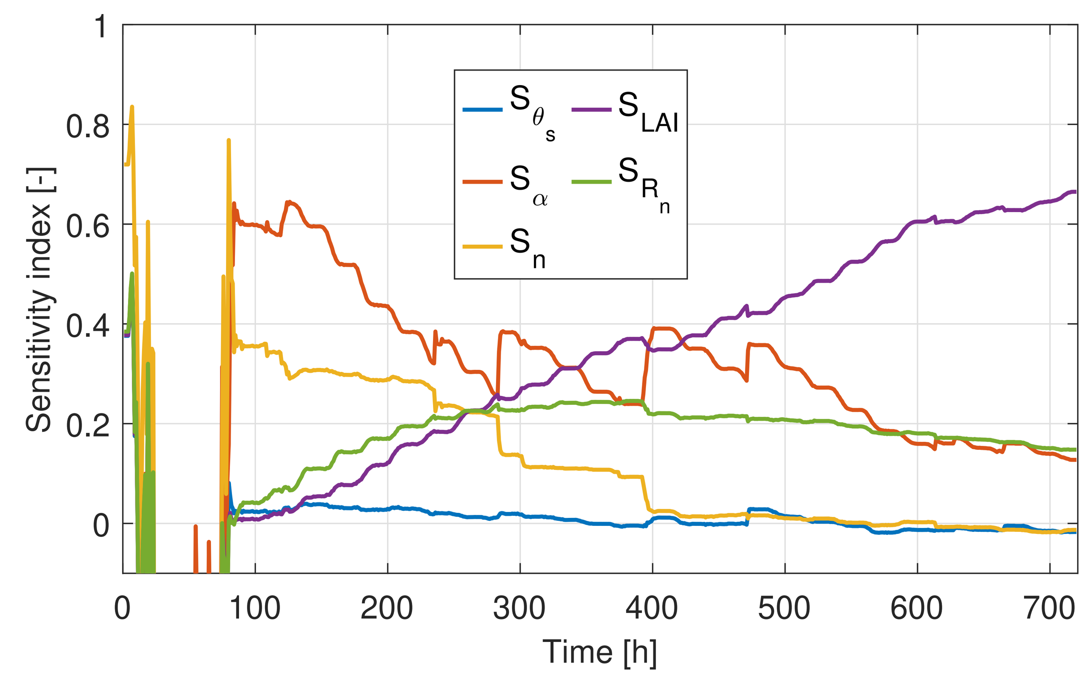


Figure 5 – First-order sensitivity indices computed using permutation method.

References

Access to the poster

- Goffart J., Mara T. and Wurtz E. *Generation os stochastic weather data for uncertainty and sensitivity analysis of a low-energy building*, Journal of Building Physics, 41(1): 41–57, 2017.
- Hégo A., Collin F., Garnier H. and Claverie R. *Approaches for green roof dynamic model analysis using GSA*, IFAC-PapersOnLine, 54(7): 613–618, 2021.