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Sensitivity analysis: a statistical tool for a green roof model analysis

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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

- Rainfall data and real water content measured in a green roof of the CEREMA of Nancy (Fig. 1 and Fig. 3)

- Simulation of the water infiltration into the layers using Richards equation (1) implemented in Hydrus-1D[®] software

$$\frac{\partial \theta(h)}{\partial t} = \frac{\partial}{\partial x} \left(K(\theta) \frac{\partial h}{\partial x} \right) - \frac{\partial K(\theta)}{\partial x} \quad (1)$$

combined with Van Genuchten model (2) and Mualem model (3)

$$\theta(h) = \frac{\theta_s - \theta_r}{(1 + |\alpha h|^n)^m} - \theta_r \quad \text{with } m = 1 - \frac{1}{n} \quad (2) \quad K(S_e) = K_s S_e^l \left(1 - (1 - S_e^{1/m})^m \right)^2 \quad \text{with } S_e(\theta) = \frac{\theta(h) - \theta_r}{\theta_s - \theta_r} \quad (3)$$

- Meteorological variables – temperature, air moisture, solar radiation and wind – and vegetation effects are taking into account using the Penman - Monteith equation and Feddes model.

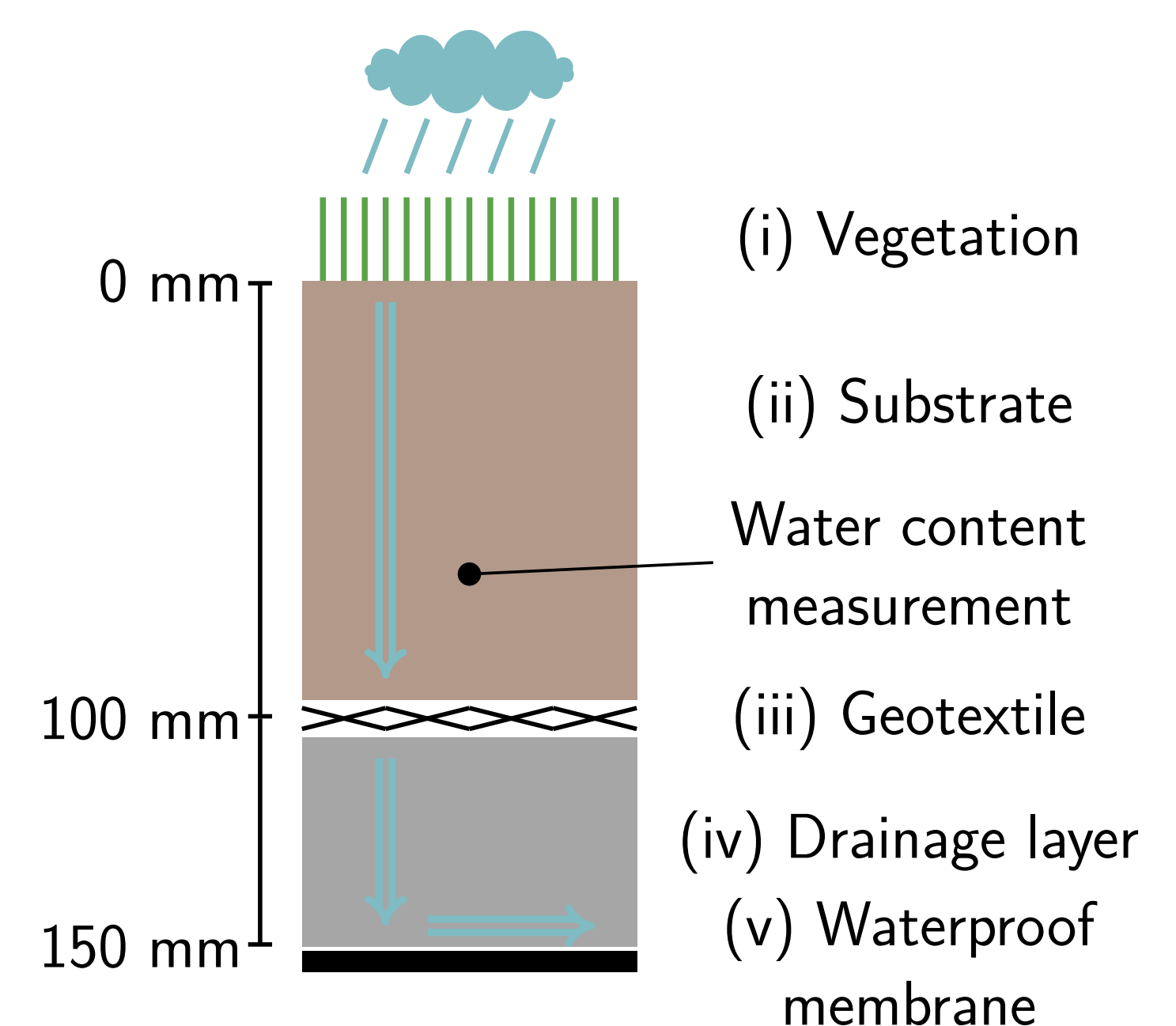


Figure 2 – Profile view of a green roof

Problem statement

- Input: Rainfall;
 - Output: Volumetric water content $\theta(t)$ in the substrate (ii) (Fig. 2);
 - 6 soil parameters: $\theta_s, \theta_r, K_s, l, n$ and α ;
 - 5 meteorological variables;
 - 4 vegetation parameters: *CropHeight, LAI, Albedo* and *RootDepth*.
- 6 parameters are considered uncertain: $\theta_s, n, \alpha, CropHeight, LAI$ and *RootDepth*

How to define these parameters to reproduce the real data ?
Which ones affect the water content (model output) ?

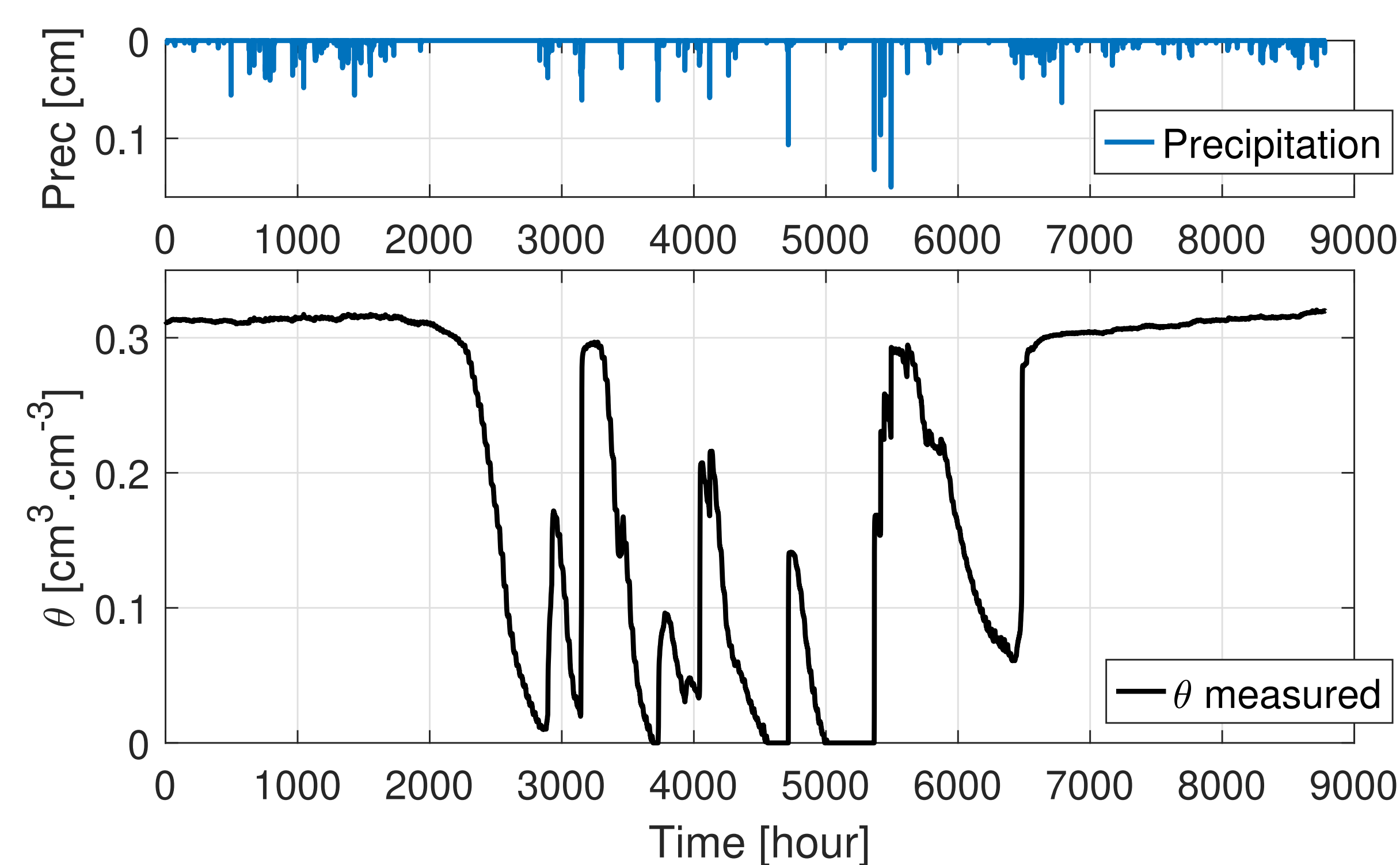


Figure 3 – Observed water content $\theta(t)$ and rainfall of 2020

Sensitivity analysis

Sensitivity analysis allows to measure the effect of the parameters on model output.

- Objectives:
- Better understand the model behavior;
 - Prioritize the model parameters by identifying their influences on the output;
 - Focus on influential parameters and fix non-influential parameters.

How varies the water content $\theta(t)$ in the substrate when the uncertain parameters vary ?

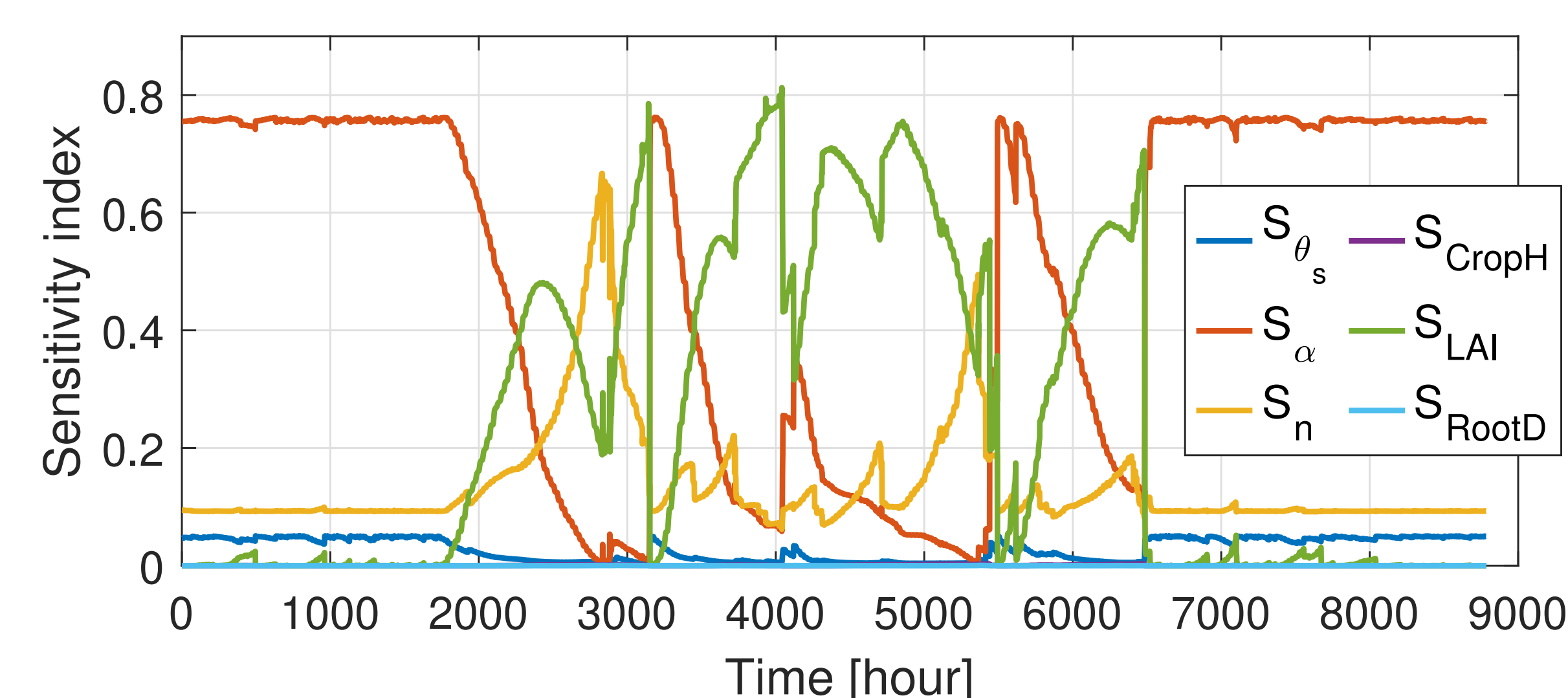


Figure 4 – Sensitivity indices $S_i(t)$ over time

- 3 parameters affect the water content θ : α (orange), n (yellow) and *LAI* (green)
- During humid period, α (orange) is the most influential
- During drying period, *LAI* (green) is the most influential

Calibration using sensitivity analysis results

- Which parameter values reduce error of simulation ...
- during humid period ? → set α
 - during drying period ? → set *LAI*
 - when it is influential ? → set n
- Non-influential parameters can be fixed to the mean value of the uncertainty interval (Fig. 5)

References

- Hégo A. et al. *Approaches for green roof dynamic model analysis using GSA*, IFAC-PapersOnLine, 54(7):613–618, 2021.
- Li Y. et al. *Green roof hydrologic performance and modeling: a review*, Water Science & Technology, 69(4):727–738, 2014.

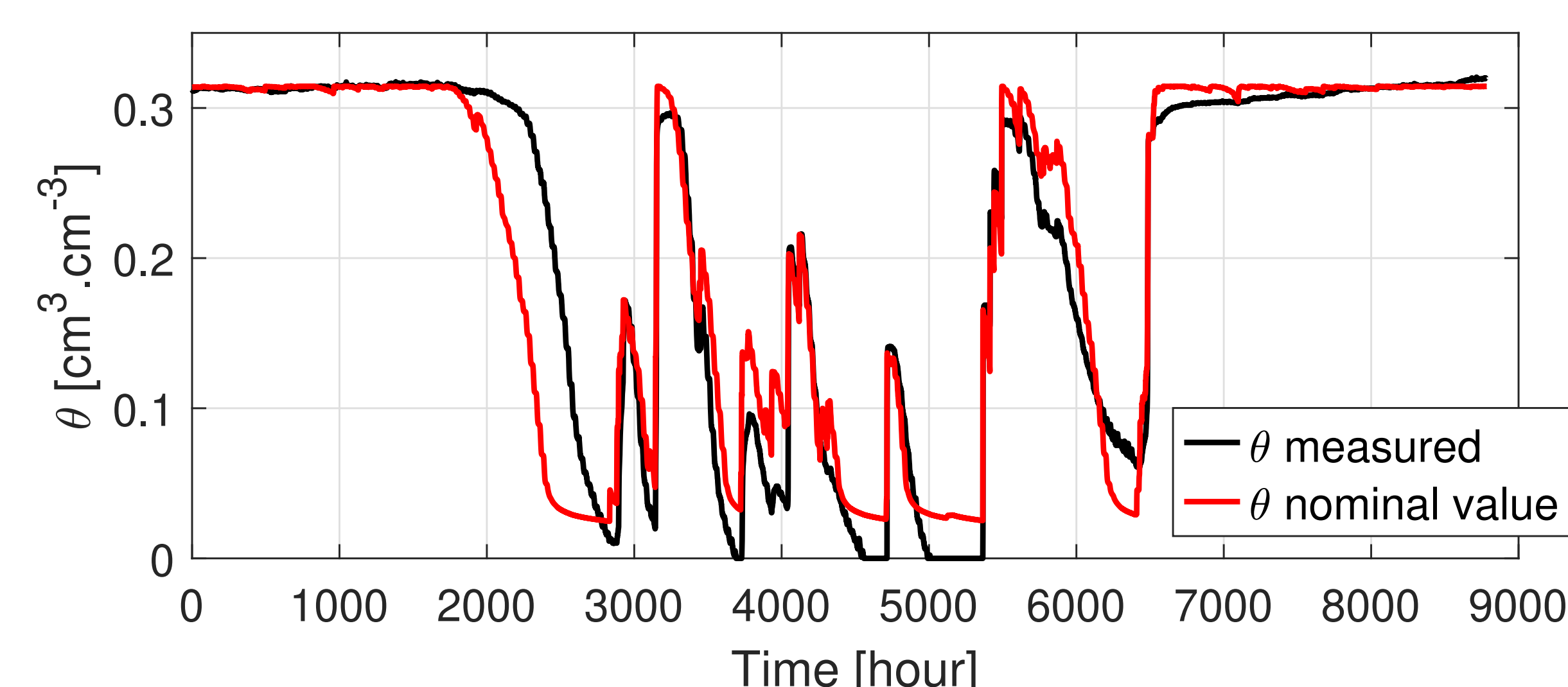


Figure 5 – Simulated water content $\theta(t)$ at nominal values