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

Axelle HEGO\textsuperscript{1}, Floriane COLLIN\textsuperscript{1}, Hugues GARNIER\textsuperscript{1}, Rémy CLAVERIE\textsuperscript{2}

\textsuperscript{1}Université de Lorraine, CRAN, CNRS UMR 7039, \textsuperscript{2}Cerema Est, Team research group, F-54510, Tomblaine, France

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

**Green Roofs hydrological modeling**

- 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\textsuperscript{5} software
  where these equations are implemented:
  \begin{align*}
  \frac{\partial h(t)}{\partial t} &= \frac{\partial}{\partial x} \left(K(\theta) \frac{\partial h(t)}{\partial x} - S(h) \right)
  \end{align*}

(1) Richards equation which describes water infiltration 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: \(\theta_i, \theta_s, K_i, l, n\) and \(\alpha\);
- 5 meteorological variables: temperatures \(T_{\text{max}}, T_{\text{min}}\), radiation \(R_n\), air moisture, wind speed;
- 4 vegetation parameters: crop height, LAI, albedo and root depth.

→ 5 parameters are considered uncertain: \(\theta_s, \alpha, \text{LAI and } R_n(t)\)

**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

<table>
<thead>
<tr>
<th>Definition of the uncertain parameters (X_i)</th>
<th>Generation of (N) samples</th>
<th>Computation of the output (Y_{\theta(t)}) (Fig. 4)</th>
<th>Computation of the sensitivity index (S_i(t)) (Fig. 5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(X_i(\omega)) (i=1,\ldots, N)</td>
<td>(\omega, t) ((N \times T))</td>
<td>(\omega, t) ((N \times T))</td>
<td>(\omega, t) ((N \times T))</td>
</tr>
</tbody>
</table>

**Challenge 1: How to generate dynamic input?**

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

\[ X_i(\omega, t) = \overline{X}(t) + \varepsilon(\omega, t) \]

with \(\omega\) the randomness, \(\overline{X}(t)\) the time mean and \(\varepsilon(\omega, t)\) a stochastic variable defined by a correlation function \(C_{\varepsilon}(t, \ell)\) and a distribution \(\varepsilon(t)\) for each instant.

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

\[
\text{Observed data (N_{\text{obs}} \times T)} = \begin{bmatrix}
\text{Time mean } \overline{X}(t) (1 \times T) \\
\text{Time variation } (N_{\text{obs}} \times T) \\
\text{Time correlation } C_{\varepsilon}(t, \ell) (T \times T)
\end{bmatrix}
\]

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

\[
\begin{bmatrix}
\text{Time correlation } C_{\varepsilon}(t, \ell) (T \times T) \\
\text{Cholesky decomp.} \\
\text{Transformation matrix } P (T \times T)
\end{bmatrix}
\]

\[
\begin{bmatrix}
\text{Independant samples following } \varepsilon(t) (N_{\text{obs}} \times T) \\
\text{Time correlated samples } \varepsilon (N_{\text{corr}} \times T)
\end{bmatrix}
\]

(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 independent
- 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?

**References**


**Access to the poster**

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

**Figure 1 – Green roof located in Tomblaine (France)**

**Figure 2 – Profile view of a green roof**

**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.**