

INTRODUCTION

Soil water infiltration experiments were conducted on both controlled and natural sites. These experiments were monitored using in-situ devices and time-lapse Ground Penetrating Radar (GPR).

A Hydrogeological and Geophysical coupled model of these experiments has been established.

The main objective is to develop a fitting methodology of the hydrodynamic parameters of the model so that it provides a correct reproduction of the GPR data observed on natural field.

A first part, presented here, consists in analyzing the sensitivity of GPR two-way travel times (TWT), to the input hydrodynamic parameters of the model.

EXPERIMENT & METHODS

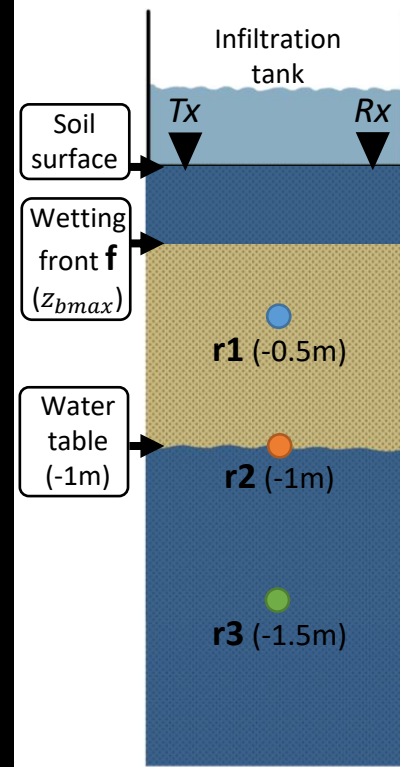


Figure 1 - Illustration of the soil model
r1, r2 and r3 are object of fixed depth

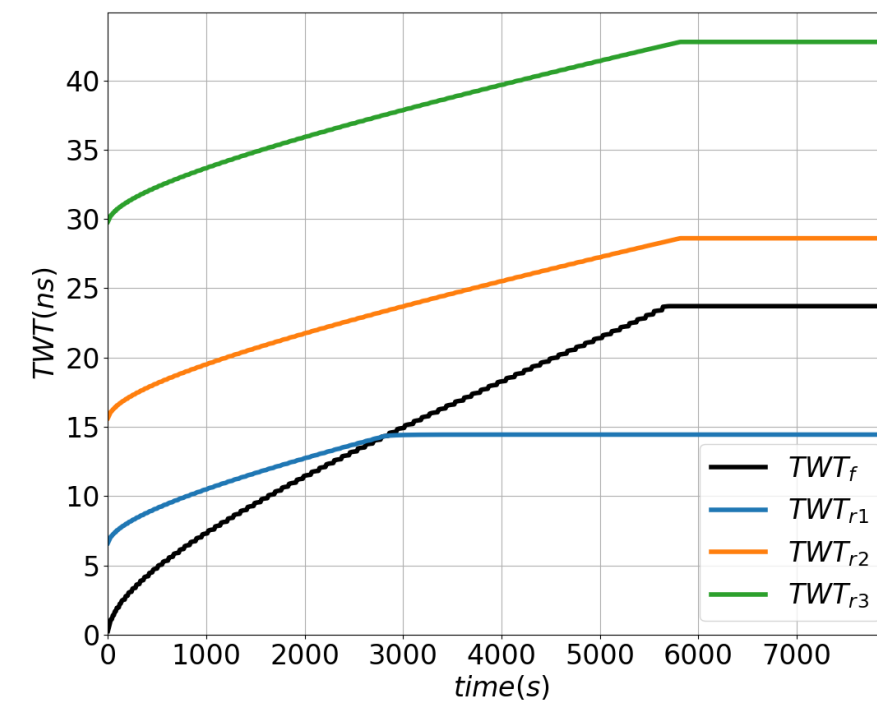


Figure 2 - Model synthetic outputs for one given set of input parameters, depicting the TWT of the waves reflected by the wetting front f and the fixed objects $r1, r2, r3$

Hydrogeological modeling

The WAMOS-1D code combines the 1D Richards equation and the Mualem – van Genuchten (MvG) model.

The water layer thickness in the infiltration tank and the depth of the water table are respectively used as the top and the bottom boundary conditions.

For a given set of MvG hydrodynamic parameters

$$X^m = (K_s, \theta_r, \theta_s, \alpha, n)^m$$

the code solves the hydrogeological model and outputs the vertical water content profile over time $\theta(z, t)$.

Geophysical modeling

$\theta(z, t)$ profile, defined in the domain cells, is converted, through a series of equations, into two-way travel time $TWT(z_b, t)$ and reflection coefficient $r(z_b, t)$ profiles, evaluated at the boundaries between domain cells.

TWT_{r1}, TWT_{r2} and TWT_{r3} are obtained by calculating the complete two-way travel time from their respective fixed depths ($r1, r2, r3$ on Fig. 1). We define TWT_f as the two-way travel time to the bottom of the infiltration (f on Fig. 1) at the boundary at z_{bmax} where $r(z_{bmax}) = \max(r)$.

For a given X^m , the GPR modeling code generate an output set

$$Y^m = (TWT_f, TWT_{r1}, TWT_{r2}, TWT_{r3})^m$$

Global Sensitivity Analysis

Sobol indices: variance-based sensitivity analysis consists in computing the Sobol indices to analyze the contribution of the variation of any input variable $x \in X^m$, to the total variation of a model output variable $y \in Y^m$.

Polynomial Chaos Expansion (PCE): surrogate model where an output variable $y \in Y^m$ can be expended as a set of multivariate polynomials.

The polynomial coefficients can be estimated in the least square sense using M realizations of the coupled hydro-geophysical model, and the Sobol indices can be calculated directly from these coefficients.

RESULTS & DISCUSSIONS

Principle :

We ran $M=1258$ random realizations of the hydro-geophysical model where each realization m of an input variable $x \in X^m$ is randomly sampled from a uniform distribution.

Observations :

- For all outputs $y \in Y^m$, the variance evolves during the infiltration through a short increasing phase I and a longer decreasing phase II.
- For TWT_f , the total variance is the most important between all outputs. K_s remains the only influential parameter during phase I, while α earns influence with time in phase II. However, the three other parameters have little to no effect.
- For TWT_{r1} , α is the most influential parameter at the start of the infiltration but with a decreasing importance with time. K_s contribution increases during phase I, quickly exceeding alpha's contribution, and decreases to zero during phase II. Compared to TWT_f , θ_s has a relatively more important contribution, remaining the only influential parameter at the end of the infiltration, but with a smaller total variance.
- TWT_{r2} and TWT_{r3} depict a similar behavior than TWT_{r1} . The total variance and θ_s contribution are more important for TWT_{r2} and even more for TWT_{r3} .

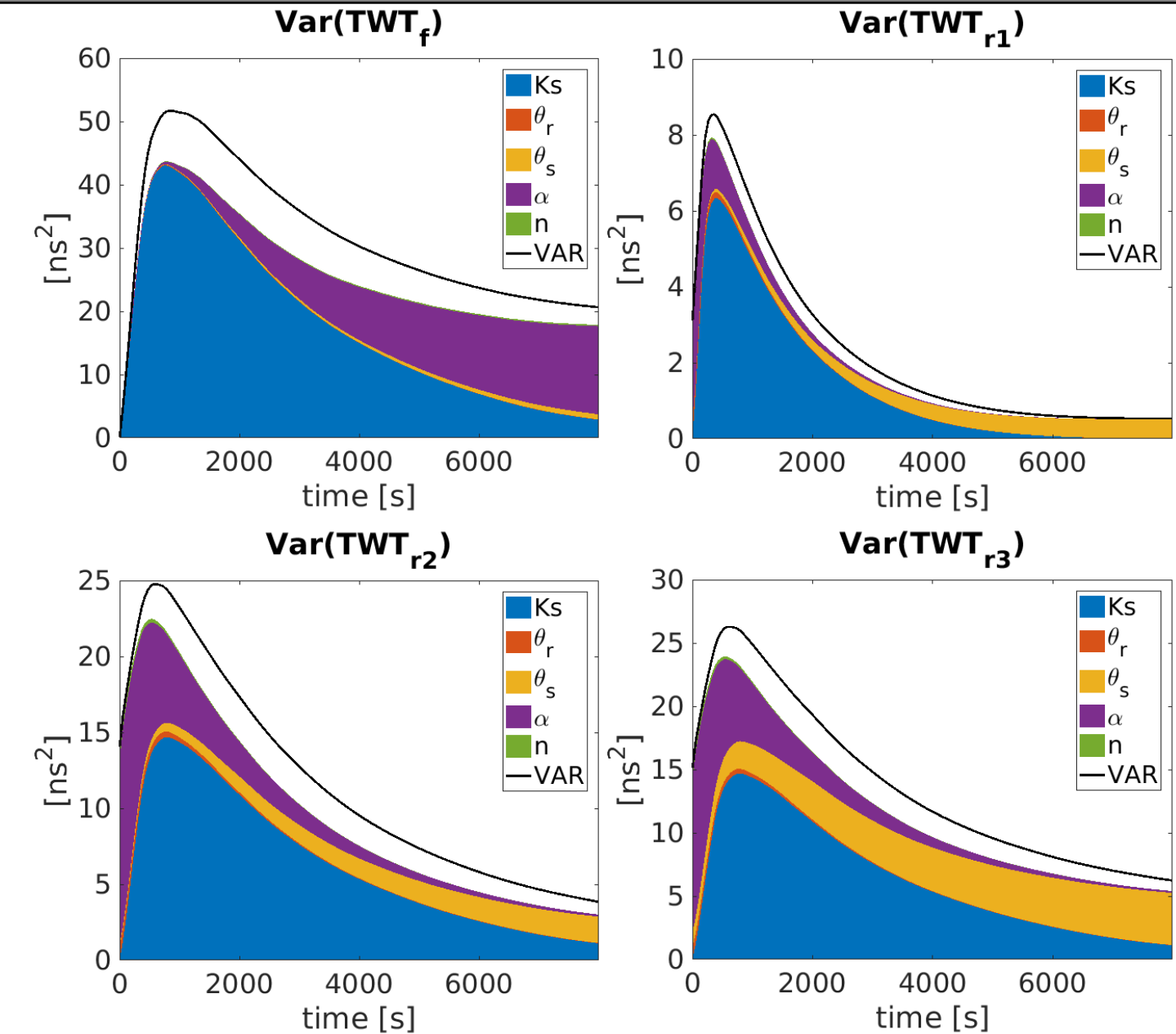


Figure 3 – Contribution of each input parameter to the total variance of each output.
The blank area between the filled areas and the black hard line correspond to the contribution of interactions between parameters ($\geq 2^{nd}$ order Sobol indices)

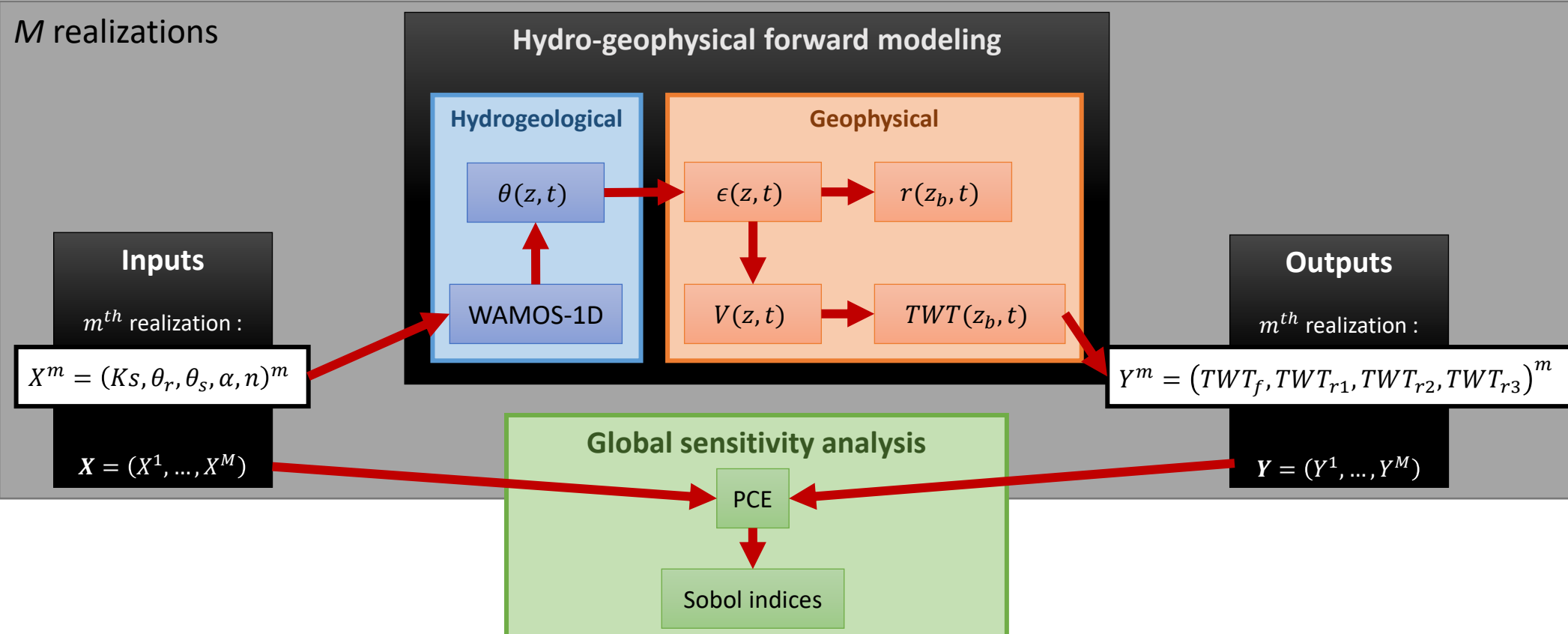
CONCLUSIONS & PERSPECTIVES

- With the use of time-lapse GPR to monitor soil water infiltration experiments, TWTs show a complementary sensitivity to the parameters K_s , α and θ_s .
- In particular, the TWTs of reflected waves on objects of fixed depths characterize a greater contribution of θ_s in long times. Furthermore, this contribution increases with the depth of the object under the water table. We assume this to be due to an increasing length of the travel path in the saturated zone.
- Upcoming runs will be performed on soil models with deeper water table level to cover the case of undetectable water table.
- The second part of this work will consider the inversion algorithm in order to determine the optimal settings for field measurements and apply the methodology on real data acquired in various contexts.

¹Institut Terre et Environnement de Strasbourg, France

References

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- [2] Leger E. et al., 2020. *Journal of Appl. Geophysics*, 182, 104176.
- [3] Younes A. et al., 2018. *Hydrol. Earth Syst. Sci.*, 22, 3561–3574



Discussion :

The influence of θ_s increases with the depth of the object under the water table, which can be related to the increasing length of the saturated travel path.

Another observation common to all outputs is the presence of interactions between input parameters contributions, as evidenced by the blank part between the filled curves and the total variance curve.

An input parameter not influential alone can have an effect when varying with one or more other input parameters. However, in additional results, we figured out that these interactions are also explained by the three singularly influential parameters K_s , α and θ_s .