Combining switching factors and filtering operators in GSA to analyze models with climatic inputs

Sébastien Roux
INRA, UMR SYSTEM, 34060 Montpellier, France

Samuel Buis
INRA, UMR EMMAH, 84914 Avignon, France

Patrice Loisel
INRA, UMR MISTEA, 34060 Montpellier, France

Introduction

This work is devoted to the analysis of models having functional inputs and is motivated by the intensive use of climatic variables in crop models. The main output of these models is the crop yield, which is estimated, among others, from daily-sampled climatic variables (Temperature, Rain, Radiation, Evapotranspiration). We want to test to what extent this fine temporal resolution is mandatory to generate accurate predictions and quantify how much *a priori* simplifications, such as lowering the temporal resolution, would affect the model results. This may lead to a better understanding of model behavior as well as to a simplification of the model and/or of the acquisition of its input variables.
To this aim, we introduce the use of filtering operators into Global Sensitivity Analysis using switching factors [1]. Low pass filters are used to reduce the temporal resolution of climatic variables. GSA is required because we want to explore the impact of this input simplification in a global exploration of model inputs. Switching factors have been proposed [1], [2] in the context of spatially distributed inputs and further analyzed in [3]. They were initially introduced to assess the sensitivity to the presence of stochastic errors in spatial functional inputs. We use them here to test the sensitivity of a model to simplifications of the temporal structure of its climatic inputs.

Methodology

The method is presented for a model f having two independent inputs: one functional (X) and one scalar (p). The scalar output Y is written as $Y = f(X, p)$. Let g be an operator that transforms X into $g(X)$. We introduce a switching factor η and a modified model f_g such as:

$$f_g(\eta, X, p) = \begin{cases} f\,(X, p) & \text{if } \eta = 0 \\ f\,(g(X), p) & \text{if } \eta = 1 \end{cases}$$

A map-labeling scheme [4] is used to perform a GSA using n_X samples of X. This leads to a GSA on the independent factors (η, l, p) of model $\tilde{f}_g$ defined as $\tilde{f}_g(\eta, l, p) = f_g(\eta, X_l, p)$, with X_l denoting the sample of X with index l. As we are in a factor fixing context, we focus on Total Sensitivity Indices (TSI) with the perspective of getting small indices for the switching factor η.

Application to a simplified crop model

We tested the method with a simplified crop model that couples a simple water balance with a radiation-driven biomass growth. The crop growth has two limiting factors: High temperature and water stress. The model has the typical input structure of classical crop models (4 climatic variables at a daily time-step). The use of a simplified definition allows for fast computations and qualitative validation of sensitivity results. We applied the proposed method using $n_x = 42$ climatic years and with 3 other factors. TSI of the 4 switching factors, of the climate label and of the 3 others factors were computed using a Sobol algorithm from the R package "Sensitivity". We used two different filtering operators: an inter-annual mean $g_1(X)(t) = \frac{1}{n_x}\sum_{i=1}^{n_x} X_i(t)$ and a local mean operator $g_2^d(X) = X * G_d$, where $*$ denotes the convolution operator and G_d is a mean filter over $(2d + 1)$ days, with d between 1 and 25.

The results presented in Fig. 1 show that the application of the inter-annual filter g_1 does not provide small TSI for both the 4 switching variables ($TSI(\eta_{rain}) > 0.2$). It means that simplification by inter-annual mean is not acceptable. This was however not the case when excluding the rain input from the simplification: In that case, the TSI of the 3 remaining switching factors are simultaneously small. Hence the simplification of these 3 variables by their inter-annual mean seems acceptable.

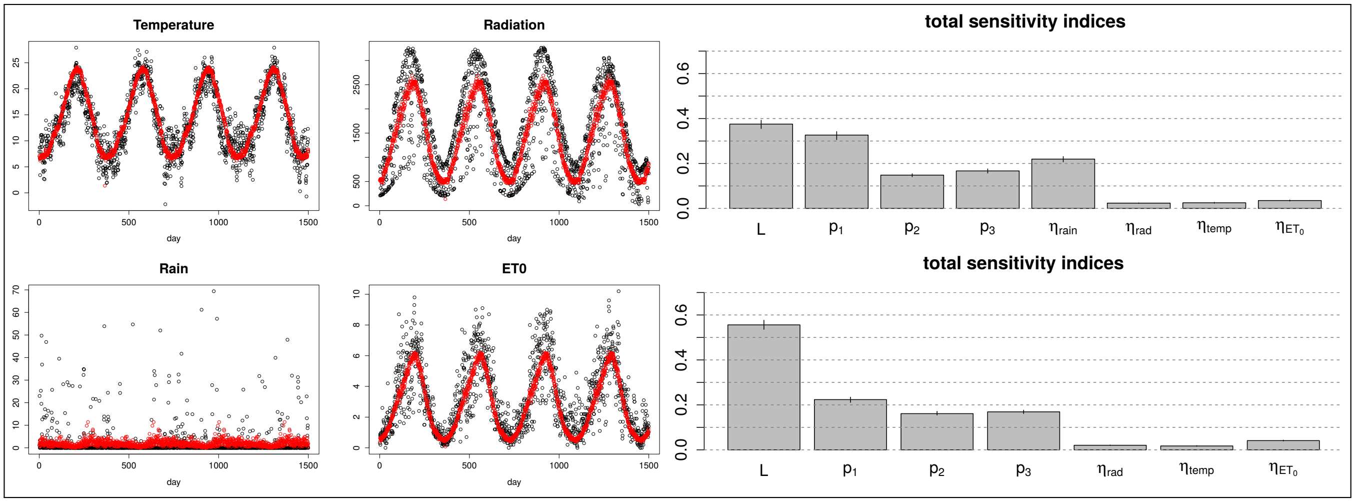

Figure 1: Left: Application of the inter-annual mean operator g_1 (in red) on the climatic variable (year 1..4 in black); Right: Total sensitivity indices when applying the filter to the 4 climatic variables (top) and to 3 of them when excluding Rain (bottom).

Using filter $g_2(d)$ we also showed that rain input can be simplified in terms of temporal resolution even with large d, but only for model settings corresponding to low run-off soil conditions. This property was expected from the model definition.

Conclusion

Combining switching factors with filtering operators to analyze models with climatic inputs seems to be a promising method. This approach can easily be extended to other input transformations in order to test the effect of other *a priori* modifications of the model input structure: An example would be a low pass filtering preserving high value applied to the rain input. One difficulty lies in the definition of such relevant transformation: It requires relevant *a priori* knowledge on the model behavior. A next step of this work is to apply the method to a more complex crop model sharing a comparable structure of model inputs.

References:

[1] M. Crosetto and S. Tarantola *International Journal of Geographical Information Science*, vol. 15, no. 5, pp. 415–437, 2001.

[2] S. Tarantola, N. Giglioli, J. Jesinghaus, and A. Saltelli *Stochastic Environmental Research and Risk Assessment*, vol. 16, no. 1, pp. 63–76, 2002.

[3] B. Iooss and M. Ribatet *Reliability Engineering & System Safety*, vol. 94, no. 7, pp. 1194–1204, 2009.

[4] L. Lilburne and S. Tarantola *International Journal of Geographical Information Science*, vol. 23, no. 2, pp. 151–168, 2009.

[Sébastien Roux; rouxs@supagro.inra.fr]