Towards Operational Products Development from Earth Observation: Exploration of SimSphere Land Surface Process Model Sensitivity using a GSA Approach

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1. INTRODUCTION

The use of simulation process models has played a key role in extending our abilities to study Earth system processes and enhancing our understanding on how different components of it interplay. The use of such models combined with Earth Observation (EO) data provides a promising direction towards deriving more accurately spatio-temporal estimates of key parameters characterising land surface interactions, as it combines the horizontal coverage and spectral resolution of EO data with the vertical coverage and fine temporal continuity of models. This study aimed to perform a Global Sensitivity Analysis (GSA) on the SimSphere Surface Vegetation–Atmospheric Transfer (SVAT) model to further extend our understanding of the model structure and to establish its coherence. For consistency and comparability to previous studies, the GSA implemented herein has also been based on a cutting edge parameterization, yet simple to apply method based on Bayesian Analysis of Computer Code Outputs (BACCO; Kennedy and O’Hagan, 2001), Whereas previous SA studies on SimSphere using BACCO assumed normal probability distribution functions (PDFs) for the model input parameters, in our study we assume uniform PDFs. It also uses PDFs of the most sensitive model inputs derived directly from the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) imagine radiometer.

2. BACKGROUND / METHODOLOGY

1. SIMSPHERE:

SimSphere was originally developed by Carlson & Boland (1978) and significantly improved by Gillies et al. (1995) & Petropoulos et al. (2013a).

It is a deterministic mathematical model that provides representations of the physical mechanisms controlling land surface interactions in a vertical profile. It implicitly refers to a horizontal area that can be composed of a mixture of bare soil & vegetation. It simulates various parameters over a 24-hour cycle and at a chosen time step, starting from a set of initial conditions in the early morning. The model inputs requirements and the number of outputs produced lead to its understanding of surface processes is shown in Fig. 2.

SimSphere verification and applications:

- As a stand alone tool in studies of: 1. Variations in vegetation patterns (e.g. Gillies et al., 2007); 2. Fire and drought impact; 3. Cropping area evolution (e.g. Davis et al., 2019); 4. Catchment scaling and drainage (e.g. Petropoulos et al., 2018).
- Sensitivity analysis with RS data (e.g. Gillies et al., 1997; Petropoulos and Carlson, 2011)
- In 3 Ph.D. theses (Gillies, 1990; Brunsdon, 2003; Petropoulos, 2008)
- It is currently used as an educational tool in 5 Universities in the world.
- Distributed globally from Aberystwyth University (http://www.aber.ac.uk/simsphere).

2. BACCO GEM SA:

- GSA is achieved from an emulator, derived from a relatively small number of model runs covering a multidimensional input space, which deducts all the SA measures related to the original deterministic model code without the need to execute further runs of the model code.
- Self-measure of emulator performance in matching the original model code is embedded, providing an accurate and reliable indication of the trustworthiness of its analysis.
- The basic SA output from GEM SA includes the computation of the main and joint effects (pairwise interactions only) of the input parameters, as well as the total effects. In addition, GEM SA provides a set of main effects plots, which are calculated for each of the model inputs.

3. BACCO GEM SA on SimSphere:

The sensitivity of the following parameters was examined due to their importance in energy balance studies:

- A design space of 400 simulations was created. All model inputs were allowed to vary except the geographical location and atmospheric profile. For these, a priori values were used from Borgo Coelli Carbo Europe project in central Italy (40° 31’ 25’’ N, 14° 57’ 28’’ E) on 17 Nov 2004. All inputs were initially assumed to be uniform, then for the most sensitive model inputs (i.e. slope, aspect, Fr) PDFs from ASTER image were taken.

3. RESULTS: Emulator Accuracy

1. Emulator performance

Table 1: Summary of statistics concerning the emulator performance when uniform PDF for inputs was assumed. Shading highlights the roughness values of the model inputs with values greater than 1.0.

2. RESULTS: SA assuming uniform PDFs

Table 2: Summary of statistics concerning the emulator performance assuming normal PDF for inputs. Shading highlights the roughness values of the model inputs with values greater than 1.0.

4. RESULTS: SA assuming uniform PDFs

Fig. 4: Sensitivity analysis results using GEM SA software comparing uniform PDF and normal PDFs (upper) and the importance of various variables for the two PDFs (lower) are shown for daily RS, daily LE and daily H.

5. RESULTS: SA using PDFs from ASTER satellite

Fig. 5: Sensitivity analysis results using GEM SA comparing uniform PDFs (derived in Eq. 1) and ASTER-derived PDF (upper) and the SA inputs for examples of variables of which SA was performed for ASTER-derived data (lower) for daily RS, daily LE and daily H.

4. CONCLUSIONS

- Our study showed comparable results to previous studies in terms of identifying the most sensitive model inputs.
- Yet, the PDFs assumption can influence the sensitivity SA measures of the model input parameters in respect to the target quantity considered each time. Some of the most sensitive model inputs for all outputs were parameters relatively easily estimated from EO data, which has important implications for the integration of the model with such data and also its use in general in future research.
- This work is significant to the community of model users and is also very timely given the efforts currently examining to use an in ED-based method for deriving operationally regional estimates of energy fluxes and soil moisture from EO data (e.g. Chauhan et al., 2003).

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