Using Global Sensitivity Analysis to Identify Controlling Processes of Complex Systems

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Project Abstract:
This project developed three new methods of global sensitivity analysis for identifying controlling processes of an environmental system that is always open and complex. For such a system, understanding all its processes and their interactions is difficult. On the other hand, since the system dynamics are determined mainly by controlling processes, efforts should be spent to better understand the controlling processes, and on the other hand, spending efforts on non- influential processes should be avoids. These are challenging because of uncertainty inherent in system processes. This project considers process model uncertainty (i.e., a process can be represented by more than one process model) and process parametric uncertainty (i.e., a process model parameter is not deterministically known but follows a distribution). The overarching scientific question to be answered in this project is as follows: *If we are not certain about the choice of process models and model parameters, can we correctly identify the controlling processes of a complex system?* We developed three methods of global sensitivity analysis to tackle this questions from different angles (theoretical and computational).

The first approach was developed for **process prioritization** to identify the process(es) that should be better understood to achieve the greatest reduction in the uncertainty of the output of system modeling. We developed a process sensitivity index, which is conceptually similar to the first-order sensitivity index of the Sobol' method. During this project, we developed a new computational method to substantially reduce the computational cost of calculating the process sensitivity index by reducing the computational cost from N^2 model runs to $2N$, where N is on the order of hundreds to thousands.

The second approach was developed for **process fixing** to screen non-influential process(es) with small contribution to the uncertainty of the output of system modeling. We developed a total process sensitivity index, which is conceptually similar to the total-effect sensitivity index of the Sobol' method. We evaluated this sensitivity index by using analytical functions and numerical groundwater models with three model uncertainty in the processes of land surface recharge, subsurface geology, and river boundary. This sensitivity index was also implemented using the computationally efficient method discussed above.

To further reduce the computational cost of process fixing, we developed the third approach that extends the design of Morris method for model parameters to model processes. Our methods reduces the number of model runs from thousands to tens, and the results are consistent with those of the total process sensitivity index discussed above,