論文の内容の要旨

Abstract of Dissertation

Title: Sensitivity Analysis and Parameter Optimization of Land Surface Models to Improve Surface Flux Estimation

(地表面フラックス算定精度向上のための陸面過程モデルの感度分析とパラメータ最適化)

Name of Author: エルファニアン　マハデイ　　**(ERFANIAN Mahdi)**

Since last decades different types of land surface models (LSMs) have been developed to predict water, energy, and bio-geochemical processes, which occur near the land surface. An accurate representation of land surface processes is critical for improving water and energy balance predictions, which can be used as input by atmospheric models. To simulate the input-state-output behavior of the land surface models with minimum uncertainty, it is necessary to estimate appropriate values for the model parameters. This process is referred to as parameter estimation.

The present-day land surface models are more complex and sophisticated which increase in model complexity means increase in the total number of parameters. In other words, total number of model parameters can be defined as a proxy for model complexity. It is difficult to estimate model parameters using full calibration method in large scales. To reduce the dimensionality of parameter optimization problem in the land surface models, one effective and efficient way is to conduct sensitivity analysis to specify the most sensitive parameters. Through identification of the most sensitive parameters, it is possible to reduce the total number of parameters, to be optimized. Therefore, two main steps in this study are firstly (1) to identify which parameters within the model are sensitive and then (2) to estimate the values of these parameters through sensitive parameter optimization.

It is crucial to conduct a comprehensive research about parameter estimation of land surface models such as Simple Biosphere Model (SiB2) and the Common land Model (CoLM) to identify the most sensitive parameters that control multiple responses of these models. In this study, to reduce the dimensionality of parameter optimization problem with these models, we employed a multi-criteria algorithm known as the Multi Objective Generalized Sensitivity Analysis (MOGSA) to identify the most sensitive parameters of each model (at a stand-alone or off-line mode) at three in-situ sites with grassland (Cabauw, Lindenberg and Tongyu). These sites have a high quality

dataset provided by International Project of Coordinated Enhanced Observing Period (CEOP), which provides a good opportunity for models evaluation and validation.

This study aims to identify that which parameters are important and functional for prediction of model responses, that is, sensible and latent heat fluxes, surface skin temperature, and net radiation as essential components to estimate the land surface energy balance. The sensitive and non-sensitive parameters were identified for each model response as individual criterion. The results of parameters sensitivity analysis vary for the sensible heat, latent heat, surface skin temperature and net radiation at each site and model. In this research, we considered 19 and 20 parameters of SiB2 and CoLM for the sensitivity analysis, respectively. A total number of 30,000 random model runs as the Monte Carlo simulations have been done for each model at all sites using different parameter ranges. The products of the Monte Carlo simulations were used in the parameter sensitivity analysis.

Within a single-objective and multi-criteria framework, the most sensitive and non-sensitive parameters of SiB2 and CoLM related to the surface roughness, soil, vegetation, and soil moisture initial conditions for surface fluxes and skin temperature prediction, were identified. The sensitivity results for single criterion and multi-criteria (global) are different for a specific model and site. The analysis showed that the sensitivity of parameters with similar physical meaning is closely related to the objective, model and location. If a specific parameter is sensitive for a particular model and location, it does not necessarily means that the parameter will be sensitive at a different location, and for a different model. The results of sensitivity analysis at Cabauw and Lindeberg sites were different when we used a different range of parameters at each site. In addition, the parameter sensitivity analysis was changed when we applied the MOGSA for a bare soil period at Tongyu site. The results showed that the sensitivity of soil and vegetation related parameters was changed during a bare soil period but sensitive parameters identified at growing season and bare soil period were consistent with land surface characteristics at this site.

The sensitivity results showed that several model parameters appear to be insensitive. This indicates that parameter identification and reduction in the number of parameters will help a modeler in a systematic approach to define which parameters truly influence model simulations. In addition, sensitivity analysis results can be changed using different parameter ranges and data period. The vegetation related parameters (vegetation cover, leaf area index), initial soil wetness of root zone layer and deep layer, land surface roughness parameters, and soil texture (%sand and %clay) were identified to be the most and common sensitive parameters.

A global optimization algorithm known as the Shuffled Complex Evolution method (SCE) was coupled with the SiB2 and the CoLM as single objective parameter estimation schemes for parameter estimation. We conducted sensitive parameter optimization and full parameter calibration approaches for different individual criterion (sensible and latent heat fluxes, surface skin temperature, and net radiation). We carried out totally 48 calibration runs (3 sites, 2 models, 4 objective parameter optimization runs, and 4 full calibration runs).

The results of sensitive parameter optimization (objective runs) compared with full calibration runs indicates that at all experiments, the objective parameter optimization can produce a minimum cost function values (RMSE) with a little degradation compared to full calibration runs. In other words, when non-sensitive parameters are omitted from the optimization process, there is a little degradation in the values of cost function (RMSE) which is considered as the quality of the model description.

The comparison of the optimal values of parameters in two calibration approaches also shows that in most cases the estimated values of parameters considered in optimization runs are almost close with full calibration cases. This implicates that the omitting non-sensitive parameters in objective runs mainly has not a large effect on the estimation of other remaining parameters. Therefore, through identification of sensitive parameters we could reduce the total number of parameter required in the optimization process. In fact, the objective parameter optimization approach by omitting non-sensitive parameters reduces the computational time required for calibration runs. This approach would be very useful for parameter estimation of land surface models at large scales.

The use of optimal values of parameters set in each single-objective optimization run gives a minimum value of RMSE for corresponding model response but it can not provide necessarily a better prediction of other model responses. It means within a single objective framework, the use of optimal set can not improve all model-simulated fields instantaneously. Furthermore, the optimal parameter sets estimated by the SCE-UA were different when we used a different range of parameters. In addition at Cabauw and Lindenberg sites, the prediction of latent heat flux was improved using a wider range but there is still a poor prediction of surface skin temperature at all sites and for both models. As a whole, SiB2 predictions were better than CoLM regardless their inability to predict the surface fluxes and skin temperate in some cases.

In this research, soil texture (%sand and % clay) has been optimized for the estimation of soil hydraulic and thermal parameters, thereby reducing the number of soil parameters in optimization process. Since there is always uncertainty in the measurement of soil parameters, the use of global soil texture data is proposed specially if the models are used for predictions at larger scale.

This research has been conducted by making use of a relatively short-term observation of forcing and validation data (6-9 months) available at three in-situ sites. It would be useful to apply the methodology using a wide range of in-situ sites and longer datasets to identify the most sensitive parameters of models for different vegetation types, location and climates. This kind of study is crucial since land surface models have been designed initially for prediction at global scale coupled with climate models.

The results of this study indicate that within a single objective framework, it is difficult to improve all model predictions at the same time. For the land surface models such as SiB2 and CoLM with a multi-input-output nature, the use of a multi-objective parameter optimization schemes would be more effective and efficient to find a set of solutions for parameter sets. The parameter range and prediction uncertainty can be also analyzed using these schemes.

The SiB2 and CoLM models at present can not estimate well the diurnal variations of roughness length for heat transfer especially over bare soil and sparsely vegetated surfaces. On the other hand, we optimized the surface roughness related parameters using the preferred ranges at the sites with the grassland vegetation but it is necessary to include an appropriate scheme in the models for better prediction of surface fluxes and skin temperature by improving the estimation of both aerodynamic and thermal roughness lengths in a more physically base. The results of sensitivity analysis suggests that when a model in unable to predict well a specific model-simulated field then a modeler needs to pay attention to sensitive parameters and associated physical parameters.

Through application of the present methodology in a large number of in-situ sites, it might be possible to define optimal values as well as suitable ranges for each of common sensitive parameters, to be used for a specific soil, vegetation and climate especially in the case that enough data is not available. This can help us (1) to develop a priori parameter estimation techniques and (2) to demonstrate the parameter transferability of land surface models.