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Uncertainty Quantification and Parameter Tuning: A Case Study of Convective Parameterization Scheme in the WRF Regional Climate Model

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The current tuning process of parameters in global climate models is often performed subjectively or treated as an optimization procedure to minimize model biases based on observations. The latter approach may provide more plausible values for a set of tunable parameters to approximate the observed climate, the system could be forced to an unrealistic physical state or improper balance of budgets through compensating errors over different regions of the globe. In this study, the Weather Research and Forecasting (WRF) model was used to provide a more flexible framework to investigate a number of issues related uncertainty quantification (UQ) and parameter tuning. The WRF model was constrained by reanalysis of data over the Southern Great Plains (SGP), where abundant observational data from various sources was available for calibration of the input parameters and validation of the model results. Focusing on five key input parameters in the new Kain-Fritsch (KF) convective parameterization scheme used in WRF as an example, the purpose of this study was to explore the utility of high-resolution observations for improving simulations of regional patterns and evaluate the transferability of UQ and parameter tuning across physical processes, spatial scales, and climatic regimes, which have important implications to UQ and parameter tuning in global and regional models. A stochastic important-sampling algorithm, Multiple Very Fast Simulated Annealing (MVFSA) was employed to efficiently sample the input parameters in the KF scheme based on a skill score so that the algorithm progressively moved toward regions of the parameter space that minimize model errors.

The results based on the WRF simulations with 25-km grid spacing over the SGP showed that the precipitation bias in the model could be significantly reduced when five optimal parameters identified by the MVFSA algorithm were used. The model performance was found to be sensitive to downdraft- and entrainment-related parameters and consumption time of Convective Available Potential Energy (CAPE). Simulated convective precipitation decreased as the ratio of downdraft to updraft flux increased. Larger CAPE consumption time resulted in less convective but more stratiform precipitation. The simulation using optimal parameters obtained by constraining only precipitation generated positive impact on the other output variables, such as temperature and wind. By using the optimal parameters obtained at 25-km simulation, both the magnitude and spatial pattern of simulated precipitation were improved at 12-km spatial resolution. The optimal parameters identified from the SGP region also improved the simulation of precipitation when the model domain was moved to another region with a different climate regime (i.e. the North America monsoon region). These results suggest that benefits of optimal parameters determined through vigorous mathematical procedures such as the MVFSA process are transferable across processes, spatial scales, and climatic regimes to some extent. This motivates future studies to further assess the strategies for UQ and parameter optimization at both global and regional scales.