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Addressing uncertainty cascade in climate change impact modelling in agriculture: How certain are we?

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Climatic conditions are determining the suitability of agriculture to produce food, feed, fuel and fiber for a growing human population. Moreover, agricultural production is greatly affected by weather extremes and climate variability, the latter referring to the variations beyond synoptic timescales of the mean state and other properties of the climate system. Thus, understanding the relationship of climate variability and agricultural production is of high importance to assess the resilience of the agricultural production systems to unfavourable weather conditions and to identify adequate measures to adapt to climate change. Climate change impact studies have to cope with the cascade of uncertainties thatenter at different levels of modelling (e.g., emission scenario, climate model structure, impact assessment models). In our studywe give an example of addressing uncetrainty cascade and propose a framework to address these uncertainties through an ensemble probabilistic approach, which accounts for uncertainties in climate model simulationsas well as parametric uncertainties in a dynamic crop model. As an example, grain maize has been chosen for the simulation purposes. Ensemble of different regional climate modelswas used in combination with perturbed parameter ensemble from a dynamic crop model, reflecting biophysical uncertainties. Since regional climate model simulations can be a subject to systematic biases, the use of such simulations to create impact assessment models can lead to unrealistic results. We therefore determine and discuss the importance of bias correction ofsimulated meteorological variables prior to their use as input data in a dynamic crop model. Statistical bias correction generally improves the statistical properties of the simulated meteorological variables with RCMs. Using this method, however, does not produce satisfactory results in terms of comparison between measured data and corrected RCM simulations in a case where RCMsare not capable of realistic simulations of long term trends of the meteorological variables under consideration. Raw and corrected RCM simulations are used as an input to the WOFOST dynamic crop model. Using biased RCM simulations as input to the crop yield model further increases the bias in yield simulations, since many processes in the crop show a non-linear response to meteorological input data. It should be emphasized, that RCMs that underestimate the number of wet events during the growing season, produce the highest yield deviations, when used as input to the WOFOST model. Using bias corrected climate model simulationsin an ensemble probabilistic approach results in probability distributions of expected yield changes. Grain maize yields are assessed in terms of change of average and inter-annual variability. Variance decomposition of the ensemble yield projections is additionally performed in order to determine the RCM inter-model variability and crop model parametric uncertainty. Ensemble yield variability is decomposed into RCMstructural uncertainty, WOFOST parametricuncertainty and inter-annual variability. The highest proportion of decomposed variability can be attributed to inter-annual yield variability. RCM inter-model variability increases during the 21st century but never exceeds the inter-annual variability. The study also shows the parametric uncertainty of the WOFOST model to be negligible compared to RCM inter-model variability. A statistical emulator of the dynamic crop model is developed in order to analyze the impact on maize yield of weather variability within the growing season. Partial least square regression was used to develop a statistical emulator of the WOFOST model. Sensitivity analysis of weather variability during the growing season revealed that maize yield most critically depends on weather conditions between 90 and 110 days after sowing, which coincides with the silking and tasseling period. High temperatures, low relative humidity and low rainfall during this period negatively affectmaize growth, leading to a decrease in dry matter production. Comparison between simulated maize yield (water limited) and potential yield variability reveals that precipitation during the growing season has a decisive impact on yield variability at the selected locations.

The ensemble-based approach used in this study, in which RCM simulations are corrected for bias prior to their use as input in the crop model, can also effectively be applied for other crops and locations. Integrating different crop models into an established probabilistic framework could be used inorder to estimate the impact of crop model selection on yield variability and compare it to parametric uncertainty and RCM inter-model variability.

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