Simulation of maize yield in current and changed climatic conditions: Addressing modelling uncertainties and the importance of bias correction in climate model simulations

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Appropriate knowledge and understanding of the impact of climatic variability on agricultural production is essential for devising an adaptation strategy. Climate change impact studies have to cope with the cascade of uncertainties that enter at different levels of modelling (e.g., emission scenario, climate model structure, impact assessment models). Our study aims at addressing these uncertainties through an ensemble probabilistic approach, which accounts for uncertainties in climate model simulations as well as parametric uncertainties in a dynamic crop model, when simulating maize (*Zea mays L.*) growth and development. Simulations from eight regional climate models were used in combination with 10,000 different parameter sets from a dynamic crop model, reflecting biophysical uncertainties.

Since regional climate model simulations can be subject to systematic biases, the use of such simulations to create impact assessment models can lead to unrealistic results. We therefore determined the importance of bias correction of simulated meteorological variables prior to their use as input data in a dynamic crop model. Statistical bias correction generally improved 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 and corrected RCM simulations in a case in which the RCM is not capable of realistic simulations of long term trends of the meteorological variables under consideration.

Raw and corrected RCM simulations were used as input to the WOFOST model. Using biased RCM simulations as input to the crop yield model further increased the bias in yield simulations, since many processes in the crop show a non-linear response to meteorological variables. Simulated yield was greatly underestimated in the case of raw RCM simulations. It is therefore important to correct RCM simulations for systematic biases prior to their use in crop model simulations on a local level. It should be emphasized, though, that RCMs that underestimated the number of wet events during the growing season, produced the highest yield deviations, when used as input to the WOFOST model (even after bias correction).

Using bias corrected climate model simulations in an ensemble probabilistic approach resulted in probability distributions of expected yield changes at three locations in Slovenia. Yield is expected to decrease on average between 10% and 16% in the 2050s and between 27% and 34% in the 2090s, while inter-annual variability is expected to increase compared to the control period between 1961 and 1990.

Variance decomposition of the ensemble yield projections was performed in order to determine the RCM inter-model variability and crop model parameter uncertainty. Ensemble yield variability was decomposed into RCM structural uncertainty, WOFOST parameter uncertainty 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 showed the parametric uncertainty of the WOFOST model to be negligible compared to RCM inter-model variability. The inter-annual variability of maize yield is expected to increase in future climate. Furthermore, projected changes in mean maize yield during the 2050s and 2090s are comparable or even higher than inter-annual yield variability, making the signal of yield change less uncertain at the selected locations.

A statistical emulator of the dynamic crop model was 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 affect maize growth, leading to a decrease in dry matter production. Comparison between simulated maize yield (water limited) and potential yield variability revealed 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. Similar studies, integrating different crop models into an established probabilistic framework, could be beneficial, in order 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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