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Multi-wheat-model ensemble responses to interannual climate variability

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A B S T R A C T

We compare 27 wheat models' yield responses to interannual climate variability, analyzed at locations in Argentina, Australia, India, and The Netherlands as part of the Agricultural Model Intercomparison and Improvement Project (AgMIP) Wheat Pilot. Each model simulated 1981–2010 grain yield, and we evaluate results against the interannual variability of growing season temperature, precipitation, and solar radiation. The amount of information used for calibration has only a minor effect on most models' climate response, and even small multi-model ensembles prove beneficial. Wheat model clusters reveal common characteristics of yield response to climate; however models rarely share the same cluster at all four sites indicating substantial independence. Only a weak relationship ($R^2 \leq 0.24$) was found between the models' sensitivities to interannual temperature variability and their response to long-term warming, suggesting that additional processes differentiate climate change impacts from observed climate variability analogs and motivating continuing analysis and model development efforts.

1. Introduction

Process-based crop simulation models have become increasingly prominent in the last several decades in climate impact research owing to their utility in understanding interactions among genotype, environment, and management to aid in planning key farm decisions including cultivar selection, sustainable farm management, and economic planning amidst a variable and changing climate (e.g., Ewert et al., 2015). In the coming decades climate change is projected to pose additional and considerable challenges for agriculture and food security around the world (Porter et al., 2014; Rosenzweig et al., 2014). Process-based crop simulation models have the potential to provide useful insight into vulnerability, impacts, and adaptation in the agricultural sector by simulating how cropping systems respond to changing climate, management, and variety choice. Such gains in insight require high-quality models and better understanding of model uncertainties for detailed agricultural assessment (Rötter et al., 2011). Although there have been a large number of studies utilizing crop models to assess climate impacts (Challinor et al., 2014a), a lack of consistency has made it very difficult to compare results across regions, crops, models, and climate scenarios (White et al., 2011a). The Agricultural Model Intercomparison and Improvement Project (AgMIP; Rosenzweig et al., 2013, 2015) was launched in 2010 to establish a consistent climate-crop-economics modeling framework for agricultural impacts assessment with an emphasis on multi-model analysis, robust treatment of uncertainty, and model improvement.

A crop model's response to interannual climate variability provides a useful first indicator of model responses to variation in environmental conditions (Arnold and de Wit, 1976). A simulation model's ability to capture historical grain yield variability has shown it can serve as a sensible basis on which to demonstrate the utility of crop models among stakeholders and decision-makers (e.g., Dobermann et al., 2000). Considering the effort required in collecting data and calibrating a crop model for a particular application, previous studies have often relied upon only a single crop model and limited sets of observational data. This approach overlooks differences in plausible calibration methodologies as well as biases introduced in the selection of a single crop model and its parameterization sets; all of which may affect climate sensitivities (Pirttioja et al., 2015). The final decision-supporting information may therefore be biased depending on the amount of calibration data available and the crop model selected for simulations.

Here we present an agro-climatic analysis of 27 wheat models that participated in the AgMIP Wheat Model Intercomparison Pilot (described briefly in the next section and more completely in the text and supporting materials of Asseng et al., 2013; and Martre et al., 2015), with a focus on how interannual climate variability affects yield simulations and uncertainties across models. This is just one of several studies to emerge from the unprecedented Wheat Pilot multi-model intercomparison and it is intended to contribute to the overall effort by highlighting important areas for continuing analysis, model improvement, and data collection. As most climate impacts assessments cannot afford to run all 27 wheat models, for the first time we examine the consistency of agro-climatic responses across locations, models, and the extent of calibration information to determine whether a simpler, smaller multi-model assessment may be a suitable representation of the full AgMIP Wheat Pilot ensemble. The design of the AgMIP Wheat Pilot also enables a novel comparison of yield responses to interannual climate variability and to mean climate changes, testing the notion that the response to historical climate variability provides a reasonable analog for future climate conditions. The purpose of this analysis is to identify differences in model behaviors, data limitations, and areas for continuing research and model improvement.

2. Materials and methods

2.1. The AgMIP Wheat Pilot

A total of 27 wheat modeling groups participated in the first