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Comparing simulated crop yields with observed and synthetic weather data

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ABSTRACT

Stochastic weather generators have been used in the development of climate scenarios which are input to agricultural simulation models that assess the climate impacts on crop growth and production. The synthetic data generated by a stochastic weather generator only mimic the observed weather data, thus discrepancies between the synthetic and the observed weather data often exist. For example, interannual variability in the synthetic data is often found to be weaker than in the observed data, i.e., the common problem of overdispersion. Here, we evaluate if the climate impact models are sensitive to such discrepancies. A stochastic weather generator (AAFC-WG) was used to generate 300 years long synthetic weather data for five Canadian locations, based on observed weather data for the baseline period of 1961–1990. The Decision Support System for Agrotechnology Transfer (DSSAT) v4.0 was employed to simulate crop growth and yield. Five major crops were simulated by the DSSAT model for three major soil types at each location, with 30-yr observed data and 300-yr synthetic data as weather input, respectively. Statistical tests were performed to investigate whether differences (both in mean and variance) of the simulated crop yields between the simulations with observed and synthetic weather data were statistically significant or not. Results showed that the differences in simulated crop yields were not statistically significant when synthetic weather data were used to substitute the observed data. Standard deviations of crop yield and biomass in simulations with synthetic weather data were, in 5 and 19% of all cases, respectively, found to be smaller by more than 20% to those simulated with observed weather. However, with only one exception, the differences in variances were not statistically significant. We conclude that reliable crop yield estimates can be obtained by combining the AAFC weather generator with the DSSAT crop growth models at the studied sites in Canada.

1. Introduction

Potential impacts of climate change on agricultural production, which is essential to global food supply and world food security, have been discussed on global, national and regional scales (e.g., Adams et al., 1990, 2003; Rosenzweig and Parry, 1994; Parry et al., 1999; Alexandrov and Hoogenboom, 2000; Aggarwal and Mall, 2002). Many of the assessments were carried out with field-scale dynamic crop simulation models, such as CERES (Ritchie et al., 1998) and CROPGRO (Boote et al., 1998), included in the Decision Support System for Agrotechnology Transfer (DSSAT) (Jones et al., 1998, 2003), as well as the Erosion Productivity Impact Calculator (EPIC) (Williams et al., 1990; Easterling et al., 1992), the Crop Growth Monitoring System (CGMS) (Boogaard et al., 1998) and CLIMCROP (Olesen et al., 2000).

The process-oriented crop models in DSSAT v4.0 have been extensively calibrated and tested with experimental data from field locations around the world (e.g., Sau et al., 1999 for CROPGRO-soybean; Carberry et al., 1989 for CERES-Maize; Kaur et al., 2007 for CERES-Wheat; Travasso and Magrin, 1998 for CERES-Barley; Griffin et al., 1993 for SUBSTOR-Potato, etc.). Recently, the CERES-Maize model in DSSAT was evaluated for simulating crop yield variability in a 50-yr long-term field crop rotation experiment in southern Ontario, Canada (Liu et al., 2011). The models have also been evaluated by running multiple simulations beyond the traditional field crop experiments with inputs that are not measured directly, but estimated from other published or unpublished sources (e.g., Carbone et al., 2003; Tsvetsinskaya et al., 2003). Such inputs include cultivar coefficients, crop management practices, soil properties, and climate scenarios. Such evaluations examine the capability of the models, not only for reproducing multiple year mean, but also for interannual variability of crop yields associated with climate variability. Because many researchers are interested in using crop models to evaluate climate change impacts on crop yields and production, the above-mentioned evaluations are crucial.

In addition to soil and crop management practices (e.g., crop cultivar selection, planting dates and fertilizer application), cli-

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mate input is obviously essential to crop simulations, especially for the purpose of assessing climate change impacts. Many studies have demonstrated the importance of climate scenarios in agriculture; for example: importance of variance change in climate scenarios (Mearns et al., 1996, 1997); the effect of spatial scale of climate change scenarios (Mearns et al., 1999a,b, 2001; Tsvetsinskaya et al., 2003); and methodologies used to construct climate scenarios (Barrow and Semenov, 1995; Barrow et al., 1996; Semenov and Barrow, 1997; Giorgi et al., 1998; Mavromatis and Jones, 1998, 1999; Mearns et al., 1999a,b; Semenov and Stratonovitch, 2010).

Many interactions between crops and weather are non-linear (Porter and Semenov, 1999, 2005). This implies that it is crucial to incorporate the variability (both intra-seasonal and inter-annual) of weather sequences to evaluate the effect of climate on agricultural production. There have been attempts to incorporate changes in climatic variability into climate scenarios (McGinn et al., 1999), but a methodologically more consistent approach is to use a stochastic weather generator (instead of historical data) in conjunction with a crop simulation model: a stochastic weather generator allows temporal extrapolation of observed weather data for agricultural risk assessment and provides an expanded spatial source of weather data by interpolation between the point-based parameters used to define the weather generator (Semenov and Porter, 1995). Furthermore, a stochastic weather generator can play an important role by providing flexibility in the construction of future climate scenarios at a location by introducing presumable climate changes or by linking possible climate changes derived from global or regional climate models (GCMs or RCMs). We adopted this methodology, i.e., using a stochastic weather generator and a crop simulation model, to assess climate change impacts on annual crop production in Canada.

The stochastic weather generator AAFC-WG (Hayhoe, 2000; Qian et al., 2004) was developed from the Richardson's weather generator WGEN (Richardson, 1981) by introducing empirical distributions for daily precipitation and the residuals of daily maximum and minimum temperatures to make the weather generator more suitable for diverse climates. The AAFC-WG was compared with the widely used weather generator LARS-WG (Semenov et al., 1998), and evaluated for its capability to reproduce common agroclimatic indices (Qian et al., 2004), for the parameter-perturbation scheme in order to generate climate scenarios for a changing/changed climate (Qian et al., 2005), as well as for the performance in reproducing daily extreme values (Qian et al., 2008). However, stochastic weather generators only generate synthetic weather data, i.e., random numbers that mimic the observed weather data; thus, discrepancies between the observed weather data and the synthetic ones are almost unavoidable. Therefore, it is important to compare simulations of climate impacts on crop yields with observed historical weather data and with synthetic weather data as input to crop simulation models, in order to verify if the simulation results are sensitive to the discrepancies between observed and synthetic weather data. Furthermore, the comparisons may be used as evaluation of the stochastic weather generator from the application prospect and provide useful information for improving stochastic weather generation algorithms.

In this study, we compared the simulation results from crop models included in DSSAT v4.0 run with observed weather data and with synthetic weather data generated by AAFC-WG for the baseline period 1961–1990. Five locations and five common crops were used in the comparison. This paper is not aimed at repeating the evaluation of the crop models in DSSAT v4.0; instead, we examine if the crop models are sensitive to the discrepancies between observed and synthetic weather data generated by a weather generator. Future studies will use crop models with climate change scenarios generated by the weather generator, to assess impacts on crop production. Data and methods are described in Section 2, followed by results and discussion in Section 3 and conclusions in Section 4.

2. Data and methods

2.1. Crop models

DSSAT v4.0 (Hoogenboom et al., 2003) is a modular based crop modelling system that incorporates more than 18 crops, as well as bare fallow. The system uses one set of code for simulating soil water, nitrogen and carbon dynamics, while crop growth and development are simulated with the CERES (cereals), CROPGRO (soybeans), SUBSTOR (potatoes) and CROPSIM (other crops) modules. DSSAT model developers and other scientists have tested the models against various single factors, such as crop yield, soil water, nitrogen, cultivar selection, planting date, and temperature (Jones et al., 2003; Alagarswamy et al., 2000; Bhatia et al., 2008; Boote et al., 1998; Hunt et al., 2001; Langensiepen et al., 2008; Soler et al., 2007; Stastna et al., 2010; Wang et al., 2009).

2.2. Locations, soils and crops

The locations are chosen to represent diverse agricultural climates, while the crops selected for simulation are the major ones grown in the regions represented by the locations under study. A total of five locations and five crops used in this study are shown in Fig. 1. Two sites (Beaverlodge and Swift Current) are on the prairies in western Canada, featuring very cold winters and relatively warm summers, with precipitation peaking in summer or early summer months. Spring cereals (barley and spring wheat) are the major crops grown on the prairies. Two other sites (London and Montreal) are located in central Canada, being cold in winter and warm in summer, with smoothly distributed precipitation throughout the year. A longer growing season, with more heat available at these sites than on the prairies, makes it possible to grow warm season crops (e.g., corn and soybean). Charlottetown in Atlantic Canada experiences relatively mild winter and summer temperatures with more precipitation (smoothly distributed) than in central Canada. The major crop grown in the region is potato. Monthly mean daily maximum and minimum temperatures and precipitation totals at the study sites are shown in Fig. 2 as 30-year means for 1961−1990 from observations together with the corresponding values from the stochastic weather generator AAFC-WG.

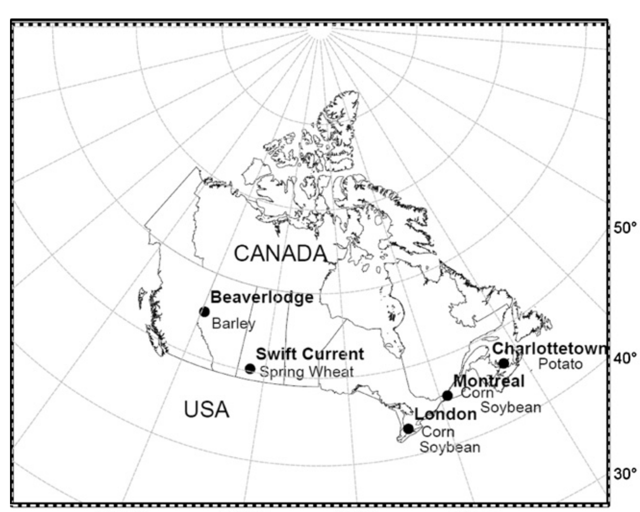

Fig. 1. Locations and major crops used in this study.