3.12 TWO-WAY COUPLING OF CROP-CLIMATE INTERACTIONS IN AREGIONAL CLIMATE MODEL

E. S. Takle[1], Z. Pan[1], W. Batchelor[1], and J. H. Christensen[2]

[1]Iowa State University, Ames, Iowa USA
[2]Danish Meteorological Institute, Copenhagen, Denmark

1. INTRODUCTION

Weather variability is the largest source of uncertainty to prediction of agricultural yields in US. Crop models constructed based on plant processes are used to simulate yields of major commodity crops. These models typically ingest weather data at daily time intervals to simulated progress toward biomass production, phenological development, and final grain yield.

Recent reports point to agricultural practices as contributing factors to regional weather characteristics that have adverse human impact. Sparks et al. (2002) suggest that extensive plantings of corn and soybeans in the Midwest are contributing to higher dew point temperatures, which exacerbate heat waves (Kunkel et al, 1996). These and other reports suggest a need for more direct coupling of time-dependent land processes into weather and climate models for more accurate simulation of crop impacts on local weather.

We are coupling crop models for corn and soybeans interactively into a regional climate model for improved representation of two-way interactions during the crop-growth period. Here we report the first stages of this research wherein we investigate one-way interactions as a means of identifying known weaknesses in the climate model that propagate to become major sources of uncertainty in the prediction of final yield by the crop model.

The coupled model is tested by comparing model-generated values for final crop yield with observed quantities for the specific years being simulated.

2. CROP AND CLIMATE MODELS

CERES-Maize

We use the crop-growth model CERES-Maize, a member of the DSSAT Crop Modeling System (DSSAT, 2002), to represent the evolution through the growing season of plant processes, biomass accumulation, and final yield. It predicts plant growth and development on a daily basis as a result of inputs of management, genetic, and pest information, as well as daily weather (solar radiation, precipitation, and max and min temperatures). The model simulates carbon and nitrogen accumulation in vegetative and reproductive components, root growth, root water uptake, and various interactions between stress and growth.

Regional Climate models

We use three regional climate models for the development of the coupled modeling system. Our long-term goal is to fully couple the crop model into the regional climate model version of MM5 (Grell, 1993). For identifying weaknesses in regional climate models as a source of input to crop models we use two unique datasets generated by a closely related regional climate model, RegCM2 (Giorgi, 1993a, b), and a second regional climate model, HIRHAM (Christensen et al., 1997). The results of coupled model sensitivity tests reported herein are based on simulations done with RegCM2 and HIRHAM as described by Pan et al (2001). These simulations were for a domain covering the continental US at 50-km resolution for the 10-yr period of 1979-1988. The regional models were forced at 6-hr intervals with lateral boundary conditions outside the continental US provided by the NCAR/NCEP reanalysis.

3. RESULTS

Precipitation is a key input variable to the crop model that accounts for a large measure of interannual variability in crop yields. We first evaluated the capability of the regional climate models (RegCM2 and HIRHAM) to simulate precipitation for the growing season at Ames, IA. Results, shown in Fig. 1, indicate that there is better agreement between the two models than there is between models and observations.

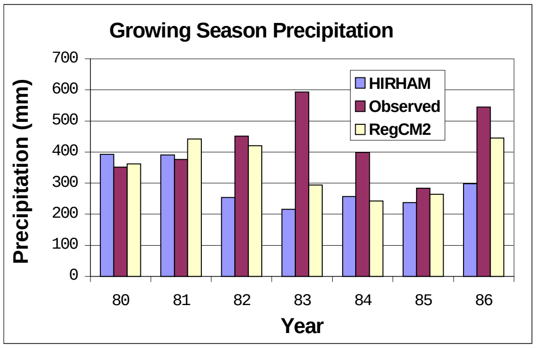

Figure 1. Growing season precipitation as simulated by RegCM2 for 10 years as compared with observed amounts for Ames, IA.

Corresponding Author: Eugene S, Takle, 3010 Agronomy Hall, Iowa State University, Ames, IA Email: gstakle@iastate.edu

In some years the models are able to simulate the seasonal total quite well, but in some years (notably 1983) both models fail to capture the large seasonal total. There is a general tendency for both models to predict lower values than observed in all years. Table 1 gives a summary of totals for the 10-year simulation period.

Table 1. Growing Season Precipitation Summary (all values in mm)

	Mean	St. Dev.
Observed	446	114
NCEP-Driven:		
RegCM2	341	87
HIRHAM	275	73

Seasonal total precipitation is not an accurate measure of plant response and final yield, however, because crops are sensitive to the amount and timing of individual rain events. To examine the characteristics of model-simulated precipitation events we plotted the distribution of daily total rainfall amounts during the May to August portion of the growing season. Results, shown in Fig. 2 for RegCM2, reveal that the model simulates too many low precipitation events and not enough events in the range most usable by a crop such as corn, which develops a deep root system by the middle of the growing season. In Fig. 3 we plot just the range of daily totals considered to be most effective in promoting crop development. Although the model simulates a large number of events in this range, the distribution is skewed toward lower daily totals with too few at the higher end of the range.

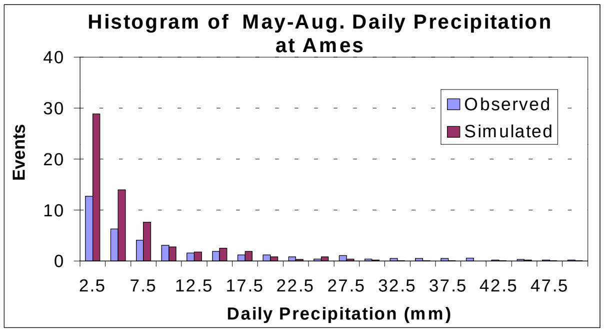

Figure 2. Distribution of daily rainfall amounts as simulated by RegCM2 for May-August in 1979-1988.

We used observed weather from Ames, IA to drive the crop model to assess the capability of the model to simulate local yields when it is driven by local weather. The validation data on corn yields for Ames, IA were taken from annual yields for the north-central reporting district of Iowa and therefore represent a regional average rather than results from a single locale. Results, given in Fig. 4, show that the crop model has higher interannual variability than the observed values. This suggests that the model is highly sensitive to interannual variability of precipitation.

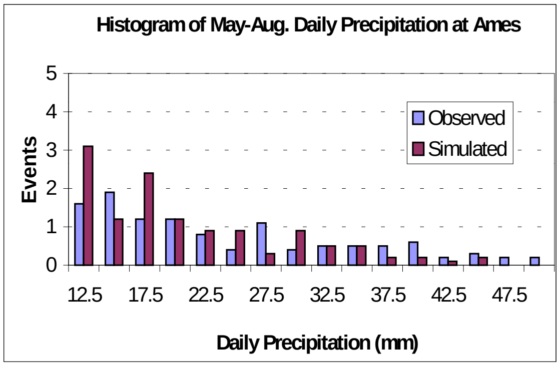

Figure 3. Distribution of daily rainfall amounts in the range most useful to the crop as simulated by RegCM2 for May-August in 1979-1988

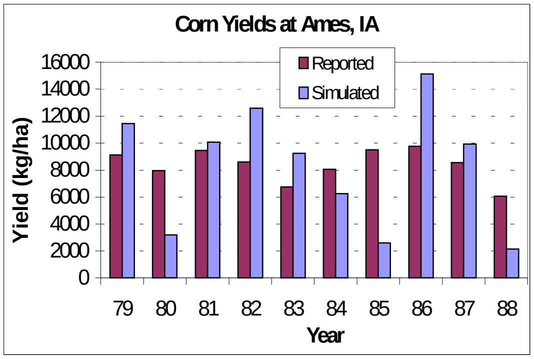

Figure. 4. Corn yields for Ames, IA as reported for the north-central crop reporting district and simulated by the crop model using weather conditions reported at Ames, IA.

We used the results of the regional climate models as input to the crop model to evaluate yields for the sub-period of 1980-1986 for which growing season precipitation was available for both models. Results in Fig. 5 reveal that, as was shown for the growing season precipitation, the models tended to agree from year to year but frequently failed to capture the observed yields shown in Fig. 4. Table 2 provides a summary and comparison of means and standard deviations of yields produced by the two climate models in comparison with observed yields and yields produced by the crop model when supplied weather conditions observed at Ames, IA. Observed weather gives a quite good simulation of

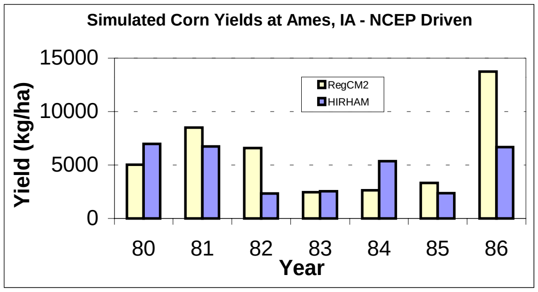

Figure 5. Simulated corn yields at Ames, IA for years for which growing season precipitation was available for both RegCM2 and HIRHAM.

Table 2. Yield Summary (all in kg/ha)

	Mean	St. Dev.
Observed Yields	8381	1214
Simulated by CERES with		
Observed weather	8259	4494
RegCM2/NCEP	5487	3796
HIRHAM/NCEP	3446	2716

mean annual yields for this location, but the interannual variability is much larger. The crop models systematically predict yields lower than observed and with larger interannual variability.

4. CONCLUSIONS

We have simulated corn crop yields for Ames, IA by use of a crop model driven by observed climatology, and climates simulated by regional climate models that use lateral boundary conditions outside the continental US for the period 1979-1988. We have compared our results with observed yields for these years in the crop reporting district that includes Ames.

Results show that the crop model is quite sensitive to interannual variation in precipitation. We conclude that for accurate simulations of corn yields by use of regional climate models, it will be necessary that the models provide the correct amounts of daily rainfall in addition to correct growing season totals.

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