P1.7 THE EFFECT OF SPATIAL SCALE OF CLIMATE CHANGE SCENARIOS ON CROP PRODUCTION IN THE SOUTHEASTERN UNITED STATES

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We use the CERES family of crop models to assess the effect of different spatial scales of climate change scenarios on the simulated yield changes of maize (*Zea mays L.*), winter wheat (*Triticum aestivum L.*), and rice (*Oryza sativa L.*) in the Southeastern United States. The climate change scenarios were produced with the control and doubled CO_2 runs of a high resolution regional climate model and a coarse resolution general circulation model, which provided the initial and lateral boundary conditions for the regional model. When considering the effect of climate change only at the individual state level, maize yields decreased in all states for both scenarios (−5 to −29%), but the differences in yields between the two scenarios were generally significant, the coarse scale showing the larger decreases. Winter wheat yield decreases (−27 to −48%) were larger than those for maize but the differences in yields produced by the two climate change scenarios were insignificant in most states. With elevated CO_2 for maize the signs of yield changes from base differed between the two scenarios in three states (positive for the fine scale). For maize the primary climate variable that explained the contrast in the yields calculated from the two scenarios is the precipitation during grain fill leading to different water stress levels. Temperature during vernalization explains some contrasts in winter wheat yields. Scenario scale resulted in significantly different rice yields, but mainly because of low variability in yields. With adaptation, the contrasts in the yields of all crops produced by the scenarios were reduced but not entirely removed. Yield changes from base remained negative for winter wheat but became positive for corn and rice. Our results indicate that spatial resolution of climate change scenarios can be an important uncertainty in climate change impact assessments, depending on the crop and management conditions.

1. INTRODUCTION

Many studies have considered the possible impacts of climate change on agriculture, in both global (Rosenzweig and Parry, 1994; Parry et al., 1999) and regional (Adams et al., 1990; Alexandrov and Hoogenboom, 2000) contexts. An important problem with most of the impact studies is the scale mismatch between the site-level scale of impact (i.e., agroecosystem) models and that of general circulation models (GCMs) used to generate climate change scenarios (i.e., grid boxes several hundred km on a side). Mearns et al. (1999, 2001a) examined the effect of scenario spatial scale in the Great Plains of the US for corn, wheat, and soybeans and found that scale of the scenarios greatly affected the results in terms of percentage change in yields. In this study we investigate further the uncertainty introduced into climate change agricultural assessments by this scale mismatch.

We use the Crop Estimation through Resource and Environment Synthesis (CERES) family of crop models (i.e., CERES-Maize [Jones and Kiniry, 1986; Hoogenboom et al., 1994], CERES-Wheat [Ritchie and Otter, 1985], and CERES-Rice [Godwin et al., 1993]) to simulate maize, winter wheat, and rice responses to climate change scenarios produced with a coarse-resolution general circulation model (GCM) and a fine resolution regional climate model (RCM). We consider three cases for each climate scenario: the effects of climatic change only, combined climatic change and elevated CO_2 effects, and the above plus effects of adaptations to climatic change.

2. MATERIALS AND METHODS

2.1. Crop Models

The crop models used in this study (version 3.1 of CERES-Maize, CERES-Wheat, and CERES-Rice) simulate carbon, water, and nitrogen balance for the

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maize, wheat, and rice crops, respectively. Modeled processes include crop phenological development, biomass production and allocation among plant parts (including roots, stems, leaves, and grain), and senescence of leaves. The models simulate both the potential biomass production and the water-, temperature-, and nutrient-limited production.

We used the crop, soil, and management data reported in a series of crop variety trial bulletins compiled by agricultural experiment stations in the Southeast to test the CERES (─Maize, ─Wheat, and ─Rice) models for their ability to reproduce both the mean and the year-to-year variability in measured yields over series of years throughout the study region. For details of crop model evaluations we refer the reader to Tsvetsinskaya et al. (2002).

2.2. Climate Scenarios

A present-day baseline climate data set and two climate change scenario data sets were constructed for the study region, which is comprised of nine states (Alabama, Arkansas, Florida, Georgia, Louisiana, Mississippi, North Carolina, South Carolina, and Tennessee). The present-day (1960-95) baseline climate data set was compiled from a network of about 500 cooperative weather stations and gridded on a 50 km equal area grid (the grid of the regional model). Each grid box was assigned a single weather station nearest to its center. The baseline data set included daily incident solar radiation, maximum and minimum air temperature, and precipitation, and served as the base for all scenarios.

A coarse resolution climate change scenario was produced from climate simulations with the Australian Commonwealth Scientific and Industrial Research Organization (CSIRO) global circulation model (hereafter referred to as the General Circulation Model, or the GCM). A fine resolution climate change scenario was produced from runs with the National Center for Atmospheric Research Regional Climate Model version 2 (hereafter referred to as the Regional Climate Model, or the RCM), which was nested in the CSIRO GCM. Both the GCM and the RCM were run under the current CO_2 conditions (330 ppmv CO_2) and the doubled CO_2 conditions (660 ppmv CO_2), assumed to be equivalent to the total effect of all greenhouse gases. The spatial resolution of the RCM was 50 km (414 RCM grid boxes covered the southeastern domain) and that of the GCM was 3.2° latitude by 5.6° longitude (11 GCM grid boxes covered the study domain). Climate change scenarios were constructed by applying monthly differences (for temperature) and ratios (for solar radiation and precipitation) between the $2xCO_2$ and control climate simulations to the present-day baseline climate data set. For RCM scenarios, a unique monthly value was applied to each of the RCM grids. For GCM scenarios, eleven unique deltas / ratios covered the southeastern domain (i.e., all RCM grids within one GCM grid box received the same deltas / ratios). Details on the baseline and climate change scenarios can be found in Mearns et al. (2002).

2.3. Southeast Regional Assessment Setup

We tested the effect of the GCM and RCM climate scenarios in the crop models for three different future climate cases: (*a*) *climate change only* (CO_2 concentration of 330 ppmv is assumed for the crop models); (*b*) *elevated* CO_2, i.e. climate change plus CO_2 fertilization effect (CO_2 concentration of 540 ppmv is assumed for the crop models); and (*c*) *adaptation*, i.e. case *b* plus adaptation to climate change (a shift in sowing dates that insured the highest yields on a state level [regional level for rice]). A *baseline* case was also produced where the crop models used observed climate data and CO_2 concentration of 330 ppmv. For specifics of crop model setup for each of the cases, we refer the reader to Tsvetsinskaya et al. (2002).

Under each of the seven cases (i.e., baseline case plus three climate cases for each of the two climate change scenarios), annual yields (in kg/ha) were computed for each RCM grid box. This produced 14,904 yield values (414 RCM grid boxes x 36 growing seasons [1960-1995]) for each case for corn, and 14,490 yield values (414 RCM grid boxes x 35 growing seasons) for each case for winter wheat. Rice yields were only simulated along the Mississippi river valley (a subdomain of 83 RCM grid boxes that spans from Arkansas to Louisiana and Mississippi), thus for each case for rice 2,988 yield values were produced (83 RCM grid boxes x 36 growing seasons).

Soil series from the State Soil Geographic (STATSGO) data base (USDA, 1994) were gridded on the RCM 50 km equal area grid. We determined soil physical properties of the dominant (i.e., the most extensive) soil series and the best (i.e., best agricultural soil in the grid box without considering its percentage) soil series (see Tsvetsinskaya et al. [2002] for details). All the crop model simulations described in this paper used the best agricultural soil series. Dryland and irrigated runs were produced (irrigated only runs for rice) and no nitrogen stress was assumed.

For each crop, we performed statistical tests on the significance of the simulated yield changes. We tested (1) whether yields produced under each climate change scenario were significantly different from those produced under the base case, and (2) whether the yields produced in the RCM cases were significantly different from those produced in the GCM cases. We employed linear modeling techniques to test the hypothesis that mean yields from *all* the scenarios were equal. If the hypothesis was rejected, then pairwise comparisons were performed to test whether selected pairs of scenarios produced significantly different mean yields. To take into account the spatial autocorrelation in the simulated yields, a mixed models approach was employed.

3. RESULTS AND DISCUSSION

We calculated the multi-year mean yields for the baseline climate scenario and for each of the six climate change scenarios/cases for the southeastern study region for maize, winter wheat, and rice. Percent changes from the base yield obtained under each of the six climate change cases were also calculated. We examined the response of the CERES crop models on three different spatial scales: at the scale of the entire Southeast region, at the scale of the individual states, and at the 50 km grid scale (i.e., the scale of the observational and RCM data sets).

On the domain-wide level, for the climate change only cases, all crops show decreases in yields compared to the base yields (Tables 1, 2, and 3). While yields decrease for all crops and all scenarios/cases, there is no significant difference between the GCM and RCM scenario yields for corn and wheat, whereas RCM scenario yield decreases are significantly larger than the GCM scenario decreases for rice. For the elevated CO_2 cases, simulated yields go up compared to the climate change cases, but the change from base conditions remains negative for all crops/scenarios. With adaptation, domain-wide percentage changes in yield for corn and rice are positive for both climate scenarios. Wheat, which showed the least change in yield with adaptation from the elevated CO_2 case, still has negative yield changes, with larger losses simulated with the RCM scenario compared to the GCM.

Table 1. Percent changes in simulated yields of dryland corn from base for the coarse- and fine-resolution cases.

State	Base Yield (t/ha)	% change from base yield Coarse 330	Fine 330	Coarse 540	Fine 540	Coarse 540+A	Fine 540+A
Alabama	7.6	-12	-5	3#	9	13	20
Arkansas	7.4	-12	-5	2#	9	22*	25
Florida	6.3	-21	-7#	-5#	10	-3#	11
Georgia	7.5	-19*	-16	-5#*	-1#	1#*	6#
Louisiana	7.9	-14	-9	-2#	3#	6*	4#
Mississippi	8.4	-14	-8	-3#	3#	9*	12
North Carolina	9.1	-15	-34	-1#	-18	-1#	-9
South Carolina	8.3	-19	-29	-5#	-14	0#*	-6#
Tennessee	9.8	-14	-25	-3#	-12	-1#	-5
Whole SE	**8.1**	**-15***	**-16**	**-2#***	**-2**	**6#***	**6#**

*Fine- and coarse-scenario yields are NOT significantly different (α=0.05).
#Climate change yield is NOT significantly different from base yield (α=0.05).
330=case with climate change only.
540=case with climate change plus elevated CO_2.
540+A=adaptation cases.

Table 2. Percent changes in simulated yields of dryland winter wheat from base for the coarse- and fine-resolution cases.

State	Base Yield (t/ha)	% change from base yield** Coarse 330	Fine 330	Coarse 540	Fine 540	Coarse 540+A	Fine 540+A
Alabama	4.7	-35*	-33	-24*	-22	-24*	-22
Arkansas	4.4	-30	-24	-19	-12	-19	-12
Florida	3.3	-65*	-59	-59*	-51	-58*	-50
Georgia	4.4	-37*	-34	-26*	-23	-25*	-22
Louisiana	4.0	-48	-38	-40	-28	-40	-28
Mississippi	4.4	-38*	-34	-28	-23	-28	-23
North Carolina	5.2	-31*	-29	-19*	-18	-19*	-17
South Carolina	4.6	-30*	-31	-18*	-18	-18*	-18
Tennessee	5.1	-32*	-27	-21*	-16	-21*	-15
Whole SE	**4.5**	**-36***	**-32**	**-26***	**-21**	**-25***	**-21**

*Fine- and coarse-scenario yields are NOT significantly different (α=0.05).
**Climate change yields are significantly different from base yield in all cases (α=0.05).

Table 3. Percent changes in simulated yields of irrigated rice from base for the coarse- and fine-resolution cases.

Region	Base Yield (t/ha)	% change from base yield					
		Coarse 330	Fine 330	Coarse 540	Fine 540	Coarse 540+A	Fine 540+A
Whole SE*	9.6	-16	-19	-3	-5	2	6

*Data set included only 83 RCM grids. Climate change yields are significantly (at the 0.05 level) different from base yield in all scenarios. GCM and RCM yields are significantly (at the 0.05 level) different in all three comparisons (α=0.05).

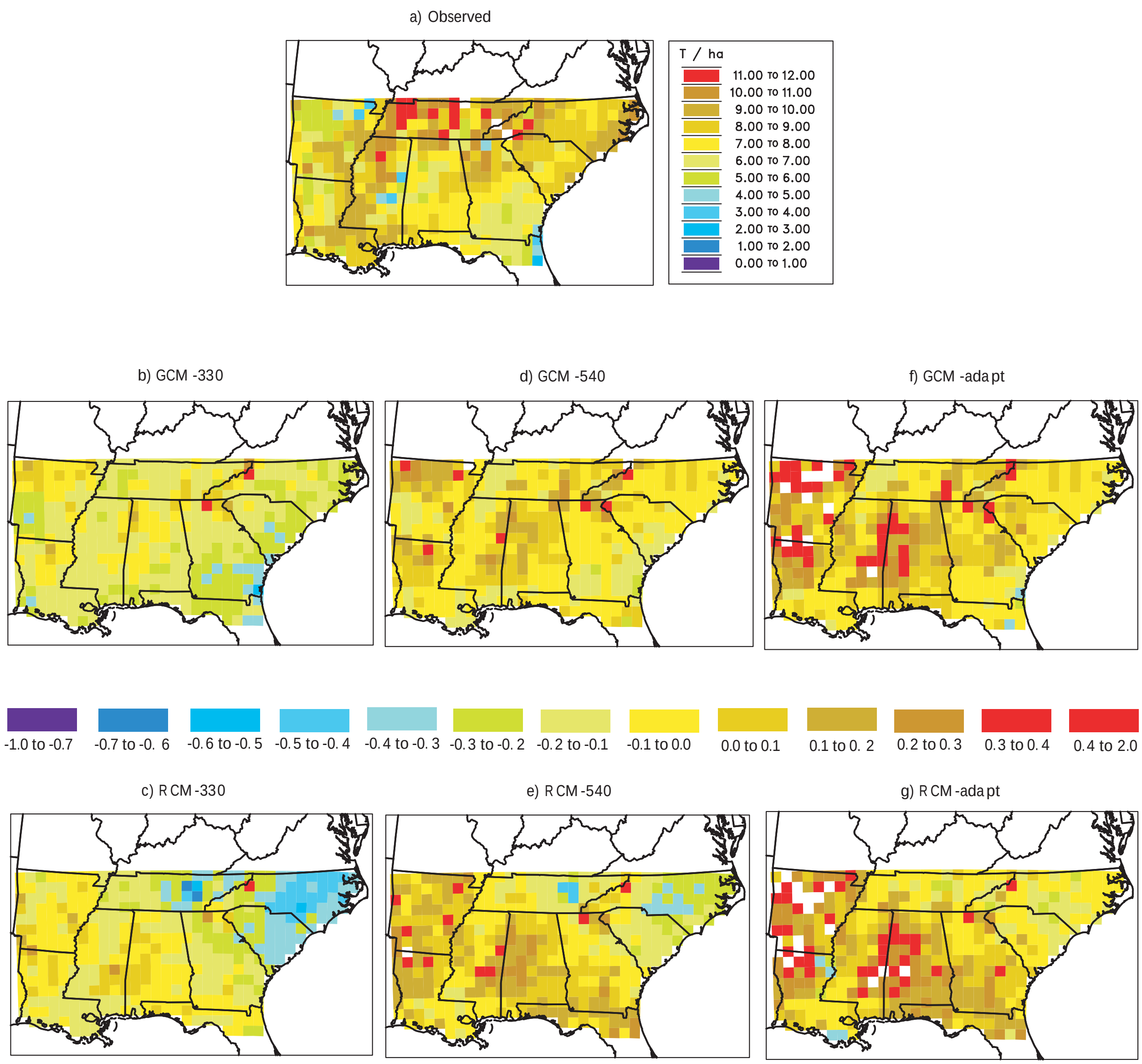

Figure 1(a-g). Simulated 36-year mean yields of dryland continuous corn under baseline climate (a), and fraction change in simulated corn yields from baseline under the six climate change cases (b-g).

Growing season lengths decreased for all crops (climate change only and elevated CO_2 cases). For corn, growing season lengths decreased by about two weeks. With adaptation, decreases were smaller, about 5 days for the RCM and 11 days for the GCM yields. Decreases for winter wheat ranged from 0 to 20 days, and for rice from 16 to 19 days. Decreases were also smaller for rice under adaptation (about 4 days).

When we considered the changes in yield aggregated at the state level, contrasts were more complex. Corn yields, which had been similar for both scenarios on the domain wide scale, exhibit greater scenario contrasts on the state level (Tables 1, 2, and 3). For the climate change only cases, the GCM scenario produces significantly larger decreases for most states, compared to the RCM scenario, particularly in the southcentral and delta states. With elevated CO_2, corn yields showed percent increases in five states with the RCM scenario, but only in Alabama and Arkansas with the GCM scenario. However, the GCM yields in all states showed no significant difference from the baseline, while the RCM yields showed significant increases in three states and significant decreases in three states. This reflects the greater spatial variability in the RCM climate scenario. With adaptation, corn yields increased for most southern states for both scenarios, but still decreased for North and South Carolina and Tennessee for the RCM scenario. Contrasts in yield changes between the scenarios diminished under the adaptation case, indicating that adaptations mitigate the unique spatial scale effects of the climate change scenarios.

Wheat yields decreased considerably from the base for all cases for both climate change scenarios, but the differences between the yields calculated for the respective GCM and RCM cases are largely not statistically significant (Table 2), which is due to both small absolute yield differences between the scenarios in some states (e.g., the Carolinas) and the effect of large temporal variability in yields in others (e.g., coefficient of variation, CV, of over 0.5 in Florida). Temporal CVs of the yields simulated from the GCM were always greater than (or equal to) those of the yields from the RCM (not shown), and CVs were always higher for the southern tier of states compared to the northern tier, reflecting the effect of more frequent crop failures in the south and under the GCM (compared to the RCM) scenario.

Rice, an irrigated crop, was the only crop that showed statistically significant differences between the GCM and RCM scenarios on the domain wide level of aggregation (the only level of analysis for rice) [Table 3]. Rice yields were very homogeneous across the rice domain, with the spatial coefficient of variation between 0.05 and 0.06 across all seven cases. Temporal variability in rice yields was also extremely low, with temporal CV rarely exceeding 0.1. Such an extremely low yield variability resulted in statistical significance of the seemingly small (i.e., 2%) yield differences.

On the 50 km grid level (see Figure 1[a-g] for corn), yield changes were yet more spatially (and temporally) variable, in terms of the range difference from baseline, than on the state level. The greatest yield losses were simulated for the climate change only cases, for all three crops. Yields went up under the elevated CO_2 and especially the adaptation cases, but adaptations did not overcome the negative impacts of the climate change in all parts of the domain.

For each crop, we investigated what aspects of the contrasts in climate scenarios were most responsible for the differences in crop yields under the two climate scenarios. Yield differences between the GCM and RCM climate change scenarios were regressed on climate variable differences during the growing season. We used an "all possible regressions" approach, which finds the best possible model fit (based on maximum R^2) that can be obtained using a particular number of predictors. We analyzed the best models containing one to three predictors. Note that additional crop model runs using a uniform soil across the Southeastern domain were used for this analysis so that the spatial variability of the soils did not confound the analysis. The percent changes in the yields from the baseline using the uniform soil were very similar to those produced with the cases using spatially varied soils.

The contrast in the size of increase in precipitation in May and the contrast in direction of change in June (particularly during the grain filling stage) were key explanatory factors for corn for the central and southwestern parts of the domain. Corn yield differences were positively related to the May and June differences (i.e., higher precipitation causes higher yields). In the Carolinas, temperature contrast (GCM-RCM) in June was strongly negatively correlated with yields (i.e., higher temperatures caused larger yield decreases).

For winter wheat, temperature differences in January, February, and March explain up to 90% of the variance in GCM and RCM yield differences in the southern and central parts of the domain. In the north, the key explanatory variables are the same as for the south plus December and April temperature differences. The winter temperature increase, compared to baseline climate, greatly affected vernalization, leading to widespread crop failures, more pronounced in the GCM scenarios. More frequent crop failures in the GCM cases in turn lead to substantially lower mean yields under the GCM compared to RCM scenario. Specifically, the crop failures were a result of the crop failing to vernalize completely, and thus the crop does not reach the point of terminal spikelet formation. Hence, grain fill is never reached and no yield is produced. For rice, the key explanatory variables are July maximum (and to a lesser degree, minimum) air temperature differences between GCM and RCM, which explain 67% of the variance.

4. CONCLUSIONS

Our analysis indicates that the spatial scale of climate change scenarios substantially affects the simulation of changes in crop yields on several levels of spatial aggregation, but that the effect is also crop and management specific. Under dryland conditions corn was the most affected and wheat the least. The effect is especially apparent at the finest spatial resolution (i.e., individual 50 km grid boxes), but persists up to the state level. The differences tend to be averaged out on the domain-wide level. While we see largest differences between the crop yield effects of the RCM and GCM scenarios when climate change only conditions are imposed, as we account for additional environmental and management factors, such as physiological effects of elevated CO_2 levels and effects of adaptations, the unique spatial scale effects of the climate change scenarios tend to diminish, but are not eliminated.

It should be noted that while the inclusion of spatial detail in scenarios clearly affects results, we still cannot conclude that we have more confidence in the results with higher resolution. This study is a sensitivity analysis of the scale effect of scenarios. More research will have to be conducted before we are able to establish the added value of high resolution climate change information.

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