ISSUES IN THE IMPACTS OF CLIMATE VARIABILITY AND CHANGE ON AGRICULTURE

Applications to the southeastern United States
Guest Editorial

As the title of this special issue suggests, the commonality of the papers included herein is a focus on the interaction of agriculture with climate variability and change in the southeastern United States. The range of topics covered is considerable, from climate modeling to remote sensing to economics. All papers result from two major projects funded by NASA MTPE and the U.S. EPA NCQERA. In addition, the USDA-ERS funded part of one study concerning economics of agriculture under climate change.

We chose to study the Southeast because it possesses characteristics that we assumed would further our main project interests, which included exploration of the uncertainty of spatial scale of climate scenarios, uncertainties in modeling adaptation in agricultural assessment work, and exploration of relationships between large scale climate modes, vegetation condition, and local daily weather variables. A central question thus arises: do the papers represent true regional studies, being fundamentally about the southeastern U.S., or do the papers concern methodological/conceptual studies, wherein the Southeast should be viewed as an apt application region? Most of the papers are hybrids, embodying characteristics of both types of studies (regional and methodological), but on balance the Southeast serves more as an apposite application region.

The Southeast is an agriculturally diverse region, where a wide variety of crops are grown. It produces about 40% of the national total value of cotton, 23% of rice, and a considerable portion of the total value for most vegetables and citrus fruits. While not significant in terms of total national production, wheat, corn, soybean, and sorghum are also produced (Hansen et al., 2001). It is a region that could be highly vulnerable to climate change given its current climate, which is probably above the optimum (in terms of temperature), for such crops as wheat and soybeans. It is also a region with physiographic characteristics that suggest it might benefit from application of higher resolution scenarios for a climate change assessment of agriculture. Such characteristics include the presence of mountains (Appalachians), complex land-use patterns, and complex coastlines. Furthermore, it is a region that has been considerably studied from the point of view of the influence of large scale climate modes, such as El Niño-Southern Oscillation, on its climate, vegetation, and crop production. This collection of characteristics and previous research indicated thus that the Southeast would act as an excellent application region for our research goals.

The first five papers form an integrated project concerning the uncertainty in agricultural and economic impacts that result from varying scales of climate change

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information. The issue of spatial scale of climate scenarios has long been a topic in climate impacts analysis (Gates, 1985), because of the mismatch of spatial scale between the climate information available from global climate models (on the order of 100s of kms) and the scale needed by many impacts models (on the order of meters to 10s of kms). In the past ten years or so techniques have been developed to provide higher resolution information regarding climate change, such as regional climate modeling and statistical downscaling (Giorgi and Mearns, 1991, 1999). Yet only recently have studies been pursued that carefully examine the effect of higher resolution information (in contrast to coarse resolution) on calculated agricultural impacts of climate change on various temporal and spatial scales (Mearns et al., 1999, 2001; Easterling et al., 2001, Guereña et al., 2001).

The project presented in these five papers takes these types of studies one step further by integrating crop model results in the context of regional economic impacts of changes in crop yields. We apply climate, crop, and economic models to explore the significance of spatial scale of scenarios for an agricultural integrated assessment. The first paper (Mearns et al., 2003) describes the climate scenarios, the next three papers (Tsvetsinskaya et al., 2003; Carbone et al., 2003; Doherty et al., 2003) present the crop modeling results, and the fifth paper (Adams et al., 2003) the economic results.

Coarse and fine scale climate scenarios for the southeastern U.S. were used, formed from general circulation model (GCM) control and $2 \times CO_2$ experiments and those of a regional climate model that employed boundary conditions from the GCM experiments. Thus, the two scenarios are dynamically related, and exhibited similar climate changes on a very broad regional scale, but detailed subregional changes were sometimes quite different. For example, both scenarios exhibited decreased precipitation in the summer, but these decreases were larger in the high resolution model, especially on the coastal plain.

The two scenarios, with horizontal resolutions of 300 and 50 km, respectively, were applied to a series of crop models representing many of the crops grown in the Southeast (corn, cotton, rice, sorghum, soybean, and wheat) to determine the effect of the resolution of the scenarios on the calculations of changes in yield (from baseline conditions) at various levels of spatial aggregation (all of the Southeast, state level, and 50 km grid level).

Most of these crop types have been modeled in numerous climate change impacts studies. Cotton, however, has less commonly been studied. Our project presents the first region-wide application of a complete cotton model in a climate change study. The changes in crop yields were then used in an agricultural economic model to determine if the spatial scale of the scenarios affects regional economics. For this latter study, crop yield changes for the other major cropping areas of the United States were also calculated, using two other sets of regional climate model runs that covered the rest of the U.S. These runs used the same regional model as for the Southeast and were driven by boundary conditions from the same GCM.

Results indicate that the effect of the scale of climate change scenarios varies with the particular crop considered, as well as the scale of aggregation of the cropping results and the management treatment (with or without adaptation measures). Some simulated crops, such as cotton, soybean, and sorghum, experienced substantial contrasts in changes in yield, regardless of the spatial aggregation level of the yield results. Others, such as corn, showed little contrast when results were aggregated to the entire Southeast region, but exhibited significant contrasts on the state and 50-km level. Winter wheat, however, exhibited very little contrast regardless of the aggregation level. Each cropping paper analyzes, for the individual crops, which differences in the climate changes are most responsible for the differences in the changes in yields. For virtually all crops, adaptation tends to mitigate the contrasting effects of the scenarios, as would be expected, since adaptation attempts to minimize the effect of all adverse climate conditions.

When all cropping results were used as input to the agricultural economic model, ASM, the coarse scale scenario clearly demonstrated a more positive effect on the overall national economic well-being in the agricultural sector, both with and without adaptation. When considering regional productivity, some regions, such as the Southeast, fare considerably worse than others, and one might expect to see agriculture, aside from cotton production, diminish as an economic force in the region as a whole. The northern and southern plains and the Pacific coast states fare better with the high resolution scenario, but the opposite is true for all other regions of the U.S.

The over arching conclusions of this integrated project are that the scale of scenario matters both in terms of changes in crop yields and in final national and regional economic results. Indeed, we were surprised that the level of aggregation and 'filtering' of the crop yields in the economic model did not essentially wash out the contrasting effects of the climate scenarios.

It is important to note that we do not claim that one scenario is in any way more plausible than the other. It must be remembered that in contrast to scenarios constructed from more recent transient climate model runs, our scenarios use equilibrium doubled CO_2 runs, and thus are less complete. However, evidence is mounting that higher resolution scenarios likely provide more realistic responses to changes in forcing (e.g., due to increased greenhouse gases) than coarse scale scenarios in regions with high relief (mountainous areas), complex coastlines, or areas with complex land-use patterns (Giorgi et al., 2001).

The southeastern United States contains elements of all three physiographic conditions. Resolving the Appalachian Mountains with the regional climate model affects the final climate changes simulated. Florida does not exist as a landmass in the coarse scale GCM, and land use in the Southeast is much more spatially complex than in the central Great Plains, for example. Hence this study demonstrates the importance of considering spatial scale of scenarios when constructing climate impact assessments, at least for agriculture, and we strongly recommend that more experiments exploring the effect of scenario spatial scale be performed.

Ultimately the uncertainty in impacts assessments due to spatial scale of climate scenarios must be put in the context of the other major uncertainties inherent in projecting future climate, particularly uncertainties in global climate model sensitivity and trajectories of greenhouse gases in the future (Mearns et al., 2001b). The European project PRUDENCE (Christensen et al., 2002) is well on its way to exploring the uncertainty of spatial scale in the context of other uncertainties. It is hoped that the United States and Canada will develop a similar project for North America.

In the integrated project discussed above, adaptation to climate change through management adjustments was an important element, but it was treated in rather simple, conventional terms. Instantaneous and complete adaptations were allowed, by altering the sowing date and/or the cultivars to maximize yields under the climate change. This approach assumes that farmers are perfectly clairvoyant. In reality, we know adaptation will be a much more temporally complex process. In the study by Easterling et al. (2003) the high resolution climate scenario (described above) is used to demonstrate the importance of the way adaptation is actually modeled in climate change agricultural studies. The authors, using the simulation of corn as the example crop, applied the high resolution scenario for the Southeast to a series of different means of modeling agricultural adaptations to climate change.

Easterling et al. (2003) introduce a new approach to adaptation: the adoption of technological innovation over time, which assumes slow growth at the beginning, followed by accelerating and then decelerating growth. Such a process is often modeled as a logistic curve. The more conventional 'clairvoyant' adaptation model was also applied. Results demonstrate that the more realistic logistic approach is less effective in ameliorating the effects of climate change. These results suggest that the 'clairvoyant' farmer assumption may be as unrealistic as the 'dumb' farmer assumption used early on in agriculture impacts studies, wherein no adaptation is assumed. The results also reinforce the decision in the integrated study described above to calculate the economic effects of changed crop yields with and without clairvoyant adaptation considered. We assumed that realistic levels of crop yield change would fall somewhere between these cases.

The final two papers in the special issue approach the issue of climatic variability and agriculture in the Southeast from the point of view of large scale circulation indices. The Peters et al. paper presents an analysis of the response of southeastern vegetation to El Niño-Southern Oscillation events using a remotely sensed vegetation condition index, the normalized difference vegetation index (NDVI) developed from the Advanced Very High Resolution Radiometer (AVHRR). Three phases of ENSO, warm, cold and neutral, and two main classes of vegetation, cropland and forest, were considered over the entire Southeast region for the period 1989–99. The major finding is that vegetation condition for both crop and forest is optimal in the neutral ENSO phase and poorest in the warm phase. This study represents the most extensive analysis to date of ENSO and vegetation condition for the southeastern U.S. using remotely sensed data, and it highlights the importance of considering the neutral ENSO phase.

Interestingly enough, in contrast to the strong signals Peters et al. (2003) found in NDVI based on ENSO phase, Katz et al. (2003), in an attempt to relate local daily climate conditions to ENSO phase, found that ENSO was not a strong determinant of daily weather variables, such as frequency of precipitation, for stations throughout the Southeast. They found instead that a Bermuda High Index (BHI), which measures the location and strength of the Bermuda High, has a stronger correlation with most daily weather factors, such as maximum and minimum temperature and daily probability of precipitation. With an easterly shift in the position of the Bermuda High, these three variables were higher than when the BHI indicated a further westerly position.

The original purpose of the Katz et al. (2003) study was to provide methods for downscaling climate information using a statistical technique. The hope was that, through these techniques, statistically generated high resolution scenarios could be formed by conditioning parameters of weather generators based on different values of the index. While a complete scenario for use in agricultural impacts work was not formed, the study provides insights into the complexities and limitations of developing scenarios on a daily timescale by conditioning on large scale indices.

The contrast in the results of the two papers suggests that vegetation condition, as represented by the NDVI, integrates variations in climate/weather in ways that may not be evident on a daily time scale, nor when analyzing weather variables individually. An interesting follow on study would be to subset the NDVI according to the BHI.

As is often the case with long-term projects, the research we produced was, in some instances, considerably different from our original plans. In the course of the project we came upon interesting problems and issues that have led to new projects, such as examination of uncertainties in input data for agricultural assessments, a project currently funded by the NSF-MMIA program. Given the interdisciplinary nature of the overall project, we also learned yet again how challenging it can be to appreciate the knowledge bases and conceptual frameworks of disciplines not our own. The members of the project team included climatologists, geographers, economists, remote sensing specialists, and statisticians. In face of the growing emphasis on interdisciplinary studies, performing the research described in this issue, beyond providing interesting findings, has also prepared us to go on to other interdisciplinary projects with greater wisdom and confidence.

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National Center for Atmospheric Research,
Environmental and Societal Impacts Group,
P.O. Box 3000,
Boulder, CO 80307-3000,
U.S.A.

LINDA O. MEARNS
Guest Editor