P3.30 IMPROVEMENTS ON CO$_2$ FLUX ESTIMATION OVER THE CENTRAL U.S. USING EXPLICIT CROP PHENOLOGY IN A REGIONAL CLIMATE MODEL

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1. INTRODUCTION

Atmospheric CO$_2$ concentration is an important climate forcing, and CO$_2$ flux over the earth's surface is a key component of the atmospheric CO$_2$ budget. Since observed CO$_2$ flux is rarely available over extensive areas, most reported CO$_2$ flux values have been estimated by climate models. Carbon sequestration by the crops is only crudely represented in models. For example, most climate models use climatological or static crop growth and development that do not change from year to year, indistinguishable between flood and drought years. Typically crops are considered as one land use type – cropland – in both general circulation models (GCMs) and regional climate models (RCMs), without differentiating between, for example, corn, soybean, or even wheat. Furthermore, without an explicit crop model computing the crop phenology, these models have to assume interannually fixed crop growth and development. GCMs are the main tools to estimate global CO$_2$ and energy budgets. Therefore the estimated budget components might contain large uncertainty because of the lack of explicit crop phenology.

2. THE COUPLED MODEL SYSTEM

To improve the computation of CO$_2$ flux (i.e., photosynthesis) from crops land we coupled the latest versions of crop models with the regional climate model. The crop models include CERES (Tsuji et al., 1994) for corn and CropGro (Boote, et al, 1998) for soybeans. Other crop models are available and can be incorporated more easily in our coupled model since CERES and CropGro both have sub-models accounting for multiple crops. We use the regional climate model MM5 (Grell, et al., 1993) whose land surface module was replaced by the LSM (Bonan, 1996), which allows for subgrid parameterization in addition to being a complete land surface model.

Compared with other models, our coupled model has the following features:

- explicit representation of different crop variety by computing individually their development and growth,
- dynamical crop phonology that varies from year-to-year depending on water and nitrogen dynamics,
- subgrid-scale treatment of land use heterogeneity,
- complete water and carbon budgets including soil maintenance, crop respiration and photosynthesis,
- two-way interactive feedback between crop development and climate through internal water and nutrition cycle in the model, and
- upgraded soil moisture module that uses a refined soil water retention relation.

3. THE EXPERIMENTS

Three growing seasons were simulated using the fully coupled model – a drought year (1988), a flood year (1993), and a normal year (1999). The model integration domain covers the whole continental U.S. with 52 km horizontal resolution. This study focuses mostly on the Midwestern U.S. where intensive crops are cultivated. Since the LSM accommodates sub-grid land use types, we assumed in our experiments that over the Midwest the surface is 85% covered by crops and 15% by bare soil. We further assumed that all crops consist of corn (in later experiments we use a combination of corn and soybean based on actual crop acreages). We namely replace the "generic crop" with corn in the Midwest while the land use types remain the same as used in typical models.

4. RESULTS

The CO$_2$ and moisture fluxes simulated using the coupled model are examined, mostly in the Midwest region where the crop types are altered.

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4.1 Carbon and Water Fluxes over the Midwest

Leaf area index (LAI) is a key factor in the determination of CO_2 and water fluxes. The typical land surface model assumes a monthly crop phenology that does not change from year to year (Fig. 1a). Compared with the interactive phenology in the coupled model, the uncoupled model gives a LAI that is too large in the early growing season and too small in the later growing season, although the seasonal mean is about right. The CO_2 and water vapor fluxes are strongly dependent on LAI in early growing stage. The biases in LAI have asymmetric effects on the fluxes. The low bias in LAI in the late growing season does not affect fluxes much. However, the positive bias in the early growing season, when LAI is less than 1, has a strong effect on these fluxes (Fig. 1b). The uncoupled model considerably overpredicts transpiration rates. During about the first 55 days after planting, the uncoupled model always has higher transpiration rates.

The difference in CO_2 flux is even larger. For the uncoupled model run, the crop started noticeable carbon fixation even during the time period when the crop had not even germinated. The amount fixed keeps increasing with time to about 12 μmol CO_2 $s^{-1}m^{-2}$ at day 60 after planting. On the other hand, the coupled model run gave positive CO_2 flux (into the atmosphere) due to the soil respiration (Fig. 2) during this period. The crop photosynthesis offsets soil respiration at about day 40; the crop field, including soil, then starts to sequester CO_2 from the atmosphere. In the run without the explicit crop model activated over the Midwest, the CO_2 flux shows a strong carbon sink over the region. With an explicit crop model the simulation shows a weaker sink; the difference between with and without explicit crop model is broadly positive, suggesting the uncoupled model overestimates CO_2 flux compared with the coupled model. The difference between the two model runs seems larger in the drought year when heat stresses were severe.

North America has been identified as a carbon sink (e.g., Fan, et al., 1998), which was the key factor for the so-called missing carbon. The carbon budget components were computed however based on coarse-resolution GCMs that cannot resolve small-scale heterogeneity. More importantly, the GCMs do not explicitly represent crop varieties. Based on our results thus far, it seems that the carbon sink could have been exaggerated because the models used for budget computation did not have explicit crop models. Therefore the missing carbon may still be an unresolved issue, thus worth further study.

4.2 The Two-way feedback

The feedback of interactive crop development has a large effect on precipitation on the local scale. The local feedback on rainfall can have both positive and negative effects (Fig. 3), depending on atmospheric instability (Pan et al. 1996). This positive and negative feedback on rainfall, and thus crop development, is likely responsible for the positive and negative areas of CO_2 difference shown in Fig. 4.

4.3 Effects of Key Parameters in LSM- Carboxylation Rate Capacity

The LSM used in this study is the first version, and now its 2nd version (LSM2) is available (Bonan et al., 2002). Instead of upgrading to LSM2, we adopted one key change: the selection of maximum carboxylation rate of Rubisco at 25 C (V_{max25}). V_{max25} is directly proportional to limiters on the photosynthesis rate, and thus influences CO_2 fluxes. Following formulations in LSM2, we increased V_{max25} by about 30% depending on vegetation types, except for the shrub category that remains unchanged.

As expected, the increase in V_{max25} caused the photosynthesis rate to increase broadly (Fig. 5). The largest reduction in net CO_2 flux is along the Appalachian Mountains where predominant land use types are broad leaf forests. The total net CO_2 flux that includes vegetation photosynthesis, maintenance, and soil respiration changed from positive to negative after the V_{max25} alteration (not shown). One possible reason for the positive net CO_2 flux over limited regions is likely associated with the warm bias of the model that introduces excessive soil and vegetation respiration while limiting growth. The new V_{max25} values apparently improve CO_2 flux in these warm regions. Figure 6 shows the time series of average flux over a sub-region of 250x250 km^2 centered at the Illinois-Kentucky border as indicated by a solid circle in Fig. 5. The spurious positive spikes are decreased while negative ones are larger in magnitudes for the new simulation.

5. SUMMARY AND CONCLUSION

We have coupled two crop models interactively with a regional climate model and tested accuracy and efficiency of the climate/ecosystem coupled model under high temporal and spatial resolutions. This newly coupled model incorporates individual crop variety, dynamic crop phonology, subgrid-scale land use heterogeneity, and two-way interactive feedback between crop development and atmospheric conditions. The newly coupled model gives noticeably smaller downward CO_2 fluxes and transpiration rates compared to those from the uncoupled model, especially during the first 50 days after planting when flux differences can reach a factor of 2 because of a relatively large difference in leaf area in the two models during early growing season. These new results suggest that the downward CO_2 flux estimated previously using uncoupled, course-resolution models may have been overestimated over the intensively cultivated U.S. Midwest and thus the notion of North America being responsible for the so-called "missing carbon" may need further evaluation using crop-climate coupled models.

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(a)

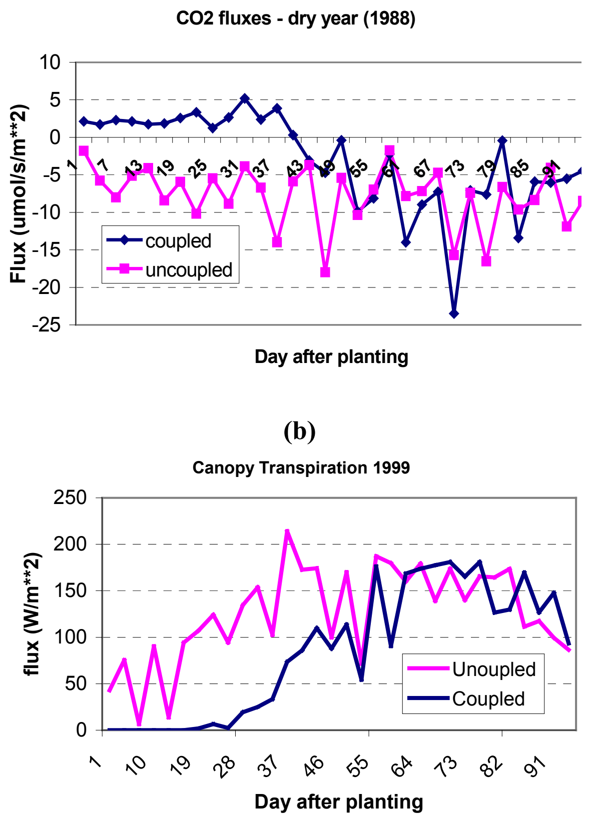

Fig. 1. Temporal variation of leaf area index (a) and daytime mean transpiration (b) at Ames, Iowa, simulated by the coupled model.

(a)

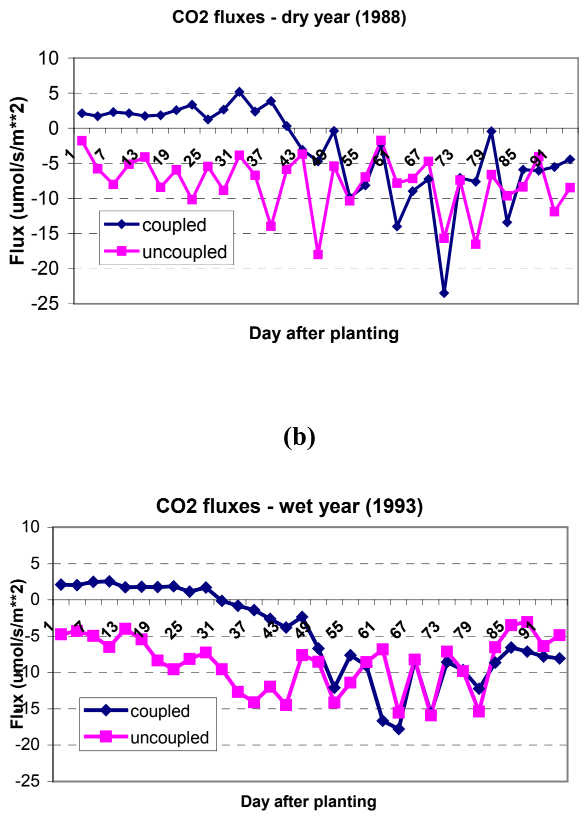

Fig. 2. Simulated net canopy CO_2 fluxes near noon over northeast Iowa. (a): 1988 and (b): 1993.

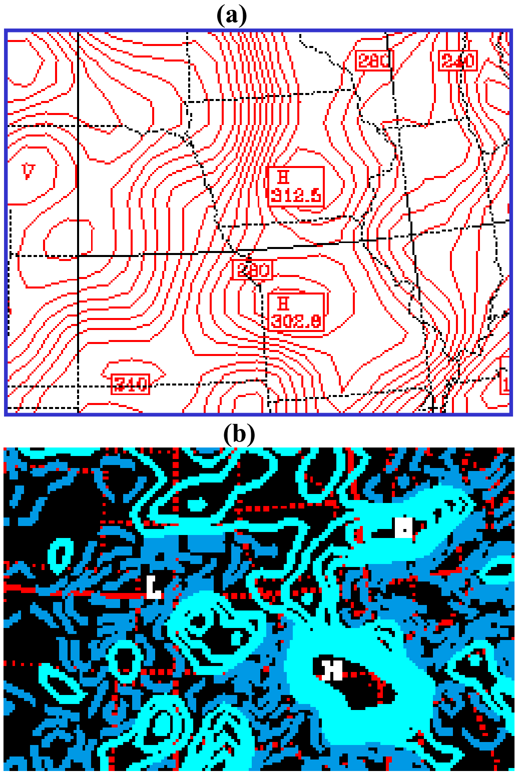

Fig. 3. (a) Simulated precipitation (mm) by the coupled model (May-July, 1993). Contour interval is 10 mm. (b) The difference in precipitation between coupled and uncoupled model runs. Dashed lines are negative.

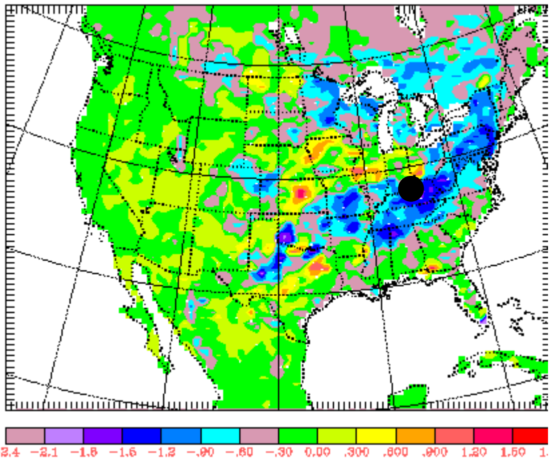

Fig. 5. Total net CO_2 flux (μ mol $m^{-2}s^{-1}$) difference between simulations with new and old V_{max25} values averaged during the whole growing season.

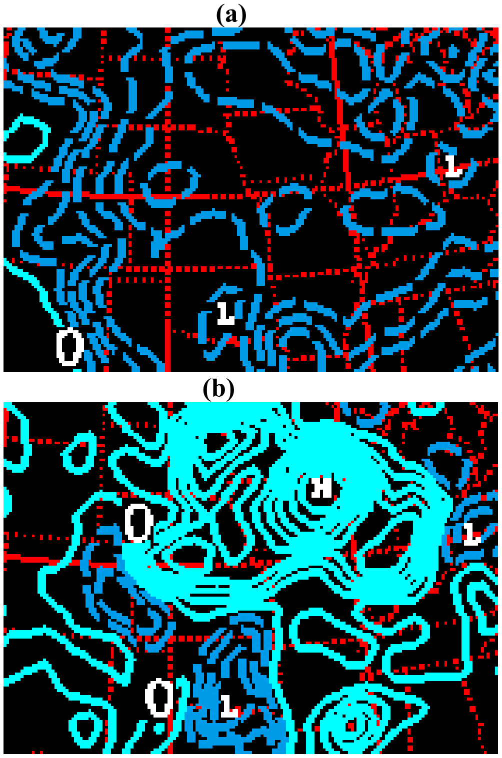

Fig. 4. Simulated net canopy CO2 fluxes averaged in growing season and precipitation (May-July, 1993). (a) CO_2 flux simulated by the coupled model. Values are in umol CO_2 m-$2s^{-1}$; Contour interval is 2; dashed lines are negative (sink). (b) The difference between coupled and uncoupled runs. Contour interval is 0.5.

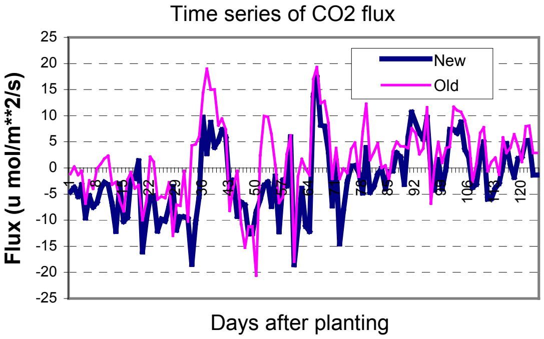

Fig. 6. Comparisons of sub-domain-averaged CO_2 fluxes between experiments using new and old V_{max25} values.