Project name: Land-Atmosphere Exchanges Across the Midcontinental Region of North America: Processes, Scaling, and Evaluation

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Project Abstract: Croplands are important man-made ecosystems. The majority of the US cropland area is concentrated in the Midwest, which has the highest uptake of carbon dioxide (CO_2) during the growing season of crops; overall, croplands encompass about one fifth of the total US land area. Since most of the decisions are made by humans, croplands are a good test bed for studying and analyzing the anthropogenic influence on the global and regional carbon cycle and land-atmosphere CO_2 exchanges. We have used a coupled land-atmosphere modeling system (SiBcrop-RAMS) in analyzing the regional scale carbon and other exchanges across the croplands in continental North America, subject to interannual variability of weather, management, and existing and expected changes in climate across the continent.

Development of a new, fine resolution crop model (i.e. SiBcrop; Lokupitiya et al., 2009) and coupling it with RAMS (a regional atmospheric model developed at Colorado State University; Pielke et al., 1992), was one of the major achievements of this project. Originally the land surface model named Simple Biosphere (SiB; Sellers et al., 1986; 1996a; 1996b) model, did not have a good representation of the dynamic events and growth stages associated with the managed cropland ecosystems. Therefore we incorporated a crop specific phenology and physiology scheme within SiB and developed SiBcrop, to further improve prediction of carbon and other land-atmosphere exchanges in croplands. Predictions from SiBcrop have been tested against the observed fluxes and other data (i.e. biomass, LAI, crop yields) at several AmeriFlux eddy covariance flux tower sites with different crop management practices in the US mid western region. The coupled SiBcrop-RAMS simulations were performed for the recently established Ring2 towers region encompassing Iowa; the coupled SiBcrop-RAMS modeling system yielded better results compared to the coupled original SiB-RAMS coupled model. Regional scale SiBcrop-RAMS simulations have also been performed for the MCI region and North America in 2007 (SiBcrop being used only crop areas, at 40 km resolutions). Preliminary results from these simulations are encouraging). We have also used the model to simulate climate change impacts or the impacts from CO_2 fertilization. This work is still being continued, and currently some preliminary results are available at site level.

Project Activities:

Overall Project objectives:

- Improve the functionality of the coupled atmosphere-biosphere modeling system, SiB-RAMS by incorporating the dynamics of agroecosystems through development of crop-specific phenology and physiology schemes.

- Testing the improved offline model for specific sites, perform high-resolution simulation of Intensive Observing periods using the fully coupled SiBccrop-RAMS model.

- Evaluation of the simulations from the fully-coupled model against airborne transects of eddy covariance measurements, atmospheric trace gas distributions, and cropland carbon inventory measurements made by other investigators involved in the Mid Continent Experiment.

- Develop high resolution vegetation and other maps for the MCI region.

Project progress:

Evaluation of the performance of original SiB over croplands, code and parameter modification for better simulation of croplands

Original SiB model was not specifically designed for cropland ecosystems, and there were certain drawbacks in simulating the specific events and growth processes relevant to croplands, which are managed ecosystems. For instance, crop rotation, specific developmental stages, harvest events, etc., were well not represented. Therefore the code and certain parameters were modified for better simulation of crops. This was done as a project component during the first year.

Development and coupling of crop specific phenology and physiology models with SiB

Originally SiB has used remotely sensed NDVI information in deriving leaf area index (LAI) and fraction of photosyntheically active radiation (fPAR) in estimating photosynthesis, respiration and other land-atmosphere exchanges. However, LAI based on NDVI had a remarkable deviation in terms of seasonality and magnitude compared to the obsereved LAI in the field. Therefore, development of crop specific phenology models for predicting LAI and carbon fluxes, and coupling those models with SiB to develop a new fine resolution crop model (SiBcrop; Figure 1) was a major project component. So far we have developed crop specific phenology and physiology models for crops having both C3 (soybean, and wheat), and C4 (corn) physiologies. Corn and soybean phenology models were developed and coupled to SiB during the year 1 of the project. However, further testing and refining of the coupled SiB-phenology scheme for these crops (the new model termed SiBcrop) has been an ongoing process.

SiBcrop was run to simulate the presence of corn and soybean in several Ameriflux eddy covariance flux tower sites (i.e. Bondville, IL, Mead, NE (both rain fed and irrigated sites), and Rosemount, MN, Ames, IA, etc.), using the meteorological forcing from 6-hourly NCEP-DOE Reanalysis 2 (Kalnay et al., 1996) weather data. The new model, remarkably improved the prediction of the CO_2 fluxes (sub hourly, diurnal, and seasonal; Figure 2) and LAI (Figures 3 and 4) compared to the original model, which had LAI prediction based on remotely sensed NDVI. In addition SiBcrop closely predicted the yields and biomass in different plant pools, as observed at the AmeriFlux field sites (Figure 5).

During the second year of the project, a phenology and physiology scheme for winter wheat was developed within SiBcrop. Crop specific parameter values were added and a phenology scheme corresponding to different growth stages and specific growth requirements by winter wheat, such as vernalization prior to reproductive, was developed. These specific events and growth stages were set based on growing degree-days and a crop-specific carbon allocation scheme, the same way as in the phenology and physiology scheme for the other crops within the model. The predicted carbon fluxes from the winter wheat simulations by SiBcrop were compared against the Ameriflux eddy covariance flux tower sites with winter wheat (Figures 3 and 4). Site level performance of SiBcrop for these major crops was further tested during the third year of the project, by participating in the NACP site interim synthesis activities, in which the comparisons were made against the site-specific observations and the predictions from several other land surface models.

Regional scale runs of coupled SiBcrop-RAMS

The coupled SiBcrop-RAMS simulations were performed for the recently established Ring2 towers region encompassing Iowa (Corbin, 2009; Miles, 2009; Fig. 6). The spatial distribution of corn and soybean in the Ring2 domain was prescribed according to a crop coverage map derived by Hansen et al. (2008) from high-resolution satellite vegetation data. We aggregated the 56-m imagery to a 1 km grid, and computed area fractions for each crop on a 10 km simulation grid. The SiBCrop model was called separately for each crop in each grid cell, and their contributions were weighted by fractional area to obtain grid-cell mean fluxes of energy, water, momentum, and CO2. The model was run over most of North America on a coarse 40-km grid, with a 10-km "nested grid" over the MidContinent region. The coupled SiBcrop-RAMS modeling system yielded better results compared to the coupled original SiB-RAMS (Fig. 6). The comparison of SiBcrop-RAMS simulations on the Ring 2 tower region was made against the calibrated CO_2 mixing ratio measurements by the NOAA Environmental Science Research Laboratory, Global Monitoring Division (formerly CMDL), and Ken Davis and his team at Penn State University (Figure 6).

Regional scale SiBcrop-RAMS simulations have also been performed for North America in 2007 (SiBcrop being used only for crop tiles, at 40 km resolution). The latter regional scale simulations were also used for the MCI synthesis, which compares top-down and bottom-up approaches for estimating regional scale carbon exchanges. Preliminary results from these simulations are encouraging, with significant improvement in the predicted carbon uptake by croplands during the summer time. These latter regional level simulations were performed during the third year of the project.

Research highlights

- SiBcrop has been able to simulate LAI, biomass, crop yields and carbon fluxes with better seasonality and magnitude, compared to the original SiB model. The new phenology scheme eliminated the need for using remotely sensed NDVI information in predicting carbon and other land-atmosphere exchanges in both rain fed and irrigated croplands.

- SiBcrop has been successfully coupled with RAMS, and the results from the simulations over the Ring 2 tower region has shown remarkable improvements in predicting carbon fluxes.

- Further testing of corn and soybean phenology scheme over several AmeriFlux eddy covariance flux tower was carried out.

- The phenology scheme for winter wheat was developed and evaluated against the observations at the AmeriFlux sites having wheat crop.

- A continental scale evaluation of carbon fluxes and biomass production by SiBcrop-RAMs system, with the input of 40-km scale crop maps for corn, soybean, and wheat has been performed for the year 2007.

- SiBcrop performance was further tested by participating in the MCI- and site interim-syntheses and regional scale analyses under the NACP, to further evaluate its performance against both observations and other models.

- During the 3-yr project period, the following presentations were made at the conferences/annual meetings on the outcome of the project:

  - Lokupitiya, E. Denning, S., Paustian, K., Baker, I., and Schaefer, K. 2007. Coupling crop specific phenology models with the Simple Biosphere Model (SiB) to improve the Land-Atmosphere Exchanges Across the US Midcontinental Region. Poster presentation at AmeriFlux meeting, Boulder, CO, held on Oct 17-18, 2007.

  - Lokupitiya, E. Denning, S., Paustian, K., Baker, I., and Schaefer, K. 2007. Using crop phenology models with SiB for improved prediction of carbon fluxes across the mid continental region of North America. Oral presentation at the Fall AGU meeting, San Francisco, CA, held on Dec 10-14, 2007.

- Lokupitiya, E. Denning, S., Paustian, K., Baker, I., and Schaefer, K. 2008. Predicting cropland carbon fluxes using SiBcrop. Oral presentation at chEAS meeting, Wisconsin, held on Aug 11-14, 2008.

- Lokupitiya, E., Denning, S., Paustian, K., Corbin, K., Baker, I., and K. Shaefer. 2008. Evaluation of the performance of SiBcrop model in predicting carbon fluxes and crop yields in the croplands of the US mid continental region. 41st Annual meeting of the American Geophysical Union. December 15-19, 2008, San Francisco, California, USA.

- Lokupitiya, E., Denning, S., Paustian, K., Corbin, K., Baker, I., and K. Shaefer. 2009. Prediction of carbon fluxes and crop yields using SiBcrop. North American Carbon Program Joint Workshop on Site-level Interim Synthesis, Regional and Continental Interim Synthesis. January 07-09, Oak Ridge National Laboratory, Tennessee, USA.

- Lokupitiya, E., Denning, S., Paustian, K., Corbin, K., Baker, I., and K. Shaefer, M. Hansen, K. Pittman. 2009. Simulation of carbon fluxes and prediction of crop yields within MCI region using SiBcrop. Second NACP (North American Carbon Program) All investigators meeting. February 17-20, San Diego, California, USA

- Lokupitiya, E., Denning, E. Paustian, K. Baker, I., Corbin, K., Shaefer, K., and A. Schuh. 2009. Estimation of carbon cycling in croplands using SiBcrop model. International Symposium on Soil Organic Matter Dynamics: Land Use, Management and Global Change. July 6-9, 2009, Colorado Springs, Colorado, USA

- Lokupitiya, E., Denning, E. Paustian, K. Baker, I., Corbin, K., Shaefer, K., and A. Schuh. 2009. Response of Carbon Fluxes in US Croplands to Changing Climate. 8th International Carbon Dioxide Conference. September 13-19, Jena, Germany.

- **Papers published**:

  - Lokupitiya, E., Denning, S., Paustian, K., Baker, I., Schaefer, K., Verma, S., Meyers, T., Bernacchi, C.J., Suyker, A., and M. Fischer. 2009. Incorporation of crop phenology in Simple Biosphere Model (SiBcrop) to improve land-atmosphere carbon exchanges from croplands. Biogeosciences, 6, 969-986.

  - Lokupitiya, E., Denning, S., Paustian, K., Baker, I., Schaefer, K., Verma, S., Meyers, T., Bernacchi, C.J., Suyker, A., and M. Fischer. 2009. Incorporation of crop phenology in Simple Biosphere Model (SiBcrop) to improve land-atmosphere carbon exchanges from croplands. Biogeosciences Discussions, **6**, 1903-1944.

Planned activities for the future:

We submitted a proposal for 1-year extension of this project, to develop fine resolution (1 km) crop maps for multiple years (2003 onwards), using the crop area information available at the National Agricultural Statistics Service (NASS) county level data and fine resolution (56 m) AWiFS crop images produced by the cropland datalayer of NASS, for performing SiBcrop-RAMS simulations on crop tiles across North America at 40 km resolution. Interannual variability of Carbon exchanges would have been studied. Predicted CO_2 mixing ratios would have been compared against the calibrated measurements from the network of tall tower measurements managed by NOAA. NICCR declined to support this work.

Other ongoing activities

Integration of agro-ecosystem modeling and analysis in the NACP Midcontinent intensive experiment in the future will be supported by NASA.

Studying the impact of climate change

It has been predicted that the current ambient CO_2 concentration will be doubled towards the latter half of the 21^{st} Century. There is significant uncertainty associated with how the agricultural ecosystems would respond to such changes in CO_2 and anticipated climate change impacts. Therefore we have also used SiBcrop model to simulate any impacts of CO_2 fertilization based on potential future climate change, anticipating that the outcome of our efforts will contribute towards improving knowledge on the subject. Given the differences in their anatomy and physiology, the response of C3 and C4 crops to CO_2 fertilization are different, as found in the chamber and FACE experiments. Elevated concentrations of CO_2 (compared to current levels) would cause enhanced rates of photosynthesis and reduced stomatal conductance. Although vast majority of C3 plants are known to show both these responses, C4 plants consistently show only reduced stomatal conductance, while the photosynthetic response is still debatable (Leaky et al., 2009). We envisage studying any differential response of C3 and C4 plants under several potential future climate change scenarios incorporating doubled CO_2 concentration, elevated temperature, and changes in precipitation. We adjusted the C3 physiology to incorporate the changes in specific leaf area and foliar total non-structural carbohydrates (Wand et al., 1999), to accommodate for the impact from increased CO_2 concentration. This work is still at preliminary stage, and only preliminary results are available at site level (Figure 7).

Further development of the model

In addition to incorporating additional crops (alfalfa, sorghum, rice), we also plan to further modify the respiration calculation in the model, using a simple microbial decomposition model. Total ecosystem respiration includes both autotrophic (plant) and heterotrophic (soil microbial) respiration. In original SiB, autotrphic respiration included canopy maintenance respiration, calculated based on a fraction of the maximum Rubisco Velocity (V_{max}), and a temperature based Q_{10} function. In SiBcrop, we replaced the half hourly autotrophic respiration calculation in SiB, with the growth and maintenance respiration calculation in the crop phenology and physiology scheme (Lokupitiya et al, 2009). We are further modifying the heterotrophic/soil respiration in SiBcrop, to incorporate decomposition scheme of litter and soil carbon pools. The heterotrophic respiration calculation in SiBcrop allows for the decomposition of litter left on the ground due to senescence and harvest removal. We have incorporated more realistic fractionation of aboveground and belowground litter among the ten soil layers, and more realistic distribution of root fractions for separate C3 and C4 crops.

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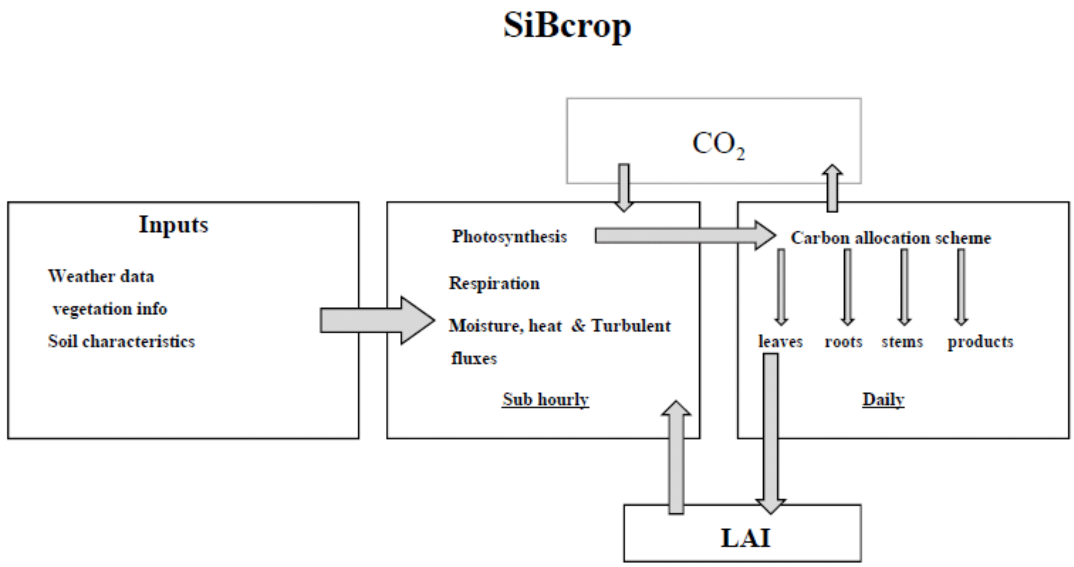


Figure 1. Basic methodological framework of SiBcrop model

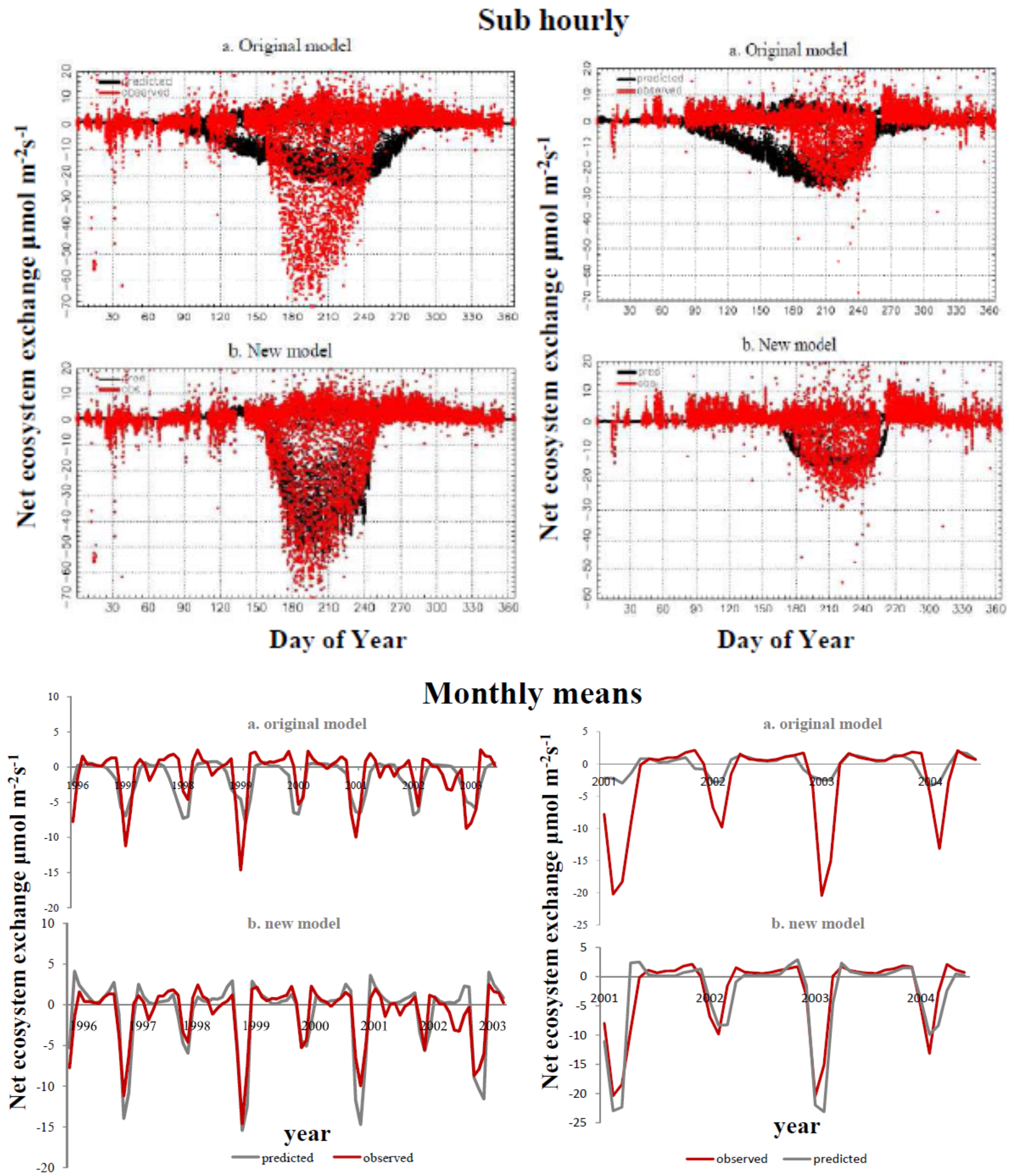
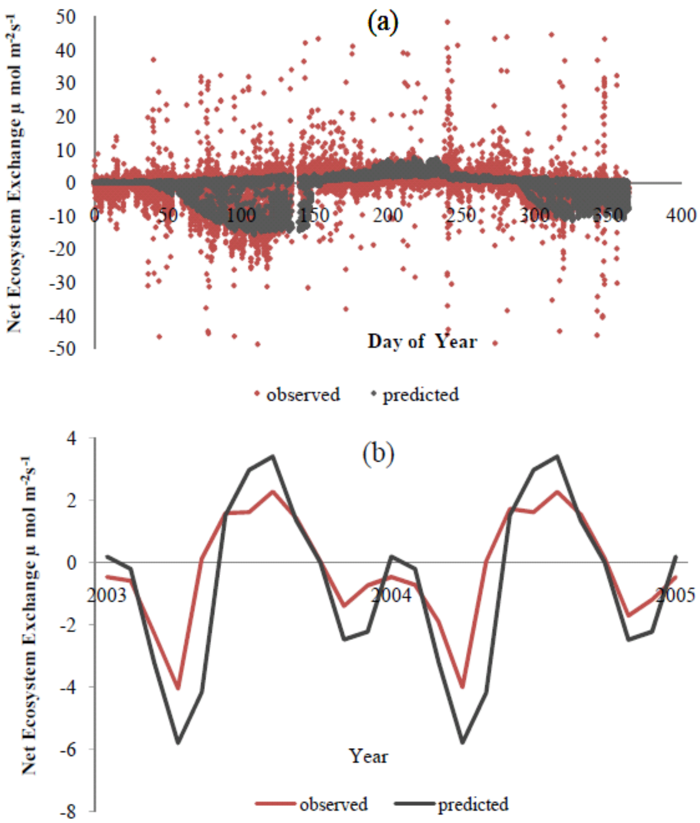


Figure 2. Net ecosystem exchange comparison of original model (SiB) against the new model (SiBcrop). Sub hourly NEE for corn (top left) and soybean (top right) in Bondville and monthly means of NEE for Bondville (bottom left) and Mead rain fed site (bottom right) showing the alternating presence of corn (odd numbered years) and soybean (even numbered years) in the field.



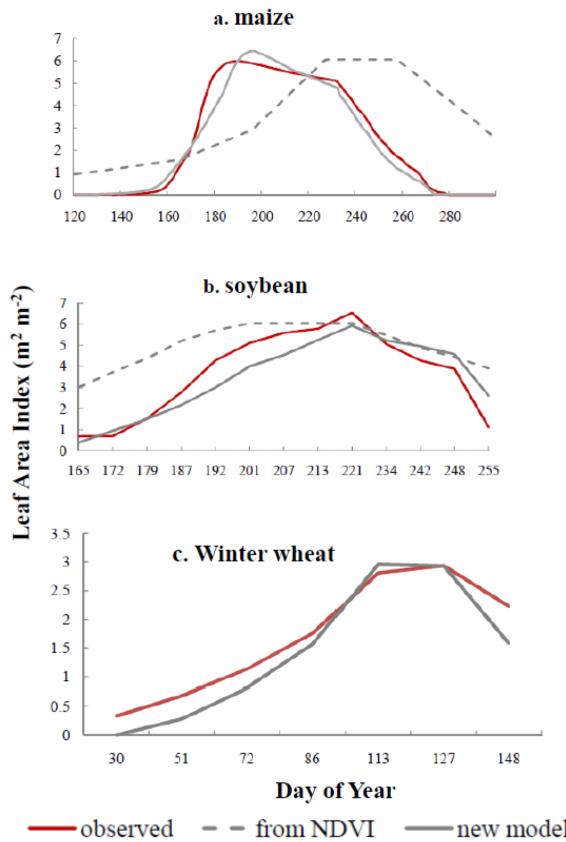


Figure 3. Net ecosystem exchange for winter wheat at ARM-SGP site: (a) sub hourly NEE in 2003, and (b) interannual NEE based on monthly

Figure 4. Some LAI curves for maize (Bondville in 1999), soybean(Bondville in 2000), and winter wheat (ARM-SGP in 2003)

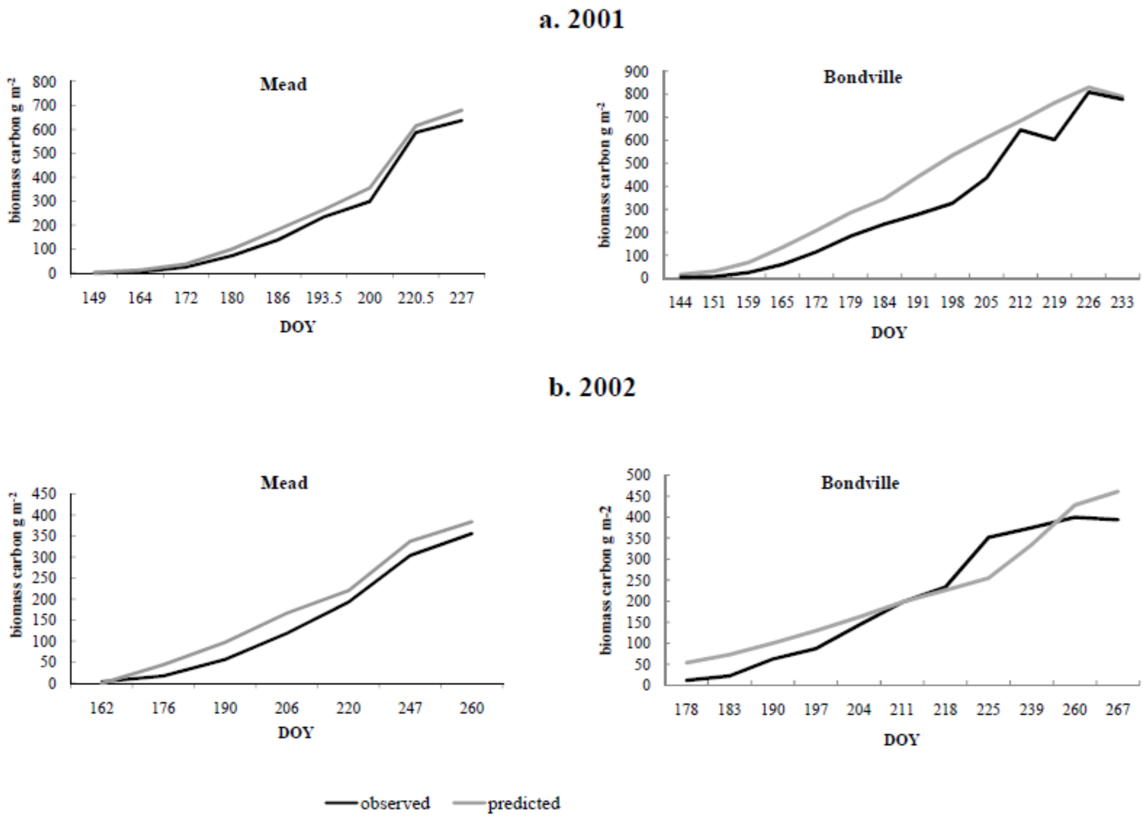


Figure 5. Observed and predicted total aboveground biomass carbon at Mead and Bondville Ameriflux eddy covariance flux tower sites during a corn year (a. 2001) and a soybean year (b. 2002).

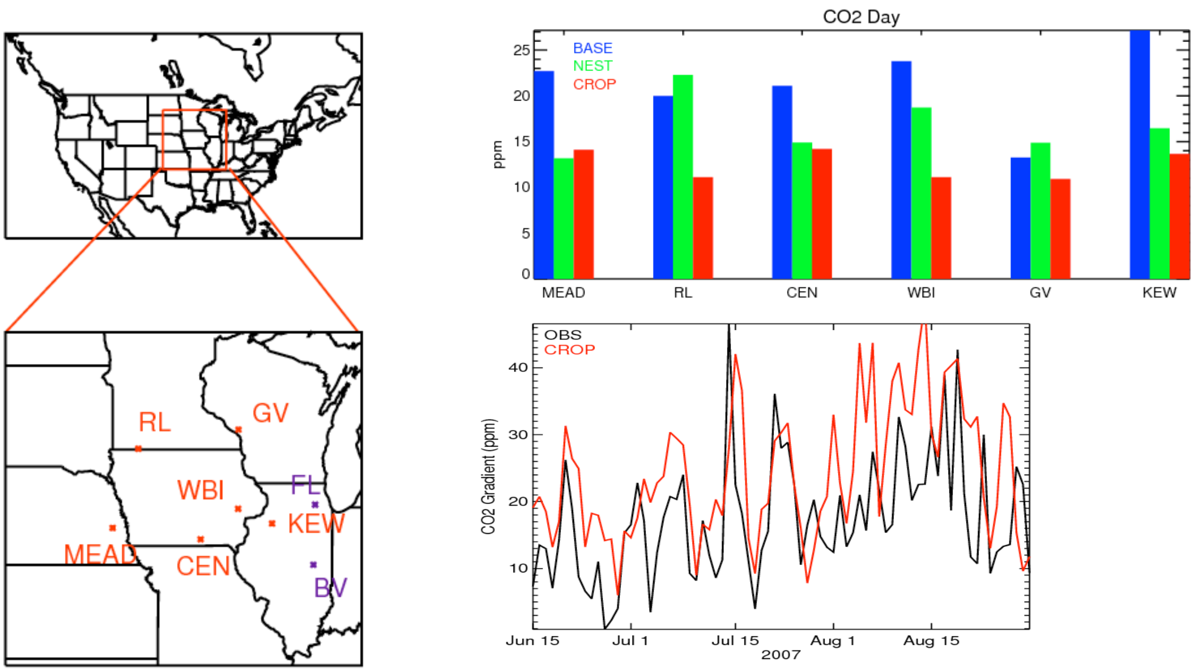


Fig. 6. Coarse (40 km) and nested (10 km) grids (encompassing the Ring 2 towers region) for coupled SiBcrop-RAMS simulations of atmospheric CO2 in summer of 2007 (left), Root-mean square error of CO2 mixing ratio (ppm) simulated by the coupled SiBcrop-RAMS model at each Ring2 tower plus the Centerville tower operated by NOAA (top right; BASE - unmodified model, NEST- 10-km nested grid with original SiB, CROP –with SiBcrop), and Maximum daytime difference in CO2 at 120 m above ground level for each day during summer 2007, as observed by the Ring2 towers and as simulated by SiBcrop-RAMS (bottom right)

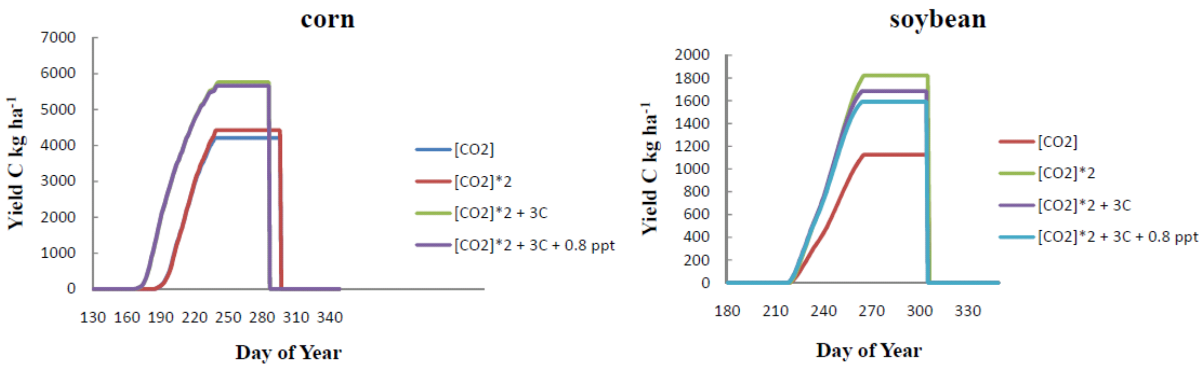


Figure 7. Change in crop yield biomass carbon during the growing season (preliminary results) simulated for Mead rain fed site under several potential future climate scenarios. [CO2]- ambient CO_2 concentration; [CO2]*2- doubled CO_2; [CO2]*2 + 3C- doubled CO_2 and potential temperature rise of 3^0C; [CO2]*2 + 3C + 0.8 ppt- doubled CO_2, temperature rise of 3^0C, and 20 percent reduction of precipitation