Baseline and Projected Future Carbon Storage, Carbon Sequestration, and Greenhouse-Gas Fluxes in Terrestrial Ecosystems of the Eastern United States

By Shuguang Liu, Jinxun Liu, Yiping Wu, Claudia J. Young, Jeremy M. Werner, Devendra Dahal, Jennifer Oeding, and Gail L. Schmidt

Chapter 7 of

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Edited by Zhiliang Zhu and Bradley C. Reed

Professional Paper 1804

U.S. Department of the Interior
U.S. Geological Survey

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U.S. Geological Survey, Reston, Virginia: 2014

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Suggested citation:
Liu, Shuguang, Liu, Jinxun, Wu, Yiping, Young, C.J., Werner, J.M., Dahal, Devendra, Oeding, Jennifer, and Schmidt, G.L., 2014, Baseline and projected future carbon storage, carbon sequestration, and greenhouse-gas fluxes in terrestrial ecosystems of the eastern United States, chap. 7 *of* Zhu, Zhiliang, and Reed, B.C., eds., Baseline and projected future carbon storage and greenhouse gas fluxes in ecosystems of the eastern United States: U.S. Geological Survey Professional Paper 1804, p. 115–156, *http://dx.doi.org/10.3133/pp1804*.

ISSN 1044-9612 (print)
ISSN 2330-7102 (online)
ISBN 978-1-4113-3794-7

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Chapter 7. Baseline and Projected Future Carbon Storage, Carbon Sequestration, and Greenhouse-Gas Fluxes in Terrestrial Ecosystems of the Eastern United States

By Shuguang Liu,[1] Jinxun Liu,[2] Yiping Wu,[3] Claudia J. Young,[2] Jeremy M. Werner,[1] Devendra Dahal,[2] Jennifer Oeding,[2] and Gail L. Schmidt[2]

7.1. Highlights

- From 2001 through 2005, the average total carbon stored in major pools (live biomass, soils (up to 20 cm in depth) and dead biomass) in the Eastern United States was estimated to be 26,962 TgC, ranging from 25,069 to 28,497 TgC. SOC in the top 20-cm soil, live biomass, and dead biomass (such as litter and woody debris) accounted for 43 percent, 42 percent, and 15 percent, respectively, of the total carbon stored in the Eastern United States.
- From 2001 through 2005, the average annual net carbon flux (which is equivalent to the NECB) in the terrestrial ecosystems of the Eastern United States was estimated to be –279.4 TgC/yr, ranging from –405.5 to –112.5 TgC/yr (negative values denote a carbon sink). Of the total NECB, live biomass accumulation accounted for –188.7 TgC/yr, followed by SOC at –65.4 TgC/yr and dead biomass pool at –25.2 TgC/yr.
- The average annual net fluxes of GHGs were estimated to be –1,024.6 $TgCO_2$-eq/yr for CO_2, 174.7 $TgCO_2$-eq/yr for N_2O, and 193 $TgCO_2$-eq/yr for CH_4 in the Eastern United States, with a sum of –656.9 $TgCO_2$-eq/yr for the baseline period, which was equivalent to 11.7 percent of the 5,594 $TgCO_2$-eq/yr of nationwide fossil-fuel emissions in 2010 (U.S. Environmental Protection Agency, 2012).
- Based on the LULC scenarios, climate-change projections, and biogeochemical models used in the terrestrial assessment, the total carbon stored in the Eastern United States in 2050 was projected to be 37,082 TgC, ranging from 25,512 to 46,002 TgC, an increase of 37.5 percent from the average baseline carbon storage.
- Between 2006 and 2050, the NECB in the terrestrial ecosystems of the Eastern United States was projected to be –224.9 TgC/yr, ranging from −403.7 to 1.4 TgC/yr, a potential decrease of 54.5 TgC/yr (or 19.5 percent reduction in the magnitude of the carbon sink). On average, about 64.3 percent of the total carbon was projected to accumulate in live biomass, 20.3 percent in SOC, and the remaining 15.4 percent in dead biomass.Forests were projected to be the primary carbon sinkwith an average value of −157.6 TgC/yr. The projected future GHG fluxes averaged –824.6 $TgCO_2$-eq/yr for CO_2, 174.7 $TgCO_2$-eq/yr for N_2O, and 198.7 $TgCO_2$-eq/yr for CH_4.
- Only a partial attribution analysis was produced on effects of controlling processes (for example, effects of wildland fire [chap. 4], effects of timber production [this chapter], general attribution of LULC change [chap. 3 and this chapter], and uncertainty contribution from the three biogeochemical models, LULC scenarios, and GCMs [this chapter]).
- Results of this assessment suggested a wide range of uncertainty in the estimated carbon sequestration rates across models, LULC scenarios, and GCM projections in ecoregions and in the Eastern United States. In addition, the results showed that the uncertainty from models were far greater than the uncertainties from LULC and GCMs. These results are important but they are high-level observations without a detailed cause-and-effect analysis, which require a further effort to explain the differences among models, LULC scenarios, and GCM projections.

7.2. Introduction

Many inventory- and modeling-based studies that use atmospheric (top-down) and ground-based (bottom-up) methods have been conducted to quantify carbon stock and changes in the United States in the past decade. These studies agree on the presence of a carbon sink in the ecosystems of

[1]U.S. Geological Survey

[2]Stinger Ghaffarian Technologies, Inc.

[3]ASRC Federal InuTeq

the conterminous United States (Houghton and others, 1999; Pacala and others, 2001; Pan and others, 2011). For example, Turner and others (1995) estimated that the total carbon stock in forests of the conterminous United States (at the beginning of 1990s) was about 36,700 TgC, with half of that amount in the soils. In 2011, the annual net carbon flux from ecosystems amounted to –227.3 TgC/yr from forested lands and –246.9 TgC/yr from all lands in conterminous United States (U.S. Environmental Protection Agency, 2012). Woodbury and others (2007) estimated that the forest sector (including forests and wood products) sequestered an average –162 TgC/yr in the United States from 1990 through 2005, providing an offset equal to 10 percent of the national total CO_2 emissions in 2005. Climate change and land-use change have profound effects on the ability of ecosystems to sequester carbon and maintain a stable carbon stock (Goward and others, 2008; Houghton, 2010; Liu and others, 2011; Pan and others, 2011). Several recent studies suggested that a lower rate of carbon sequestration by ecosystems than these contemporary rates is possible in future years as the result of climate change and land-use change (Hurtt and others, 2002; Birdsey and others, 2006; Liu and others, 2012b), whereas other studies (such as Woodbury and others, 2007) estimated that forests in the United States would continue to sequester carbon in the near future at a rate similar to those of recent years.

As described in chapter 1 of this report, the scope of the assessment required a methodology that integrated several technical components, including LULC change, wildland fire disturbances, and modeling of terrestrial and aquatic carbon fluxes (fig. 1–2). The objective of this chapter is to describe methods used to estimate carbon stock, carbon fluxes, and the rate of sequestration in terrestrial ecosystems in the Eastern United States and present the results of the terrestrial assessment.

7.3. Methods and Data

7.3.1. Ecosystem Biogeochemical Models

Consistent with the approach used for the regional assessments conducted for the Great Plains (Zhu and others, 2011) and the Western United States (Zhu and Reed, 2012), the Century version 4.0 (Parton and others, 1987, 1994; Metherell and others, 1993), Erosion Deposition Carbon Model (EDCM; appendix 1; Liu and others, 2003), and Land Greenhouse-Gas Accounting Tool (LGAT; appendix 2) biogeochemical models were used for simulating ecosystem biogeochemical cycles and estimating carbon stock and flux values.

Major model-data intercomparison studies have shown diverse results of different models on estimating carbon stocks and fluxes (Schwalm and others, 2010; Huntzinger and others, 2012). These studies suggested that a collective use of multiple models would yield more useful information than any single model. Perhaps a major advantage of using several models together is the consideration that the range of results obtained from the models could serve to illustrate uncertainties stemming from inherent biases of the individual models. Based on the above considerations, an ensemble modeling strategy was adopted and implemented in the General Ensemble Biogeochemical Modeling System (GEMS; Liu, 2009; Liu and others, 2012c). For this assessment, the three biogeochemical models were run in an ensemble fashion on the GEMS platform to share input data and produce the range of results to quantify uncertainties of model outputs (appendix 3).

Running GEMS or any biogeochemical models over a large area is challenging because of the high computation load. To speed model simulations, a sampling approach can be implemented in GEMS in addition to the conventional approach that supports only wall-to-wall or per-pixel simulations. Using this sampling approach, users can choose different sampling densities to run GEMS to meet their needs. For example, EDCM and Century models can be both run with a 10×10 subsample factor to allow for adequate time of processing, generating statistics, and assessing the results. With this sampling scheme, only one pixel is simulated and processed for every 100 pixels (that is, 1 out of 10 pixels in each the x and y directions). The adequacy of sample intensity should be evaluated before full deployment over large areas.

The concept of a joint frequency distribution (JFD) table was originally used and implemented in GEMS to speed up model simulations and address input data uncertainty (see Liu and others, 2004; Liu, 2009). Containing one or multiple pixels, each JFD record in the table represents a unique combination of environmental conditions derived from overlay operations of multiple geospatial data layers, such as LULC, soil, and climate. The JFD approach is most efficient when the number of strata is relatively small and the spatial resolutions of the geospatial data layers are coarse. However, this efficiency decreases as the study area, resolution of the spatial data layers, and number of spatial data layers increase. The extreme of the JFD approach is the case that each JFD record contains only one pixel (that is, each pixel is uniquely defined by the spatial data layers), which then becomes the per-pixel model simulation. In this case, there is no need for explicit JFD tables in per-pixel GEMS simulations because operating on the geospatial data layers directly can gain efficiency by eliminating some searching and computing algorithms.

The major biogeochemical processes of the carbon cycle simulated by the two process-based models (that is, Century and EDCM) include NPP, photosynthetic allocation, litter fall, mortality, decomposition of plant tissues, and SOC. There is no need to predetermine endpoints of maximum carbon-carrying capacity or predefine paths to describe how the endpoints are approached because the dynamics of vegetative and soil carbon pools are controlled by the fluxes of inputs and outputs. The endpoints and paths, varying in space with specific site conditions, are tightly coupled with and regulated by the nitrogen and water cycles, disturbances, and management activities.

7.3.2. Input Data

Major input datasets included climate, LULC, soils, elevations, biomass, land management activities, and natural disturbances such as wildland fires. These datasets were obtained from different sources (table 7–1) and converted to standard spatial and temporal resolutions, projections, and data formats. Examples of input data layers (maps) are provided for the baseline (fig. 7–1) and projected future (fig. 7–2) periods of this assessment.

As with the previous assessments (Zhu and others, 2011; Liu and others, 2012a), this assessment relied on nationwide geospatial data layers to characterize the spatial and temporal distributions of land-management activities and natural disturbances. Examples of processing and formatting techniques for the data layers are given in Schmidt and others (2011). Major land-management activities and natural disturbances included in model runs for this assessment are listed in table 7–2, with examples for 2005 given in figure 7–3.

The spatial resolution of some data layers listed in table 7–2, especially those derived from censuses and inventories, was at the county, State, or FIA-unit level. These data layers were further downscaled to pixels to generate spatially explicit map layers using a Monte Carlo approach and some other additional information (techniques described in Schmidt and others (2011)). The most common pixel resolution among all the map layers was 250 m. The map series had individual maps for each year from 1992 through 2050. Annual maps showing areas of forest clearcuts were produced as part of the LULC change modeling detailed in chapter 3 of this report. Annual maps of wildland fire disturbances were modeled as described in chapter 4 of this report.

The county-level crop management information used in this assessment included crop type, crop rotation, fertilization, manure addition, tillage practices, irrigation, and harvesting practices. Crop management activities were downscaled to pixel level on the LULC maps using a probability-based Monte Carlo approach and the crop composition information derived from the USDA agricultural census data (U.S. Department of Agriculture, National Agricultural Statistics Service, 2011). All the crop management data layers (except irrigation) were subsequently generated from these land-cover data layers, and more than 20 major crops were presented consistently for the United States (Schmidt and others, 2011). The tabular data about manure application were derived from the USDA census (U.S. Department of Agriculture, National Agricultural Statistics Service, 2011), which included, for each crop type in each State, the Federal Information Processing Standard (FIPS) code for each State, the year the crop was planted, the total planted area, the percentage of the planted area that was treated with manure, the amount of manure that was applied, the rate at which the manure was applied, the rate at which the nitrogen in the manure was applied, and the rate at which the carbon in the manure was applied. A gridded manure dataset for all agricultural lands in the region was generated from this tabular data along with the land-cover maps using a Monte Carlo approach.

The information about tillage practices was acquired from the Conservation Technology Information Center (CTIC) in tabular format. The tabular data included the FIPS code for each State, the year the area was tilled, the total planted area that was tilled, the total percentage of residue on all tilled areas, the planted area for each tillage type, and the percentage of residue for each tillage type by crop type within the State. The tillage practices included in the database included conventional, mulch, no-till, reduced, and ridge tillage. A gridded dataset showing the spatial and temporal changes of tillage practices for all agricultural lands was generated from these tabular data along with the land-cover maps using a Monte Carlo approach. An irrigation map derived from the MODIS (U.S. Geological Survey, 2010) for the United States was used to characterize the locations of irrigated land. Because of the lack of data showing the temporal changes in irrigation across the Eastern United States, this assessment assumed that the locations of irrigated land did not change over time during the assessment period.

Only nitrogen fertilization on agricultural lands was considered in this assessment. Forest fertilization was not included in the assessment due to the lack of spatially explicit information. A nationally consistent procedure was put in place to generate crop- and location-specific nitrogen-fertilization data for all agricultural lands (Schmidt and others, 2011). The tabular dataset included the FIPS code for each State, the year the planted area was fertilized, the total planted area where nitrogen fertilizer was applied, the percentage of total area that was fertilized with nitrogen, the rate of application for nitrogen fertilizer, and the total amount of nitrogen fertilizer applied for each crop type within each State. Because several States in the Eastern United States did not report this information, this assessment assumed that agricultural lands were automatically fertilized every year in order to satisfy growth requirements.

The selective or partial forest clearcutting (thinning) information used in this assessment included thinning ratio, thinning age, and thinning intensity, which were calculated from the FIA database (U.S. Department of Agriculture, 2012a) at the FIA-unit level (see appendix 4). Mortality caused by disturbances (insects, disease, fire, animals, weather, vegetation, or other) was also included in the assessment of the Eastern United States. A mortality ratio was calculated for each FIA unit by forest type from the FIA database. Because of the lack of data showing the temporal changes in partial cutting and mortality across the Eastern United States, this assessment assumed that the ratios did not change over time during the assessment period.

7.3.3. Model Run Setup

7.3.3.1. Model Initialization

The soil properties that were initialized based on data from the SSURGO database (U.S. Department of Agriculture, Natural Resources Conservation Service, 2009) included soil thickness, organic carbon storage, texture (fractions of sand, silt, and clay), bulk density, and drainage. The total SOC pool was partitioned into active (5 percent), slow (45 percent), and passive (55 percent)

Table 7–1. Input data used in the model runs for the assessment of carbon fluxes and storage in the Eastern United States.

[Most of the input data have a 250-meter spatial resolution and variable temporal characteristics, although most data cover the first decade of the 21st century. LGAT, Land Greenhouse Gas Accounting Tool; EDCM, erosion deposition carbon model; LULC, land use and land cover; MIROC 3.2-medres, Model for Interdisciplinary Research on Climate version 3.2 medium resolution; CGCM3.1, The Third Generation Coupled Global Climate Model; CSIRO Mk3.5, Commonwealth Scientific and Industrial Research Organisation Mark 3.5; Db 0.33 bar H_2O, the oven-dry weight of the less than 2 millimeters of soil material per unit volume of soil at a water tension of 0.33 bar (as used in the Soil Survey Geographic database); FIA, Forest Inventory and Analysis; USDA, U.S. Department of Agriculture; GCM, general circulation model; K factor, an erodibility factor that quantifies the susceptibility of soil particles to detachment by water; mm, millimeter; MODIS, moderate resolution imaging spectrometer; NASA, National Aeronautics and Space Administration; PRISM, parameter-elevation regressions on independent slopes model]

Data category	Data types and characteristics	Data source	Model		
			LGAT	EDCM	Century
LULC	LULC classes	Chapter 3 of this report	X	X	X
Climate	Past (baseline) and future climate datasets: Monthly minimum and maximum temperature, monthly total precipitation	Past climate: PRISM Climate Group (2012) Projected future climate: MIROC 3.2-medres, CSIRO Mk3.5, and CGCM3.1 GCMs, Canadian Forest Service (Joyce and others, 2011)		X	X
Soil	Total sand	Soil Survey Geographic database (U.S. Department of Agriculture, Natural Resources Conservation Service, 2009)		X	X
	Total clay			X	X
	Total silt			X	X
	Soil thickness			X	
	Soil organic carbon		X	X	X
	Available water capacity			X	
	DB 0.33 bar H_2O			X	
	K factor			X	X
Forest	Biomass	Geodata (U.S. Department of Agriculture, Forest Service, 2012b)	X		
	Stand age	Chapter 3 of this report	X	X	X
	FIA species growth curves, height, diameter, and biomass measurements	Forest Inventory and Analysis (U.S. Department of Agriculture, Forest Service, 2012a)	X		
	Timber product output	Renewable Resources Planning Act of 1974 timber product output (U.S. Department of Agriculture, Forest Serivce, 2011d)	X		
Crops and crop management	Derived crop type	Schmidt and others (2011)	X	X	X
	USDA crop yield table	U.S. Department of Agriculture, National Agricultural Statistics Service (2011e)		X	X
	Derived fertilizer spatial data using USDA fertilization table	U.S. Department of Agriculture, Economic Research Service (2011b); Schmidt and others (2011)	X	X	X
	Derived manure spatial data using USDA manure table	U.S. Department of Agriculture, Economic Research Service (2011a); Schmidt and others (2011)	X	X	X
	Derived tillage spatial data using Conservation Technology Information Center tillage table	Conservation Technology Information Center (2012); U.S. Department of Agriculture, Economic Research Service (2011a); Schmidt and others (2011)	X	X	X
	Irrigation	U.S. Geological Survey (2010)	X	X	X
Elevation	Elevation	U.S. Geological Survey (2012b)		X	X
Remote sensing	Net primary production	Zhao and others (2005)		X	X
Fire	Fire severity	Eidenshink and others (2007); chapter 4 of this report		X	X
Reference information	State and county Federal information processing standard	U.S. Census Bureau (2012)	X	X	X
Initial conditions	Forest litter biomass	Forest Inventory and Analysis (U.S. Department of Agriculture, Forest Service, 2012a)	X	X	X
	Above ground live biomass		X	X	X
	Below ground live biomass		X	X	X
	Down deadwood biomass		X	X	X
	Standing dead biomass		X	X	X

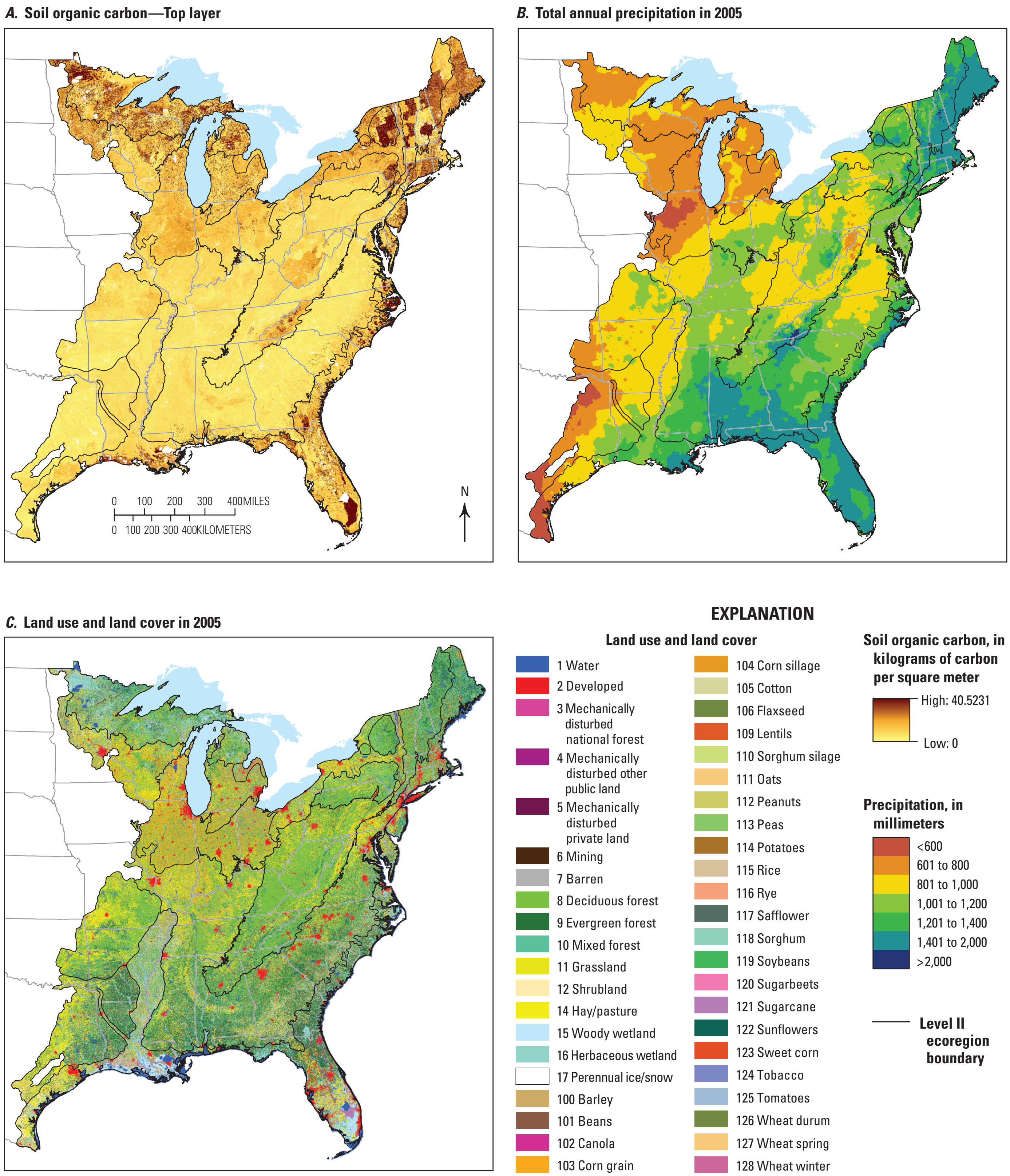
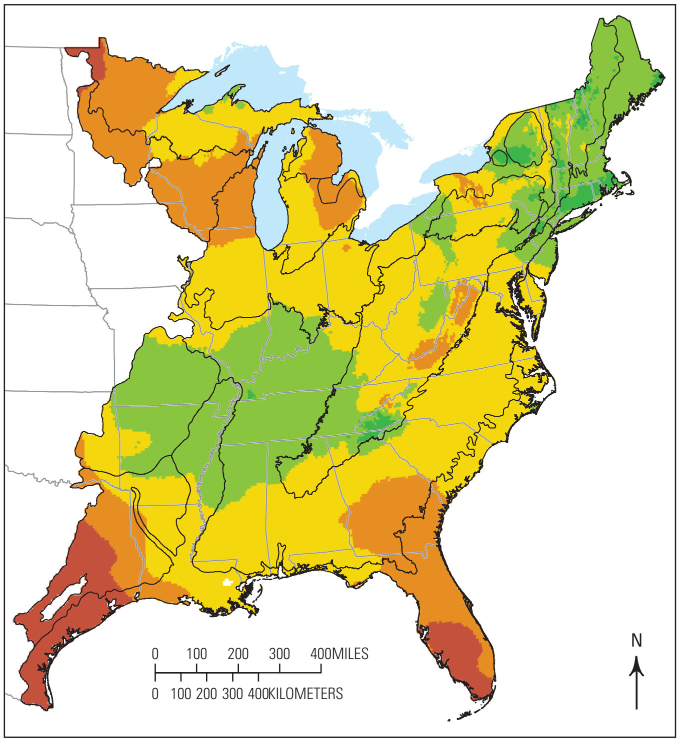
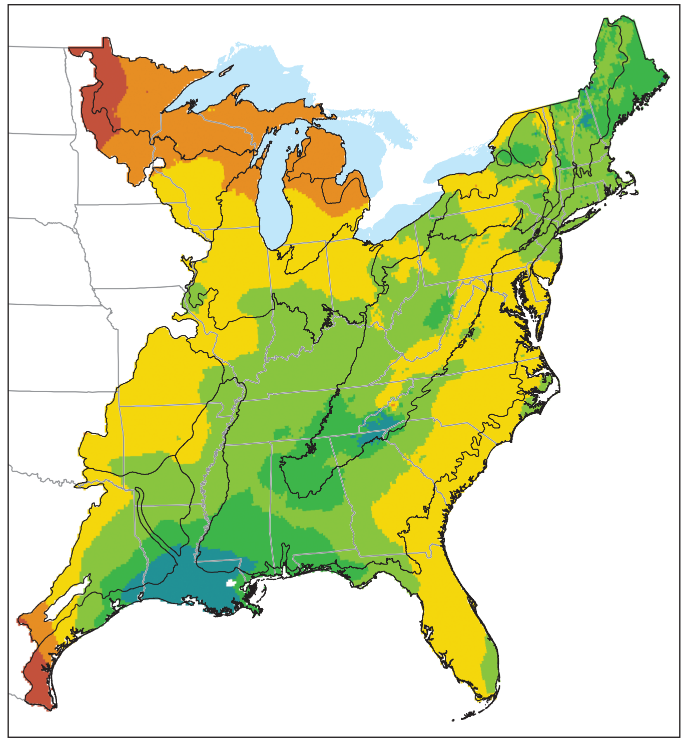


Figure 7–1. Examples of maps showing input data for the Eastern United States. *A*, Soil organic carbon (SOC) for the top 0 to 5 centimeters of the soil layer; data were derived from the Soil Survey Geographic (SSURGO) database (U.S. Department of Agriculture, Natural Resources Conservation Service, 2009). *B*, Total precipitation in 2005 (PRISM Climate Group, 2012). *C*, Land use and land cover (LULC) in 2005, from chapter 3 of this report with the agricultural lands class downscaled to the crop types. Level II ecoregions are shown in figure 1–1.

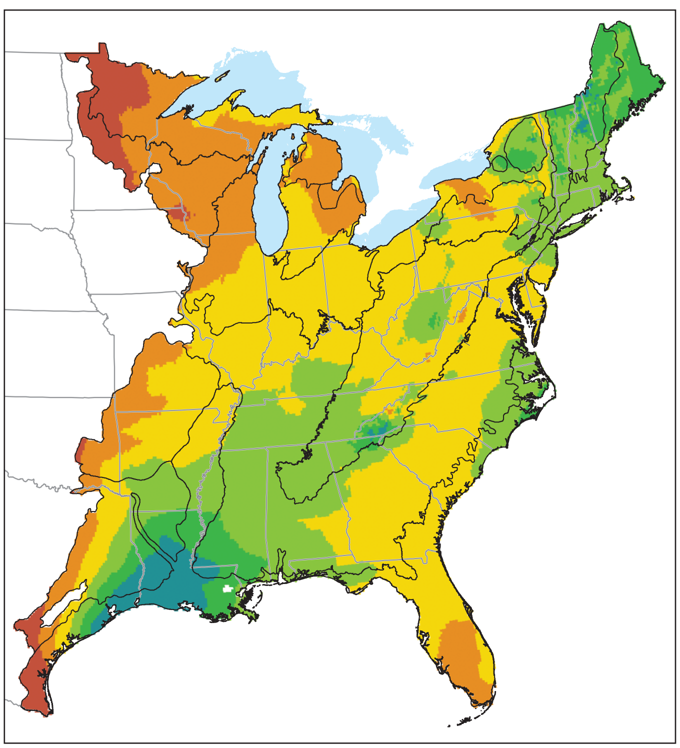
A. **Precipitation, 2050—MIROC scenario A1B**



B. **Precipitation, 2050—MIROC scenario A2**



C. **Precipitation, 2050—MIROC Scenario B1**



D. **Land use and land cover, 2050—Scenario A1B**

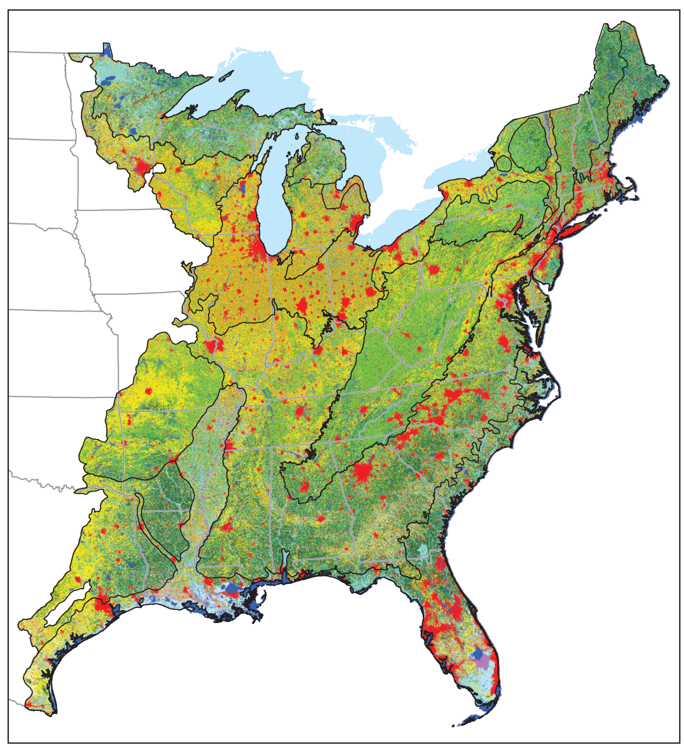


Figure 7–2. Maps showing projected total annual precipitation under Intergovernmental Panel on Climate Change Special Report on Emission Scenarios (SRES; Nakićenović and others, 2000) scenarios *A*, A1B, *B*, A2, and *C*, B1 in 2050 and *D*, projected land use and land cover (LULC) under SRES scenario A1B in the Eastern United States in 2050. Precipitation data were projected by the Model for Interdisciplinary Research on Climate version 3.2 medium resolution (MIROC 3.2–medres) general circulation model (Joyce and others, 2011). Projected LULC change was from chapter 6 of this report with downscaling of agriculture to crop types by Schmidt and others (2011). Level II ecoregions are shown in figure 1–1.

Table 7–2. Major land-management activities and natural disturbances included in model runs for the assessment of carbon fluxes and storage in the Eastern United States.

[m, meters; NA, not applicable; PRISM, parameter-elevation regressions on independent slopes model; FIA, Forest Inventory Analysis]

Management activities or natural disturbances	Data source	Spatial resolution	Time period	References
Forest harvesting or clearcuts	Stand age, chapter 3 of this report	250 m	1992–2050	U.S. Geological Survey (2012a)
	U.S. Department of Agriculture Forest Inventory Analysis Resource Planning Act timber product output	State	2002	U.S. Department of Agriculture, Forest Service (2011d)
Forest thinning	Thinning ratio from forest inventory data	FIA unit	Average for 1997–2010	U.S. Department of Agriculture, Forest Service (2012a)
Forest mortality	Mortality ratio from forest inventory data	FIA unit	Average for 1997–2010	U.S. Department of Agriculture, Forest Service (2012a)
Wildland fire: extent, severity, frequency	Chapter 4 of this report	250 m	1992–2050	Chapter 4 of this report
Drought	Precipitation from PRISM and the Canadian Forest Service	250 m	1992–2050	Canadian Forest Service (2012); PRISM Climate Group (2012)
Crop yield	U.S. Department of Agriculture crop yield table	County	1992–2050	U.S. Department of Agriculture National Agricultural Statistics Service (2011e)
Fertilization	U.S. Department of Agriculture Economic Research Service fertilization table	County	1992–2050	U.S. Department of Agriculture Economic Research Service (2011b)
Manure	U.S. Department of Agriculture manure table	County	1992–2050	U.S. Department of Agriculture Economic Research Service (2011a)
Tillage	Conservation Technology Information Center tillage table	County	1992–2050	Conservation Technology Information Center (2012); U.S. Department of Agriculture Economic Research Service (2011a)
Irrigation	U.S. Geological Survey	250 m	Static	U.S. Geological Survey (2010)

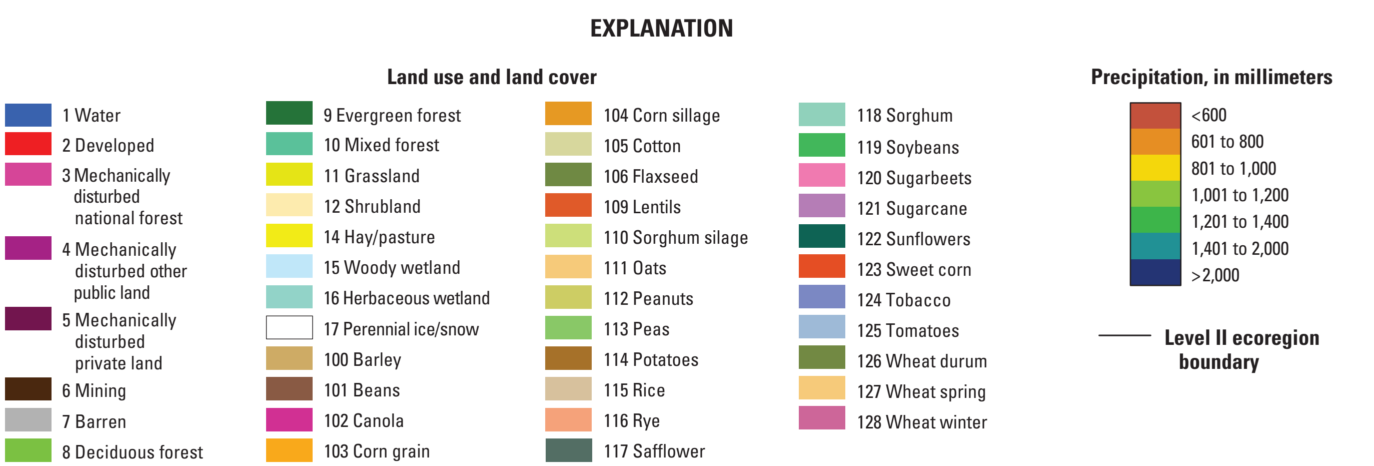


Figure 7–2.—Continued

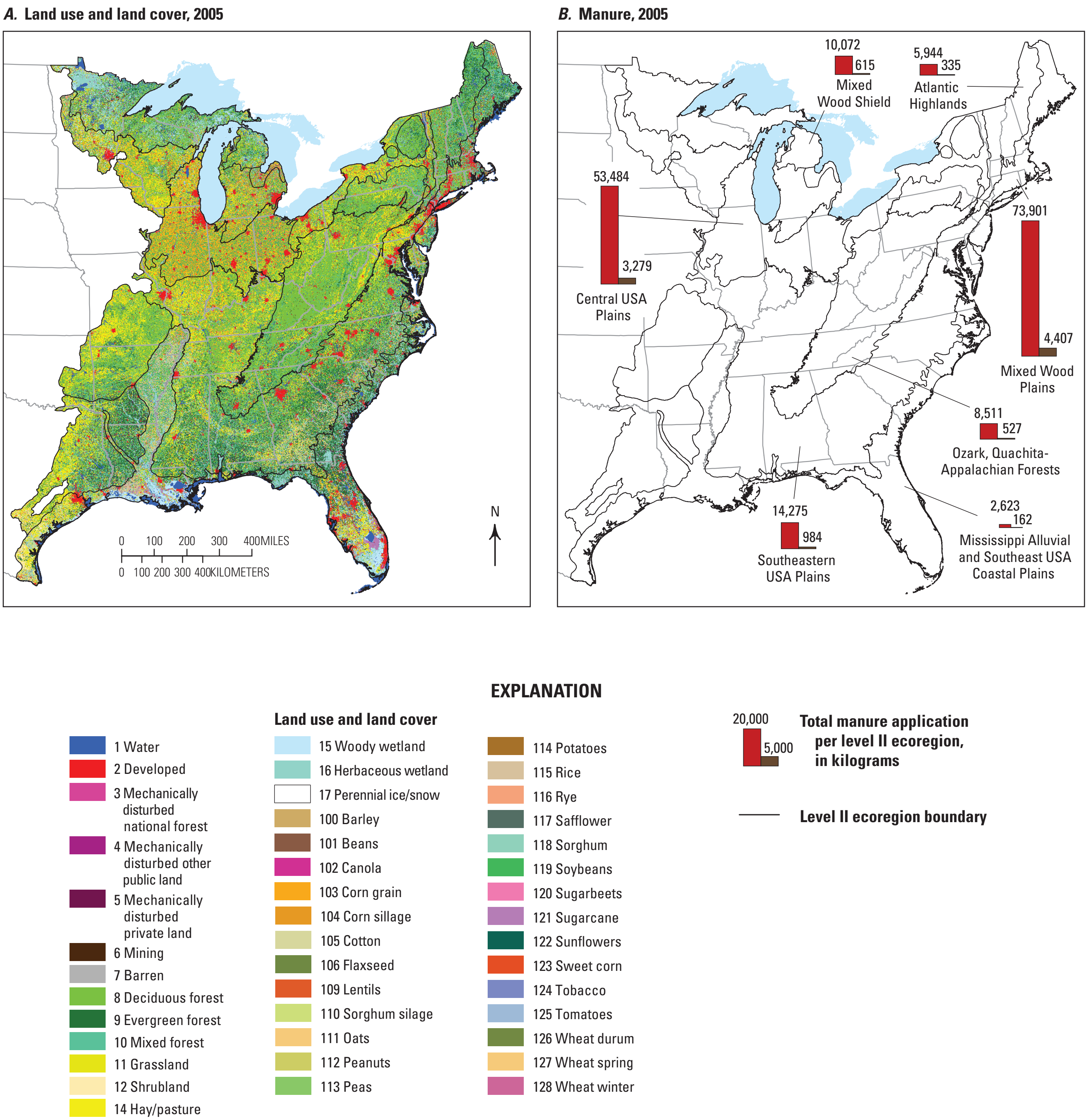


Figure 7–3. Maps showing examples of *A*, land use and land cover; *B*, manure; *C*, tillage; *D*, irrigation; and *E*, stand age data layers for land-management activities and natural disturbances in the Eastern United States for 2005. Level II ecoregions are shown in figure 1–1.

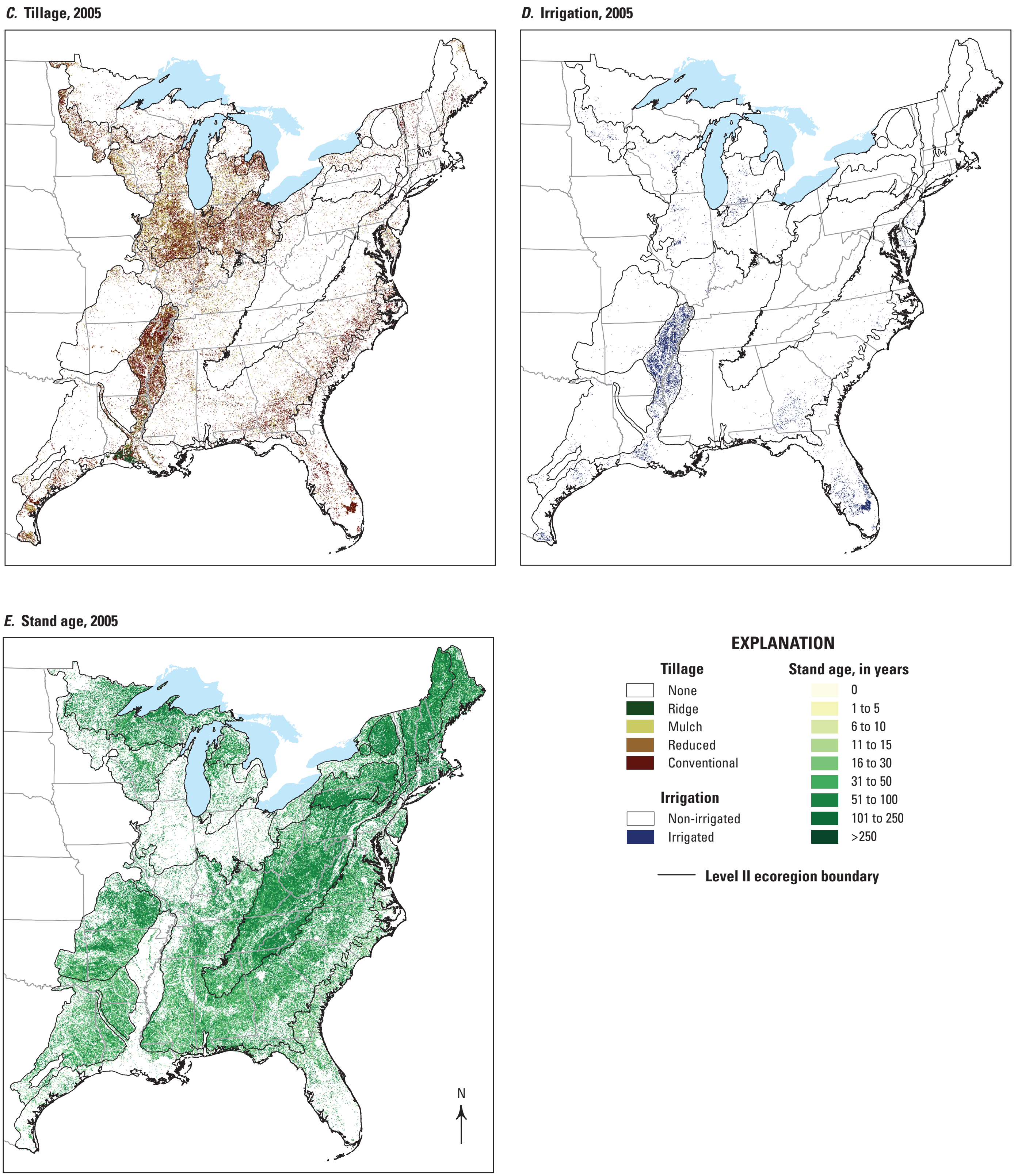


Figure 7–3.—Conitnued

classifications for Century and EDCM initialization (Liu and others, 2003). Forest biomass carbon pools (aboveground and belowground live biomass or dead biomass consisting of forest litter and dead, woody debris) were initialized using the initial forest-age map (derived from FIA data; U.S. Department of Agriculture, Forest Service, 2012b), forest type (evergreen, broadleaf, and mixed), and the relation between forest age and carbon stock. For consistency and to avoid potential errors, the initialization of the SOC and biomass was done using the LGAT, and the outputs from the LGAT for 1992 (the first year of the model simulations) were then read directly by the Century model and the EDCM as initial conditions.

7.3.3.2. Model Calibration and Validation

Model calibration, the process of adjusting model parameters to minimize the difference between simulations and observations, was only applied to Century and the EDCM as all coefficients of the LGAT could be derived directly from field measurements. The observed data for calibration (from 2001 through 2005) included county-based grain yield survey data by crop type (U.S. Department of Agriculture, National Agricultural Statistics Service, 2011) and 250-m-resolution NPP data from the MODIS for other LULC types, such as forests and grasslands (Zhao and others, 2005). The MODIS NPP was found to lack consistent performance for calibrating crop production. As the result, crop yield data from the USDA were used. An automated calibration was implemented for EDCM using the Shuffled Complex Evolution (SCE–UA) method (Duan and others, 1992) and the R-language Flexible Modeling Environment (R–FME) software package (Soetaert and Petzoldt, 2010; Wu and Liu, 2012). On the other hand, manual calibration was used for Century model. The potential maximum production parameter (PRDX) was adjusted by comparing the modeled grain yield with the USDA county-level statistics of grain yield and the forest NPP with the county-level MODIS-derived NPP from 2001 through 2005. Appendix 5 summarizes the derived PRDX values of 13 main ecosystem types by county across all ecoregions in the Eastern United States.

Observational data used for validation included USDA forest biomass values (U.S. Department of Agriculture, Forest Service, 2012a), aboveground biomass from the Woods Hole Research Center National Biomass and Carbon Dataset for the Year 2000 (Kellndorfer and others, 2004), the MODISderived NPP (Zhao and others, 2005), and the USDA grain yield (U.S. Department of Agriculture, National Agricultural Statistics Service, 2011) for 2006, 2008, and 2010. Maps, binned scatter-plots, and correlation plots were generated for different ecosystems in each ecoregion of the Eastern United States in order to compare the simulated results of the process-based models with observational data. Simple linear-regression modeling, the R^2, and the root mean square error (RMSE) between the observed and modeled data were calculated to evaluate the performance of the models. Some of the results of the validation are shown in figure 7–4 and table 7–3. Figure 7–4 shows the comparison between NPP estimated by MODIS and NPP simulated by Century and EDCM in all seven ecoregions of the Eastern United States in 2006. Table 7–3 summarizes validation metrics from different models in the Mixed Wood Shield ecoregion in 2006 and serves as an example of statistics used in the models; other ecoregions, not shown in this report, show similar results.

7.3.3.3. Ensemble Modeling

Multiple GEMS simulations were run continuously for 1992 through 2050 with the following setup:

- Three models were run on the GEMS platform. EDCM and Century were run at monthly time steps with a sampling intensity of 1 percent (or 1 pixel for each 10 pixels in the x direction and 10 pixels in the y direction) for this report. The validity of the sampling rate was confirmed by comparing results with those produced with per-pixel simulations (see appendix 6). The LGAT was run at annual time steps on a per-pixel basis because the time for each run was much shorter than the other two process-based models.
- Three LULC scenarios were incorporated. Each of the scenarios was developed (chapters 2 and 3 of this

Table 7–3. Biogeochemical models in the General Ensemble Modeling System in the Eastern United States for 2006.

[Based on aggregated results at the county level. RMSE, root mean squared error; $gC/m^2/yr$, grams of carbon per square meter per year; R^2, coefficient of determination; EDCM, Erosion Deposition Carbon Model; LGAT, Land Greenhouse Gas Accounting Tool]

Observation	Model	System	RMSE, in $gC/m^2/yr$	R^2
National Biomass and Carbon Dataset (Kellndorfer and others, 2012) live biomass	LGAT	Forest	0.819	0.95
U.S. Department of Agriculture, Forest Service live biomass	LGAT	Forest	0.698	0.97
Moderate resolution imaging spectroradiometer-derived net primary production	Century	Forest	0.139	0.90
	EDCM	Forest	0.172	0.86
	Century	Grassland/shrubland	0.005	0.96
	EDCM	Grassland/shrubland	0.008	0.92
U.S. Department of Agriculture grain yield	Century	Winter wheat	0.001	0.90
	EDCM	Winter wheat	0.001	0.72

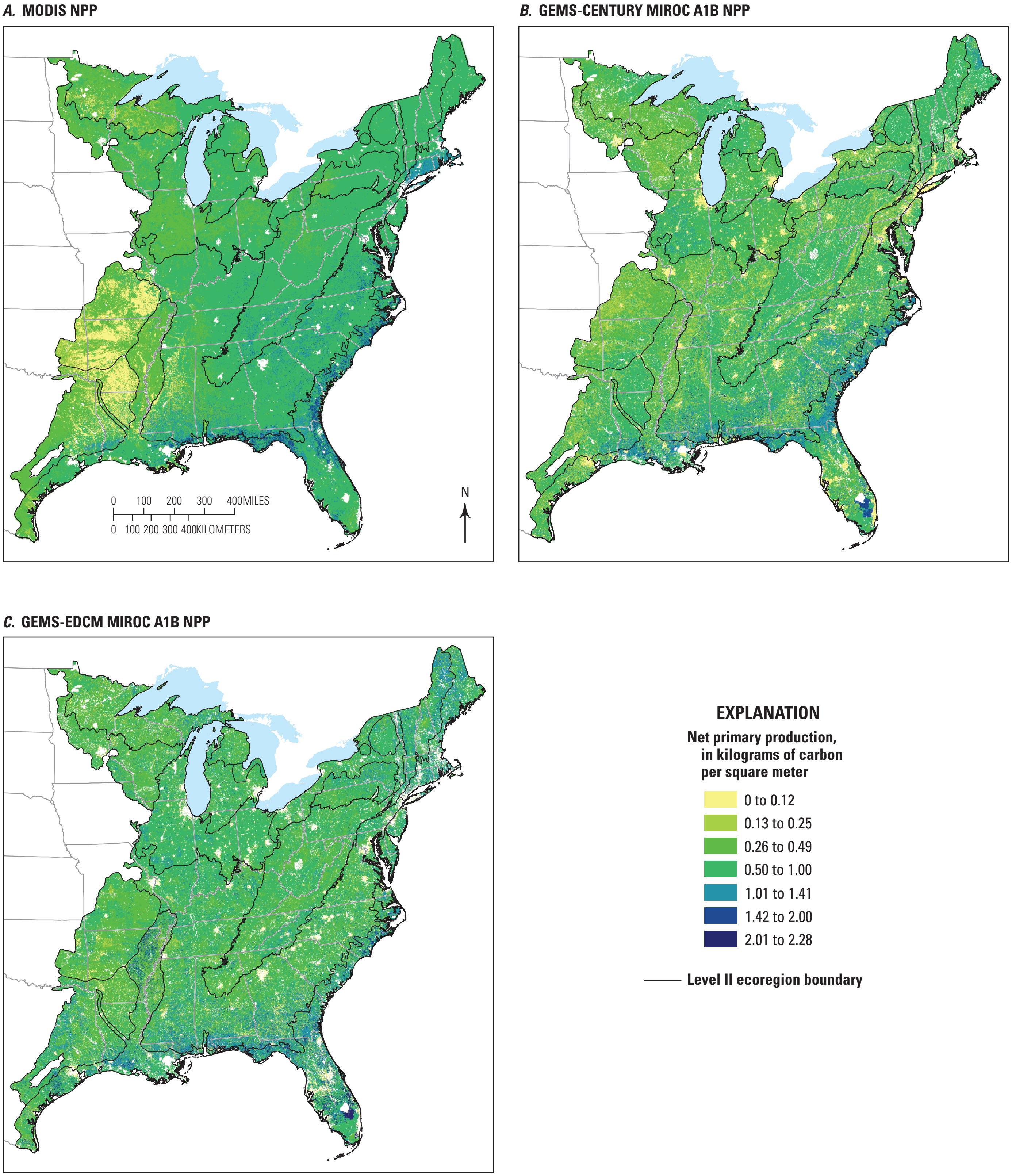


Figure 7–4. Maps showing a comparison of net primary production (NPP) in the Eastern United States for 2006 estimated by *A*, the moderate resolution imaging spectroradiometer (MODIS), *B,* the Century model run in conjunction with a General Ensemble Biogeochemical Modeling System (GEMS) model under Intergovernmental Panel on Climate Change Special Report on Emissions Scenarios (SRES; Nakićenović and others, 2000) scenario A1B using the Model for Interdisciplinary Research on Climate version 3.2 medium resolution (MIROC 3.2–medres) general circulation model (GCM), and *C*, the Erosion Deposition Carbon Model (EDCM) in conjunction with GEMS run under SRES scenario A1B using the MIROC 3.2-medres GCM. Level II ecoregions are shown in figure 1–1.

report) in accordance with scenario A1B, A2, or B1 from the SRES (Nakićenović and others, 2000).

- Three GCM (MIROC 3.2-medres, CSIRO Mk3.0, and CCCma CGCM3.1; table 7–1) climate change projections associated with each LULC scenario were processed. Each of the GCMs corresponded to one of the SRES scenarios.

The models were run for the same land base from 1992 through 2050, with 1992 through 2000 used as model spin-up, 2001 through 2005 as the baseline period, and 2006 through 2050 as the scenario or projection period. Although a longer spin-up time window would be desirable (for example, thousands of years could be used to reach a quasisteady state of SOC under natural conditions (Liu and others, 2003)), the process would also require corresponding historical LULC data, which were not available for this analysis.

A total of 21 model runs were performed based on the combinations of models, LULC scenarios, and GCM projections. It was not 27 model runs (that is, three models for each of the three LULC scenarios for each of the three GCMs) because the LGAT is not designed to simulate the effects of climate change and therefore only had three runs (one for each of the three LULC scenarios). It should be noted that only three unique model simulations, generated by the three models with no variation in LULC and climate, existed from 1992 through 2006 because there were no alternative scenarios for climate and LULC data during the historical period. All three models produce all the individual carbon pools. For this assessment, CH_4 and N_2O were simulated only by the LGAT due to extreme challenges in simulating hydrological conditions, a critical controlling factor for N_2O and CH_4, in many wetlands over large areas using the process-based models Century and EDCM. The emission factors of N_2O and CH_4 compiled from literature are provided in appendix 7.

7.3.4. Definitions, Output, and Analysis

7.3.4.1. Definitions of Carbon Stocks and Fluxes and Uncertainty

The key concepts and terminology of carbon stocks and fluxes used in this chapter, including net carbon flux, NPP, NEP, and NECB, consistent with previous reports for the Great Plains (Zhu and others, 2011) and Western (Zhu and Reed, 2012) regions of the United States, are defined in chapter 1 of this report and follow conventions used in the published literature (Chapin and others, 2006).

Three measures of uncertainty, where appropriate, were used in this chapter—standard deviation, range, and relative uncertainty. Uncertainty, meaning “doubt about the validity of a measurement”, can be measured by a “parameter, associated with the result of a measurement, that characterizes the dispersion of the values that could reasonably be attributed to the measurand” (International Organization for Standardization, 1995). An example of the parameter is the standard deviation, which is referred as the “standard uncertainty.” Ranges of values can be used as a measure of the dispersion or variation.

A “variability index” (V), a measure of relative uncertainty, was defined for this report and calculated to represent the relative dispersion of responses of carbon stock or flux to different models, LULC, or GCMs:

$$V=(C_{max}-C_{min})/C_{mean}, \qquad (7\text{–}1)$$

where

C_{max} is the maximum carbon stock or flux among all models, LULC scenarios, or GNMs;

C_{min} is the minimum carbon stock or flux among all models, LULC scenarios, or GNMs; and

C_{mean} is the average carbon stock or flux among all models, LULC scenarios, or GNMs.

The variability index is similar to the relative sensitivity as both quantify the response of model result to the changing conditions. The larger the variability index, the more sensitive the GEMS to that variable and the greater the contribution of that variable to the overall uncertainty of GEMS results.

7.3.4.2. Output and Further Processing

For this assessment, all the carbon stocks reported were the carbon storage at the end of each year, and CH_4 and N_2O fluxes were the annual total fluxes. Annual maps of the following variables were generated from each model run:

- the total live biomass carbon (forest total carbon, FRSTC), including both aboveground and belowground
- SOC in the top 20-cm layer
- other components, including those that were not counted in the live biomass and SOC, such as coarse woody debris, litter, and understory
- CH_4 and N_2O only from the LGAT
- carbon removal from fields by timber and grain harvest or land cover conversion

The amounts of carbon removed from ecosystems by timber and grain production were tracked in GEMS. However, the fate of the offsite carbon in timber and grain products was not tracked. Therefore, the offsite contribution of the harvests was not included in this assessment. Fire emissions were tracked by GEMS according to the extent and severity data layers generated in chapter 4. When a land was converted from type A to type B, for example, the emissions of carbon were added to cover type B, consistent to IPCC good practice guidance (Watson and others, 2000). The following variables were calculated, when appropriate, based on the model output variables listed above:

- The minimum, maximum, standard deviation, and average of carbon stocks and fluxes in FRSTC, SOC, other pools, and all system carbon pools (the sum of the first three carbon stocks), as simulated by the 3 (baseline period) and 21 (projection period) model simulations, were summarized by ecoregion and ecosystem type.

- The annual carbon stock change in a given year (*t;* in other words, the net carbon flux and the NECB at ecosystem level) was calculated as the stock difference between year *t* and the previous year (*t*–1) as $C_{t-1} - C_t$.
- The average NECB during the baseline period was calculated as the difference of total system carbon stock between 2001 and 2005 divided by the duration, which is 5 years), as follows: $NECB = (C_{2001} - C_{2005}) / 5$, where C_{2001} and C_{2005} represent the carbon storage at the beginning of 2001 and the end of 2005, respectively.
- Similarly, the average NECB during the projection period was calculated as the difference of total system carbon stock between 2006 and 2050 divided by the duration, which is 45 years, as follows: $NECB = (C_{2006} - C_{2050}) / 45$, where C_{2006} and C_{2050} represent the carbon storage at the beginning of 2006 and the end of 2050, respectively.

Based on these calculations, negative NECB would indicate carbon sequestration in terrestrial ecosystems, and this notion is consistent with previous reports of the national assessment (Zhu and others, 2011; Zhu and Reed, 2012).

Global warming potentials (GWP) of CH_4 and N_2O fluxes in CO_2-eq were calculated using 21 as a factor for CH_4 and 310 as a factor for N_2O (U.S. Environmental Protection Agency, 2012). CO_2 flux was calculated from the NECB using a molecular factor of 3.667 to convert carbon to CO_2. The total annual GWP of GHG fluxes was calculated as the sum of the GWP of CO_2, CH_4, and N_2O.

7.3.4.3. Analysis

The outcome of assessing carbon sequestration and GHG emissions is often influenced by diverse factors, including models, land use, disturbances, and climate. Many aspects of the carbon dynamics and GHG fluxes quantified in this assessment can be analyzed at a range of spatial and temporal scales. In this report, the focuses of our analysis are the following:

- Present and analyze the minimum, maximum, and average of the carbon stocks and GHG fluxes, estimated by ensemble modeling, during the baseline and projection periods for all ecosystems in each ecoregion of the Eastern United States. This helps answer the following questions:
  - What are the spatial patterns of carbon storage and GHG fluxes in the Eastern United States?
  - How much carbon could be sequestered in vegetation and soils by ecosystem and ecoregion?
  - How will carbon sequestration strengths of different ecosystems change over time (that is, between the baseline and the projection period)?
  - What are the uncertainties of the estimates?
- Examine and compare the projected average carbon stocks in 2050, projected average annual NECB from 2006 through 2050, and the variability index by model, LULC scenario, and GCM for each ecoregion and for the entire Eastern United States. This helps answer the following questions:
  - What are the differences in the estimated carbon sequestration potentials across ecoregions and within the Eastern United States?
  - What are the results of using different models, LULC scenarios, and GCMs on the estimated carbon sequestration?
  - What is the major contributor among models, LULC, and GCMs to the uncertainty in the estimated carbon sequestration in various ecoregions and the entire Eastern United States?
- Examine the effects of major land use activities and disturbances (fire (chap. 4 of this report) and forest harvesting activities, including clearcutting and partial cutting) on carbon dynamics.
- Perform an integrated analysis of carbon stocks and fluxes for the baseline period by synthesizing results from fire emissions and aquatic systems. Similar integration could not be done for the projection period owing to the lack of data for aquatic systems.
- Identify major limitations of this assessment and future directions for carbon cycle research, assessment, and monitoring in the region.

7.4. Results

7.4.1. Baseline Ecosystem Carbon Stocks

Maps of estimated annual carbon stocks by the terrestrial ecosystems and ecoregions from 2001 through 2005 were produced using the three models. The magnitude and spatial pattern of the carbon stock estimated from 2001 through 2005 remained relatively stable; for this reason, the estimates for 2005 (the last year of the baseline period) are presented in this report. The map in figure 7–5 shows the spatial distribution and uncertainty estimates of total ecosystem carbon stock (carbon in live and dead biomass plus SOC in the top 20-cm soil layer) in the Eastern United States in 2005. The high carbon storage locations are shown mostly in the northern States where soil carbon content was high (carbon in 20-cm soil layer more than 5 kgC/m^2) and along the Atlantic Ocean and Gulf of Mexico coastal regions where wetlands were dominant. The Blue Ridge hydrographic province also had high carbon storage because of high forest biomass. The uncertainty map, which shows the standard deviation, shows that high carbon storage regions usually had higher model uncertainty.

Table 7–4 lists the range (minimum to maximum) and the average of the estimated amounts of carbon stored as estimated by the three models (LGAT, Century, and EDCM) for 2005, the last year of the baseline conditions. The total estimated carbon storage averaged 26,961.8 TgC (ranged from 25,068.8 to 28,497 TgC across the three models) for the Eastern United States. Among all the ecoregions within the Eastern United States, the Southeastern USA Plains ecoregion stored the most carbon with more than 7,794.2 TgC (29 percent), followed by the Ozark, Ouachita-Appalachian Forests (18 percent), Mississippi Alluvial and Southeast USA Coastal Plains (15 percent), Mixed Wood Plains (13 percent), Atlantic Highlands (10 percent), Mixed Wood Shield (10 percent), and Central USA Plains (6 percent) ecoregions. SOC in the top 20-cm soil, live biomass, and other carbon pool (such as litter and woody debris) accounted for 43 percent, 42 percent, and 15 percent of the total carbon storage in the Eastern United States, respectively. Breaking down different ecosystems, forests, agricultural lands, wetland, grassland/shrubland, and other lands stored 68 percent, 15 percent, 15 percent, 1 percent, and 1 percent of the total carbon, respectively. Among different ecosystems, forest was the dominant carbon storage location for the Mixed Wood Shield, Atlantic Highlands, Mixed Wood Plains, Southeastern USA Plains, and Ozark, Ouachita-Appalachian Forests ecoregions. Carbon storage in the Central USA Plains ecoregion was predominantly in agricultural lands, whereas carbon storage in the Mississippi Alluvial and Southeast USA Coastal Plains ecoregion was predominantly in wetlands.

Carbon density (that is, carbon storage per unit area) for a specific ecosystem varied substantially between ecoregions. The Atlantic Highlands ecoregion had the highest carbon storage density (15 kgC/m^2), followed by the Mixed Wood Shield (12 kgC/m^2), Ozark, Ouachita-Appalachian Forests (9.2 kgC/m^2), Mixed Wood Plains (9.1 kgC/m^2), Southeastern USA Plains (7.8 kgC/m^2), Mississippi Alluvial and Southeast USA Coastal Plains (7.7 kgC/m^2), and Central USA Plains (6.3 kgC/m^2) ecoregions.

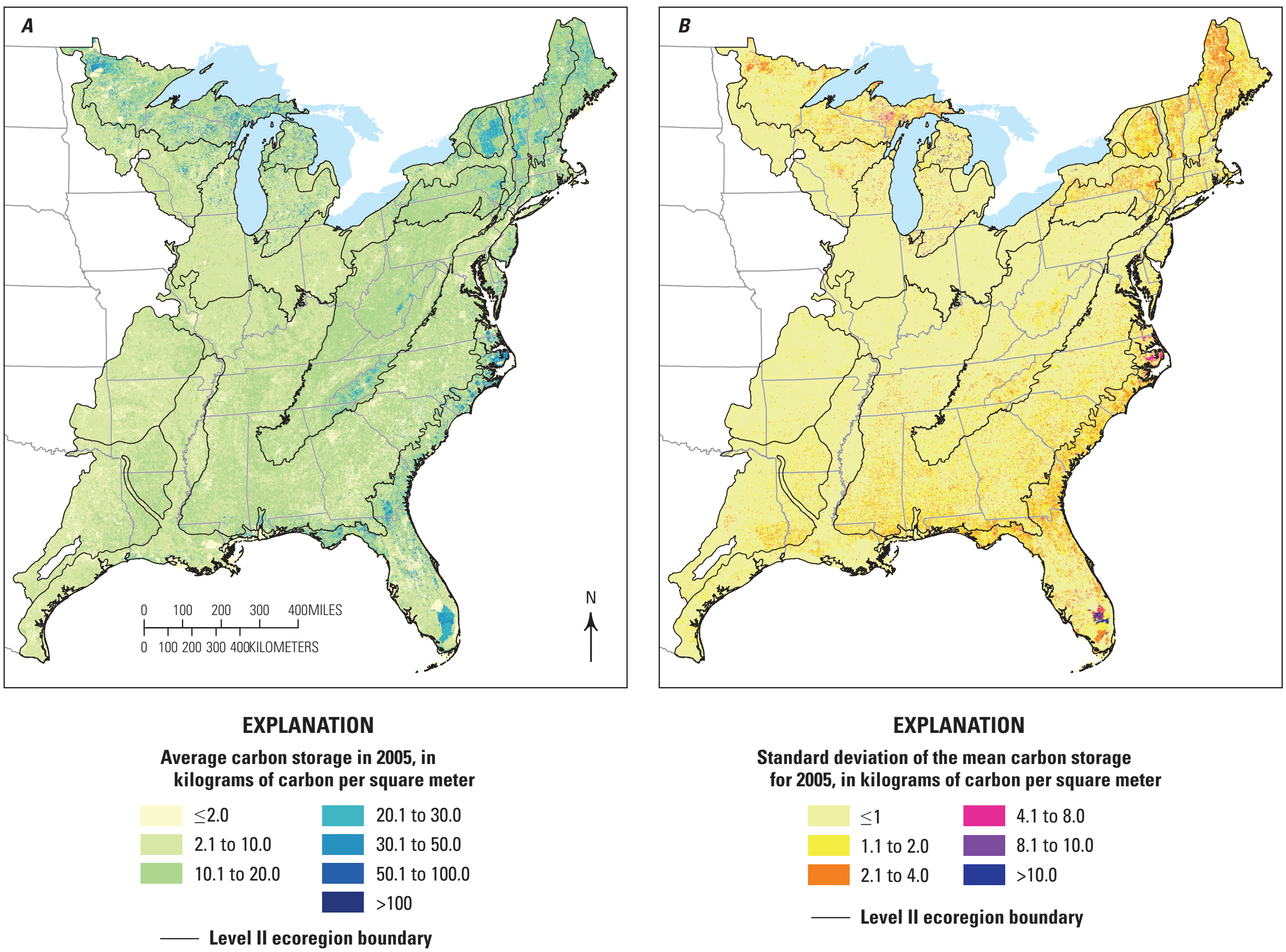


Figure 7–5. Maps showing the *A*, average amount and *B*, standard deviation from the average amount of carbon stored in the Eastern United States in 2005. The estimated average amount of carbon stored in 2005 was derived by averaging the results from three General Ensemble Modeling System (GEMS) models (Land GHG Accounting Tool, Century, and Erosion Deposition Carbon Model). Level II ecoregions are shown in figure 1–1.

For forest, the highest carbon density was in the Atlantic Highlands ecoregion (16.8 kgC/m^2) and the lowest carbon density was in the Southeast USA Coastal Plains ecoregion (11 kgC/m^2). For grassland/shrubland, the highest carbon density was in the Atlantic Highlands ecoregion (8.2 kgC/m^2) and the lowest carbon density was in the Ozark, Ouachita-Appalachian Forests ecoregion (3.9 kgC/m^2). For agricultural lands, the Central USA Plains ecoregion had the highest carbon density (5.7 kgC/m^2), whereas the Ozark, Ouachita-Appalachian Forests ecoregion had the lowest carbon density (3 kgC/m^2). For wetlands, the Atlantic Highlands ecoregion had the highest carbon density (19.2 kgC/m^2), whereas the Ozark, Ouachita-Appalachian Forests ecoregion had the lowest carbon density (9.4 kgC/m^2).

7.4.1.1. Mixed Wood Shield

In this northern ecoregion of the Eastern United States, the total carbon storage in 2005 was 2,596 TgC, ranging between 2,470 and 2,745 TgC across the three models, of which 32 percent was in live biomass, 53 percent was in soil, and 15 percent was in ground litter and dead woody biomass. Among the different ecosystems, forest occupied 51 percent of the total land area and held 52 percent of the total carbon stock (1,360 TgC). Grassland/shrubland occupied 2 percent of the land area and took 1 percent of the carbon storage (26 TgC). Agricultural land area occupied 10 percent of land area with 4 percent of the total carbon storage (105 TgC). The wetland system occupied 27 percent of land area, but accounted for 42 percent of the total carbon storage (1,100 TgC). Carbon densities were 19.2 kgC/m^2, 12.3 kgC/m^2, 6.7 kgC/m^2, 5 kgC/$m^{2,}$ and for wetland, forest, grassland/shrubland, and agricultural land, respectively.

7.4.1.2. Atlantic Highlands

The total carbon storage of this ecoregion in 2005 was 2,808 TgC, ranging between 2,619 and 3,008 TgC across models, of which 45 percent was in live biomass, 37 percent was in soil, and 17 percent was in ground litter and dead woody biomass. Forest had the major portion of carbon stock (2,608 TgC, 93 percent of the total), followed by agricultural land (95 TgC, 3 percent of the total) and wetland (92 TgC, 3 percent of the total). The grassland/shrubland only had 2.5 TgC (0.1 percent of the total). This ecoregion had the highest forestland area percentage (83 percent) in the eastern ecoregions. The forest carbon density was also the highest (16.9 kgC/m^2). The carbon densities of wetland, grassland/shrubland, and agricultural land were 17.9 kgC/m^2, 8.2 kgC/m^2, and 5.2 kgC/m^2, respectively.

7.4.1.3. Mixed Wood Plains

This northern ecoregion was dominated by wetland and forest ecosystems, which accounted for 41 and 38 percent, respectively, of total land area. The total carbon storage in this ecoregion in 2005 was 3,550 TgC, ranging from 3,369 and 3,786 TgC across all models, of which 55 percent was in soil, 32 percent was in live biomass, and 13 percent was in ground litter and dead woody biomass. Forest had the major portion of carbon storage (2,234 TgC, 63 percent of the total), followed by agricultural land (883 TgC, 25 percent of the total) and wetland (345 TgC, 10 percent of the total). Grassland/shrubland occupied 0.6 percent of the total land area and accounted for only 0.4 percent (14 TgC) of total carbon storage. Carbon densities were 15.1 kgC/m^2, 14.3 kgC/m^2, 6.1 kgC/m^2, and 5.5 kgC/m^2 for forest, wetland, grassland/shrubland, and agricultural land, respectively.

7.4.1.4. Central USA Plains

As a primarily agricultural region, the Central USA Plains mainly consisted of agricultural and pasture lands. Together, they accounted for 78 percent of the total land area. Forest, wetland, and grassland/shrubland covered 10 percent, 2 percent, and 0.5 percent, respectively, of total land area. The total carbon storage of this ecoregion in 2005 was 1,500 TgC, ranging from 1,442to 1,565 TgC across models, of which 74 percent was in soil, 17 percent was in live biomass, and 9 percent was in ground litter and dead woody biomass. Crop land had the greatest portion of carbon stock (1,057 TgC, 70 percent of the total), followed by forest (320 TgC, 21 percent of the total), wetland (68 TgC, 5 percent of the total) and grassland/shrubland (8 TgC, 1 percent of the total). Carbon densities were 14.6 kgC/m^2, 13.5 kgC/m^2, 6.6 kgC/m^2, and 5.7 kgC/m^2 for wetland, forest, grassland/shrubland, and agricultural land, respectively.

7.4.1.5. Southeastern USA Plains

This is the largest ecoregion in the Eastern United States with significant forest and agricultural lands, covering 55 and 31 percent, respectively, of total land area. Wetland covered 6 percent of the total land area, and grassland/shrubland covered only 1 percent of the total land area. The total carbon storage of this ecoregion in 2005 was 7,794 TgC, ranging from 7,065 to 8,266 TgC across the three models, of which 51 percent was in live biomass, 33 percent was in soil, and 16 percent was in ground litter and dead woody biomass. Forest land had the greatest portion of carbon stock (6,052 TgC, 78 percent of the total), followed by cropland (895 TgC, 11 percent of the total), wetland (732 TgC, 9 percent of the total), and grassland/shrubland (48 TgC, 1 percent of the total). Carbon densities were 12.1 kgC/m^2, 11 kgC/m^2, 4.3 kgC/m^2, 3 kgC/m^2 for wetland, forest, grassland/shrubland, and agricultural land, respectively.

7.4.1.6. Ozark, Ouachita-Appalachian Forests

Approximately 72 percent of this ecoregion is forest. The total carbon storage of this ecoregion in 2005 was

Table 7–4. Carbon stored in the Eastern United States in 2005.

[Carbon storage is by carbon pool for each ecoregion and ecosystem. Only soil organic carbon (SOC) in the top 20 centimeters of the soil layer was calculated. km^2, square kilometers; max, maximum; min, minimum; TgC, teragrams (or 10^{12} grams) of carbon]

Ecoregion	Ecosystem	Area, in km^2	Biomass, in TgC			SOC, in TgC		
			Min	Max	Average	Min	Max	Average
Mixed Wood Shield	Forests	110,556	508.3	534.9	530.2	534.2	600.8	564.5
	Grass/shrub	3,796	0.9	4.5	2.9	18.1	19.7	19.4
	Agriculture	20,986	0.0	6.8	3.0	88.7	102.8	94.3
	Wetlands	57,336	241.2	306.6	279.4	676.3	724.2	704.2
	Other	22,926	0.0	0.0	0.0	0.6	27.3	6.3
	Total	**215,599**	**750.5**	**852.7**	**815.6**	**1,317.9**	**1,474.8**	**1,388.6**
Atlantic Highlands	Forests	154,954	1,206.4	1,273.2	1,238.8	836.1	989.4	904.1
	Grass/shrub	306	0.1	1.0	0.5	1.6	1.7	1.6
	Agriculture	18,194	0.0	3.3	1.7	82.8	92.8	88.1
	Wetlands	5,123	30.8	36.9	33.8	44.6	47.9	46.0
	Other	8,973	0.0	0.2	0.1	1.9	26.2	10.3
	Total	**187,550**	**1,237.3**	**1,314.7**	**1,274.9**	**967.0**	**1,158.0**	**1,050.1**
Mixed Wood Plains	Forests	147,983	958.4	999.5	977.5	821.7	943.6	876.2
	Grass/shrub	2,247	0.4	2.6	1.5	10.4	11.2	10.6
	Agriculture	159,756	0.0	66.3	37.1	761.5	846.1	793.9
	Wetlands	24,231	97.2	110.6	103.4	194.4	211.9	201.7
	Other	54,639	0.0	2.0	0.9	19.2	162.2	70.3
	Total	**388,858**	**1,056.0**	**1,181.0**	**1,120.3**	**1,807.3**	**2,175.0**	**1,952.6**
Central USA Plains	Forests	23,787	153.7	170.5	160.0	97.3	115.8	108.2
	Grass/shrub	1,175	0.0	1.0	0.6	6.3	6.9	6.6
	Agriculture	185,336	0.0	109.5	62.4	884.5	953.0	919.5
	Wetlands	4,675	21.7	25.5	23.6	35.8	38.5	37.0
	Other	24,055	0.0	2.2	0.9	18.3	83.1	44.7
	Total	**239,027**	**175.4**	**308.7**	**247.5**	**1,042.2**	**1,197.3**	**1,116.1**
Southeastern USA Plains	Forests	550,022	3,434.0	3,567.7	3,502.3	1,141.4	1,546.1	1,477.7
	Grass/shrub	11,262	9.4	15.2	12.7	23.5	30.9	28.3
	Agriculture	306,678	0.3	85.2	47.2	670.1	831.8	745.3
	Wetlands	60,762	361.4	421.5	390.5	213.1	256.7	241.9
	Other	65,622	0.0	4.1	1.9	26.4	102.8	56.4
	Total	**994,346**	**3,805.1**	**4,093.8**	**3,954.6**	**2,074.6**	**2,768.4**	**2,549.6**
Ozark, Ouachita-Appalachian Forests	Forests	372,212	2,542.7	2,645.3	2,567.9	849.1	1,143.3	1,069.2
	Grass/shrub	3,903	0.7	4.2	2.3	9.7	12.1	11.1
	Agriculture	117,760	0.1	23.0	13.0	273.4	337.8	303.8
	Wetlands	2,592	11.5	12.6	12.1	7.5	9.0	8.6
	Other	24,020	0.0	1.1	0.5	7.9	37.9	20.0
	Total	**520,486**	**2,554.9**	**2,686.2**	**2,595.8**	**1,147.6**	**1,540.1**	**1,412.7**
Mississippi Alluvial and Southeast USA Coastal Plains	Forests	101,944	607.1	750.9	708.7	445.3	492.3	479.6
	Grass/shrub	28,618	13.0	33.1	24.5	85.2	90.3	87.9
	Agriculture	143,291	0.1	36.7	20.1	459.8	524.2	493.4
	Wetlands	116,763	466.5	615.5	565.0	999.0	1,059.2	1,009.4
	Other	116,144	0.0	2.1	0.9	21.1	201.9	70.1
	Total	**506,760**	**1,086.7**	**1,438.2**	**1,319.2**	**2,010.3**	**2,367.9**	**2,140.3**
Eastern United States	Forests	1,461,458	9,410.6	9,942.1	9,685.5	4,725.2	5,831.3	5,479.4
	Grass/shrub	51,306	24.5	61.6	44.9	154.8	172.8	165.4
	Agriculture	952,000	0.4	330.8	184.5	3,220.8	3,688.4	3,438.5
	Wetlands	271,482	1,230.3	1,529.3	1,407.8	2,170.8	2,347.5	2,248.8
	Other	316,380	0.0	11.7	5.3	95.3	641.4	278.0
	Total	**3,052,626**	**10,665.9**	**11,875.4**	**11,328.0**	**10,366.9**	**12,681.5**	**11,610.0**

Table 7–4. Carbon stored in the Eastern United States in 2005.—Continued

[Carbon storage is by carbon pool for each ecoregion and ecosystem. Only soil organic carbon (SOC) in the top 20 centimeters of the soil layer was calculated. km^2, square kilometers; max, maximum; min, minimum; TgC, teragrams (or 10^{12} grams) of carbon]

Ecoregion	Ecosystem	Area, in km^2	Others, in TgC			Total, in TgC		
			Min	Max	Average	Min	Max	Average
Mixed Wood Shield	Forests	110,556	232.1	295.2	265.6	1,299.7	1,424.3	1,360.3
	Grass/shrub	3,796	0.0	4.9	3.2	22.5	28.9	25.5
	Agriculture	20,986	0.0	12.4	7.3	98.4	109.6	104.7
	Wetlands	57,336	107.4	123.9	116.0	1,048.9	1,154.6	1,099.6
	Other	22,926	0.0	0.2	0.1	0.8	27.3	6.4
	Total	**215,599**	**339.5**	**436.6**	**392.2**	**2,470.3**	**2,744.5**	**2,596.4**
Atlantic Highlands	Forests	154,954	390.9	531.4	464.8	2,437.5	2,779.3	2,607.7
	Grass/shrub	306	0.0	0.7	0.4	1.8	3.0	2.5
	Agriculture	18,194	0.0	9.3	5.1	89.0	102.1	94.9
	Wetlands	5,123	11.1	13.2	12.2	87.4	97.7	91.9
	Other	8,973	0.0	1.3	0.8	3.2	26.2	11.2
	Total	**187,550**	**402.0**	**555.9**	**483.2**	**2,619.0**	**3,008.2**	**2,808.2**
Mixed Wood Plains	Forests	147,983	347.4	416.7	380.6	2,127.8	2,344.7	2,234.3
	Grass/shrub	2,247	0.0	2.4	1.5	12.0	15.1	13.6
	Agriculture	159,756	0.0	75.2	51.6	873.6	907.7	882.6
	Wetlands	24,231	39.1	40.3	40.1	332.0	356.2	345.2
	Other	54,639	0.0	4.5	2.8	23.8	162.2	74.0
	Total	**388,858**	**386.6**	**539.1**	**476.6**	**3,369.1**	**3,785.9**	**3,549.6**
Central USA Plains	Forests	23,787	50.1	52.7	51.8	310.3	330.2	319.9
	Grass/shrub	1,175	0.0	0.9	0.6	6.9	8.8	7.8
	Agriculture	185,336	0.0	97.6	75.1	1,039.7	1,072.4	1,057.0
	Wetlands	4,675	7.4	8.2	7.7	65.7	70.8	68.4
	Other	24,055	0.0	1.0	0.7	19.3	83.1	46.4
	Total	**239,027**	**57.5**	**160.5**	**135.9**	**1,441.9**	**1,565.3**	**1,499.5**
Southeastern USA Plains	Forests	550,022	880.3	1,228.9	1,072.0	5,525.4	6,338.1	6,052.0
	Grass/shrub	11,262	0.0	12.7	7.3	38.4	58.9	48.2
	Agriculture	306,678	0.0	180.2	102.7	805.8	1,012.3	895.3
	Wetlands	60,762	80.9	124.8	99.9	655.4	753.7	732.4
	Other	65,622	0.0	13.0	8.1	39.7	102.8	66.3
	Total	**994,346**	**961.2**	**1,559.7**	**1,290.0**	**7,064.7**	**8,265.8**	**7,794.2**
Ozark, Ouachita-Appalachian Forests	Forests	372,212	720.8	769.2	744.3	4,215.2	4,417.0	4,381.4
	Grass/shrub	3,903	0.0	2.7	1.7	12.5	18.1	15.1
	Agriculture	117,760	0.0	56.8	30.6	311.3	394.6	347.4
	Wetlands	2,592	3.3	4.1	3.6	23.2	24.6	24.3
	Other	24,020	0.0	3.8	2.3	11.8	37.9	22.8
	Total	**520,486**	**724.1**	**836.7**	**782.5**	**4,574.0**	**4,892.2**	**4,791.0**
Mississippi Alluvial and Southeast USA Coastal Plains	Forests	101,944	172.6	269.0	230.2	1,225.1	1,497.6	1,418.6
	Grass/shrub	28,618	0.0	24.0	14.1	108.0	147.4	126.4
	Agriculture	143,291	0.0	120.5	70.4	537.6	644.6	583.8
	Wetlands	116,763	107.2	179.0	145.6	1,633.0	1,743.6	1,720.0
	Other	116,144	0.0	4.9	3.0	26.1	201.9	74.0
	Total	**506,760**	**279.9**	**597.4**	**463.3**	**3,529.8**	**4,235.1**	**3,922.8**
Eastern United States	Forests	1,461,458	2,794.2	3,563.1	3,209.4	17,141.1	19,131.1	18,374.2
	Grass/shrub	51,306	0.0	48.4	28.7	202.1	280.2	239.0
	Agriculture	952,000	0.0	552.1	342.8	3,755.3	4,243.2	3,965.7
	Wetlands	271,482	356.4	493.4	425.2	3,845.5	4,201.0	4,081.8
	Other	316,380	0.0	28.8	17.8	124.8	641.4	301.1
	Total	**3,052,626**	**3,150.7**	**4,685.8**	**4,023.8**	**25,068.8**	**28,497.0**	**26,961.8**

4,791 TgC, ranging from 4,574 to 4,892 TgC across models, of which 54 percent was in live biomass, 29 percent was in soil, and 16 percent was in ground litter and dead woody biomass. Forest land had the greatest portion of carbon stock (4,381 TgC, 91 percent of the total), followed by cropland (347 TgC, 7 percent of the total), wetland (24 TgC, 1 percent of the total) and grassland/shrubland (15 TgC, 0.3 percent of the total). Carbon densities were 11.8 kgC/m^2, 9.4 kgC/m^2, 3.9 kgC/m^2, and 3 kgC/m^2 for forest, wetland, grassland/shrubland, and agricultural land, respectively.

7.4.1.7. Mississippi Alluvial and Southeast USA Coastal Plains

In this largest coastal ecoregion in the United States, cropland, wetland, forest, and grassland/shrubland occupied 28 percent, 23 percent, 20 percent, and 6 percent, respectively, of total land area. Other lands mostly have no natural vegetation cover (such as, barren and urban) and encompassed 23 percent of the total land area. The total carbon storage of this ecoregion in 2005 was 3,923 TgC, ranging from 3,530 to 4,235 TgC across models, of which 54 percent was in soil, 34 percent was in live biomass, and 12 percent was in ground litter and dead woody biomass. Wetland had the greatest portion of carbon stock (1,720 TgC, 44 percent of the total), followed by forest land (1,419 TgC, 36 percent of the total), cropland (584 TgC, 15 percent of the total) and grassland/shrubland (126 TgC, 3 percent of the total). Carbon densities were 14.7 kgC/m^2, 13.9 kgC/m^2, 4.4 kgC/m^2, and 4.1 kgC/m^2 for forest, wetland, grassland/shrubland, and agricultural land, respectively.

7.4.2. Baseline Net Ecosystem Carbon Fluxes

The magnitude and spatial distribution of the average net carbon fluxes across the Eastern United States are shown in figure 7–6, which indicates a strong carbon sink associated with forest areas in the region. The standard deviations were generally positively correlated with carbon gains, as was expected.

Table 7–5 lists the minimum, maximum, and average of the carbon stock change (that is, the NECB) by carbon pool (live biomass, dead biomass, and soil), ecosystem type, and ecoregion in the Eastern United States averaged from 2001 through 2005. The overall NECB ranged from –405.5 to –112.5 TgC/yr among the three models, with an average of –279.4 TgC/yr, of which –188.7 TgC was attributed to live biomass accumulation, –65.4 TgC to soil carbon pool, and –25.2 TgC to dead biomass carbon pool. The forest ecosystem was the largest carbon sink (81 percent of the total), followed by wetland (13 percent), agricultural lands (4 percent), and grassland/shrubland (1 percent). On a per-unit area basis, the magnitude of the carbon sink in forests, wetlands, grassland/shrubland, and agricultural lands was –155 gC/m^2/yr, –132 gC/m^2/yr, –41 gC/m^2/yr, and –12 gC/m^2/yr, respectively. Although all the ecoregions were carbon sinks from 2001 through 2005, certain individual ecosystems in specific ecoregions were not. For example, agricultural lands in the Mixed Wood Shield ecoregion and grassland/shrubland in the Central USA Plains ecoregion were estimated to be carbon neutral, and agricultural lands in the Atlantic Highlands and Mixed Wood Plains ecoregions were estimated to lose carbon at a rate of 0.2 TgC/yr and 1.5 TgC/yr, respectively.

7.4.2.1. Mixed Wood Shield

The average estimate for net ecosystem carbon flux in this ecoregion was approximately –14.5 teragrams of carbon per year (TgC/yr), ranging from –18.6 to –6.3 TgC/yr across models, of which 76 percent was allocated to live biomass, 13 percent to soil, and 11 percent to ground litter and dead woody biomass. Among the different ecosystems, the forest ecosystem sequestered –9.7 TgC/yr (67 percent of the total), wetland –4.5 TgC/yr (31 percent), grassland/shrubland – 0.3 TgC/yr (2 percent of the total), and agricultural land (carbon neutral).

7.4.2.2. Atlantic Highlands

The average estimate for net carbon flux in this overwhelmingly forested ecoregion was –24.7 TgC/yr, ranging from –28.6 to –15.0 TgC/yr across models, of which 81 percent was allocated to live biomass, 18 percent to soil, and 1 percent to ground litter and dead woody biomass. The forest ecosystem sequestered –24.2 TgC/yr (98 percent of the total), followed by wetland with –0.6 TgC/yr (2 percent of the total). Agricultural land lost carbon at a small rate of 0.2 Tg/yr.

7.4.2.3. Mixed Wood Plains

The average estimate for net carbon flux in this ecoregion was –22.4 TgC/yr, ranging from –26.2 to –12.4 TgC/yr across the three models, of which 84 percent was allocated to live biomass, 9 percent to ground litter and dead woody biomass, and 7 percent to soil. Forest sequestered –20.9 TgC/yr (93 percent of the total), followed by wetland with –2.1 TgC/yr (9 percent of the total) and grassland/shrubland with –0.1 TgC/yr (0.5 percent of the total). Agricultural land was a carbon source at a rate of 1.5 TgC/yr.

7.4.2.4. Central USA Plains

The ecoregion was dominated by agricultural lands (78 percent of the total land area). The average estimate for net carbon flux was –5.2 TgC/yr, ranging from –7.4 to –2.9 TgC/yr across models, of which 46 percent was allocated to ground litter and dead woody biomass, 44 percent to live biomass, and 10 percent to soil. Forest sequestered –2.7 TgC/yr (52 percent of the total), followed by agricultural land (–1.6 TgC/yr, 31 percent of the total), wetland (–0.4 TgC/yr, 8 percent of the total), and grassland/shrubland (carbon neutral).

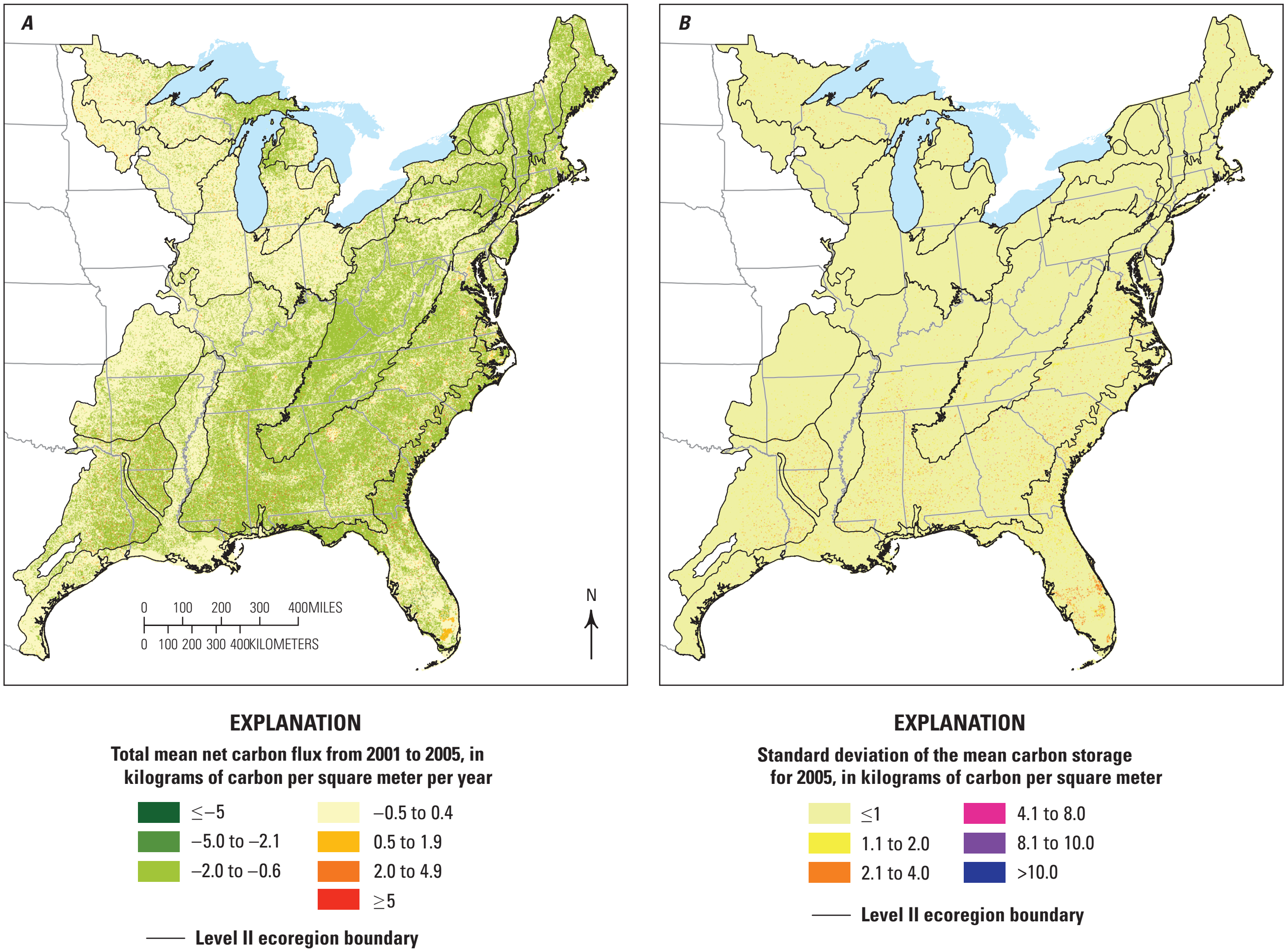


Figure 7–6. Maps showing carbon flux in ecosystems of the Eastern United States. *A*, The average net carbon flux derived from each of the three General Ensemble Modeling System (GEMS) models (Land GHG Accounting Tool, Century, and Erosion Deposition Carbon Model) and averaged for the baseline years (2001 through 2005). *B*, The standard deviation of the three models for the baseline years. Negative values indicate net carbon gains and positive values indicate net carbon losses. Level II ecoregions are shown in figure 1–1.

7.4.2.5. Southeastern USA Plains

This largest ecoregion in this assessment was dominated by forests and agricultural lands (55 percent and 31 percent, respectively, of total land area). The average estimate for net carbon flux was –112.2 TgC/yr, ranging from –176.7 to –39.4 TgC/yr across the three models, of which 62xpercent was allocated to live biomass, 29 percent to soil, and 9 percent to ground litter and dead woody biomass. Forest sequestered –93.4 TgC/yr (83 percent of the total), followed by wetland (–12.6 TgC/yr, 11 percent of the total), cropland (–4.7 TgC/yr, 4 percent of the total), and grassland/shrubland (–0.6 TgC/yr, 0.5 percent of the total).

7.4.2.6. Ozark, Ouachita-Appalachian Forests

In this heavily forested ecoregion (72 percent of the total area), the average estimate for net carbon flux was –60.7 TgC/yr, ranging from –84.6 to –30.4 TgC/yr across models, of which 65 percent was allocated to live biomass, 29percent to soil, and 6 percent to ground litter and dead woody biomass. Forest sequestered –58 TgC/yr (96 percent of the total), followed by agricultural land (–1.8 TgC/yr, 3 percent of the total), wetland (–0.4 TgC/yr, 1 percent of the total), and grassland/shrubland (–0.2 TgC/yr, less than 0.5 percent of the total).

7.4.2.7. Mississippi Alluvial and Southeast USA Coastal Plains

The costal ecoregion consisted of agricultural lands (28 percent), wetlands (23 percent), other lands (23 percent), forests (20 percent), and grassland/shrubland (6 percent). The mean estimate for net carbon flux was –39.7 TgC/yr, ranging from –63.4 to –6.2 TgC/yr across models, of which 70 percent was allocated to live biomass, 18 percent to soil, and

Table 7–5. Net ecosystem carbon balance in the Eastern United States from 2001 through 2005.

[Data are by carbon pool for each ecoregion and ecosystem Negative numbers indicate carbon sequestration; positive numbers indicate a loss of carbon to the atmosphere. Only soil organic carbon (SOC) in the top 20 centimeters of the soil layer was calculated. km^2, square kilometers; max, maximum; min, minimum; TgC/yr, teragrams (or 10^{12} grams) of carbon per year]

Ecoregion	Ecosystem	Area, in km^2	Biomass, in TgC/yr			SOC, in TgC/yr		
			Min	Max	Average	Min	Max	Average
Mixed Wood Shield	Forests	110,556	–7.2	–3.3	–6.6	–3.1	–0.1	–2.1
	Grass/shrub	3,796	0.0	0.1	0.0	–0.3	–0.2	–0.2
	Agriculture	20,986	–0.1	0.0	0.0	–0.1	0.4	0.2
	Wetlands	57,336	–5.9	–1.5	–4.5	–0.4	0.9	0.2
	Other	22,926	0.0	0.0	0.0	0.0	0.1	0.0
	Total	**215,599**	**–13.3**	**–4.7**	**–11.0**	**–3.9**	**1.1**	**–1.9**
Atlantic Highlands	Forests	154,954	–21.0	–12.1	–19.3	–8.8	0.1	–4.6
	Grass/shrub	306	0.0	0.0	0.0	–0.1	0.0	–0.1
	Agriculture	18,194	0.0	0.0	0.0	0.0	0.5	0.3
	Wetlands	5,123	–0.7	–0.2	–0.6	–0.1	0.0	–0.1
	Other	8,973	0.0	0.0	0.0	–0.1	0.1	0.0
	Total	**187,550**	**–21.8**	**–12.3**	**–19.9**	**–9.1**	**0.8**	**–4.4**
Mixed Wood Plains	Forests	147,983	–18.1	–11.1	–17.0	–5.7	0.7	–3.2
	Grass/shrub	2,247	0.0	0.0	0.0	–0.1	–0.1	–0.1
	Agriculture	159,756	–0.4	0.1	0.0	0.8	3.1	2.5
	Wetlands	24,231	–2.0	–1.1	–1.7	–0.5	–0.1	–0.3
	Other	54,639	–0.1	0.0	–0.1	–1.3	0.2	–0.6
	Total	**388,858**	**–20.7**	**–12.1**	**–18.8**	**–6.8**	**3.9**	**–1.6**
Central USA Plains	Forests	23,787	–2.0	–1.6	–1.8	–1.0	0.1	–0.7
	Grass/shrub	1,175	0.0	0.0	0.0	0.0	0.1	0.0
	Agriculture	185,336	–1.4	0.1	–0.1	0.1	1.2	0.7
	Wetlands	4,675	–0.4	–0.2	–0.3	–0.1	0.0	–0.1
	Other	24,055	–0.1	0.0	0.0	–1.1	0.0	–0.5
	Total	**239,027**	**–3.9**	**–1.6**	**–2.3**	**–2.1**	**1.4**	**–0.5**
Southeastern USA Plains	Forests	550,022	–85.6	–32.5	–61.3	–36.8	0.7	–24.4
	Grass/shrub	11,262	–0.1	0.0	0.0	–0.7	0.0	–0.4
	Agriculture	306,678	–0.7	0.8	0.2	–11.0	1.4	–3.6
	Wetlands	60,762	–9.9	–3.6	–7.9	–5.1	–0.7	–3.3
	Other	65,622	–0.2	0.0	–0.1	–1.4	–0.3	–0.9
	Total	**994,346**	**–96.6**	**–35.2**	**–69.2**	**–55.0**	**1.2**	**–32.6**
Ozark, Ouachita-Appalachian Forests	Forests	372,212	–52.0	–26.2	–39.3	–18.6	0.2	–15.4
	Grass/shrub	3,903	0.0	0.0	0.0	–0.2	0.0	–0.1
	Agriculture	117,760	–0.3	0.0	0.0	–4.3	1.0	–1.3
	Wetlands	2,592	–0.3	–0.1	–0.2	–0.2	0.0	–0.1
	Other	24,020	–0.1	0.0	0.0	–0.5	0.0	–0.3
	Total	**520,486**	**–52.6**	**–26.2**	**–39.6**	**–23.8**	**1.2**	**–17.3**
Mississippi Alluvial and Southeast USA Coastal Plains	Forests	101,944	–20.9	–3.0	–15.1	–4.3	1.1	–2.1
	Grass/shrub	28,618	–0.2	0.0	–0.1	–0.8	0.1	–0.5
	Agriculture	143,291	0.0	0.1	0.0	–5.1	1.3	–2.1
	Wetlands	116,763	–15.9	–3.0	–12.7	–4.6	1.5	–1.5
	Other	116,144	–0.1	0.0	–0.1	–1.6	–0.2	–1.0
	Total	**506,760**	**–37.2**	**–5.9**	**–27.9**	**–16.4**	**3.8**	**–7.1**
Eastern United States	Forests	1,461,458	–206.8	–89.7	–160.4	–78.2	2.9	–52.3
	Grass/shrub	51,306	–0.3	0.2	–0.1	–2.2	–0.1	–1.3
	Agriculture	952,000	–3.0	1.2	–0.1	–19.7	9.1	–3.5
	Wetlands	271,482	–35.2	–9.8	–27.9	–11.1	1.6	–5.0
	Other	316,380	–0.7	0.0	–0.3	–6.0	–0.2	–3.2
	Total	**3,052,626**	**–246.1**	**–98.1**	**–188.7**	**–117.2**	**13.3**	**–65.4**

Table 7–5. Net ecosystem carbon balance in the Eastern United States from 2001 through 2005.—Continued

[Data are by carbon pool for each ecoregion and ecosystem Negative numbers indicate carbon sequestration; positive numbers indicate a loss of carbon to the atmosphere. Only soil organic carbon (SOC) in the top 20 centimeters of the soil layer was calculated. km^2, square kilometers; max, maximum; min, minimum; TgC/yr, teragrams (or 10^{12} grams) of carbon per year]

Ecoregion	Ecosystem	Area, in km^2	Others, in TgC/yr			Total, in TgC/yr		
			Min	Max	Average	Min	Max	Average
Mixed Wood Shield	Forests	110,556	–3.5	1.6	–1.0	–12.4	–4.7	–9.7
	Grass/shrub	3,796	–0.2	0.0	–0.1	–0.4	–0.2	–0.3
	Agriculture	20,986	–0.4	0.0	–0.2	–0.4	0.4	0.0
	Wetlands	57,336	–0.8	0.4	–0.3	–5.3	–1.7	–4.5
	Other	22,926	0.0	0.0	0.0	–0.1	0.1	0.0
	Total	**215,599**	**–5.0**	**2.0**	**–1.6**	**–18.6**	**–6.3**	**–14.5**
Atlantic Highlands	Forests	154,954	–3.3	2.3	–0.2	–27.5	–15.3	–24.2
	Grass/shrub	306	0.0	0.0	0.0	–0.1	0.0	–0.1
	Agriculture	18,194	–0.2	0.0	–0.1	–0.1	0.5	0.2
	Wetlands	5,123	–0.1	0.1	0.0	–0.7	–0.3	–0.6
	Other	8,973	0.0	0.0	0.0	–0.1	0.1	0.0
	Total	**187,550**	**–3.7**	**2.4**	**–0.3**	**–28.6**	**–15.0**	**–24.7**
Mixed Wood Plains	Forests	147,983	–3.0	1.7	–0.8	–22.6	–13.5	–20.9
	Grass/shrub	2,247	–0.1	0.0	0.0	–0.2	–0.1	–0.1
	Agriculture	159,756	–1.7	0.0	–1.0	0.3	2.6	1.5
	Wetlands	24,231	–0.3	0.1	–0.1	–2.4	–1.5	–2.1
	Other	54,639	–0.2	0.0	–0.1	–1.3	0.1	–0.7
	Total	**388,858**	**–5.2**	**1.8**	**–2.0**	**–26.2**	**–12.4**	**–22.4**
Central USA Plains	Forests	23,787	–0.4	0.0	–0.2	–3.0	–2.1	–2.7
	Grass/shrub	1,175	0.0	0.0	0.0	0.0	0.1	0.0
	Agriculture	185,336	–2.9	0.0	–2.1	–2.8	–0.4	–1.6
	Wetlands	4,675	–0.1	0.0	–0.1	–0.5	–0.3	–0.4
	Other	24,055	0.0	0.0	0.0	–1.1	–0.2	–0.6
	Total	**239,027**	**–3.4**	**0.0**	**–2.4**	**–7.4**	**–2.9**	**–5.2**
Southeastern USA Plains	Forests	550,022	–19.3	3.4	–7.7	–141.7	–37.7	–93.4
	Grass/shrub	11,262	–0.3	0.0	–0.2	–1.0	0.1	–0.6
	Agriculture	306,678	–3.9	1.0	–1.2	–14.9	3.2	–4.7
	Wetlands	60,762	–2.4	–0.6	–1.4	–17.5	–4.9	–12.6
	Other	65,622	–0.2	0.4	0.1	–1.6	–0.1	–0.9
	Total	**994,346**	**–26.2**	**4.3**	**–10.4**	**–176.7**	**–39.4**	**–112.2**
Ozark, Ouachita-Appalachian Forests	Forests	372,212	–7.4	1.6	–3.2	–78.0	–31.1	–58.0
	Grass/shrub	3,903	–0.1	0.0	–0.1	–0.3	0.0	–0.2
	Agriculture	117,760	–0.9	0.0	–0.4	–5.2	0.9	–1.8
	Wetlands	2,592	–0.1	0.0	–0.1	–0.6	–0.1	–0.4
	Other	24,020	–0.1	0.0	0.0	–0.5	0.0	–0.3
	Total	**520,486**	**–8.6**	**1.6**	**–3.8**	**–84.6**	**–30.4**	**–60.7**
Mississippi Alluvial and Southeast USA Coastal Plains	Forests	101,944	–1.6	1.3	–0.3	–26.8	–2.6	–17.4
	Grass/shrub	28,618	–0.7	0.0	–0.3	–1.5	0.0	–0.9
	Agriculture	143,291	–5.9	0.0	–2.9	–11.0	1.3	–5.0
	Wetlands	116,763	–1.9	–0.5	–1.1	–22.3	–4.4	–15.2
	Other	116,144	–0.2	0.0	–0.1	–1.8	–0.5	–1.2
	Total	**506,760**	**–10.2**	**0.8**	**–4.7**	**–63.4**	**–6.2**	**–39.7**
Eastern United States	Forests	1,461,458	–38.6	11.8	–13.5	–312.1	–107.0	–226.2
	Grass/shrub	51,306	–1.4	0.0	–0.7	–3.5	–0.1	–2.1
	Agriculture	952,000	–15.8	1.0	–7.9	–34.1	8.4	–11.5
	Wetlands	271,482	–5.7	–0.4	–3.0	–49.3	–13.3	–35.9
	Other	316,380	–0.8	0.5	–0.2	–6.6	–0.5	–3.7
	Total	**3,052,626**	**–62.3**	**12.9**	**–25.2**	**–405.5**	**–112.5**	**–279.4**

12 percent to ground litter and dead woody biomass. Forest sequestered –17.4 TgC/yr (44 percent of the total), followed by wetland (–15.2 TgC/yr, 38 percent of the total), agricultural land (–5 TgC/yr, 13 percent of the total) and grassland/shrubland (–0.9 TgC/yr, 2 percent of the total).

7.4.3. Baseline GHG Fluxes

The minimum, maximum, and average estimates of GHG fluxes for the baseline years are listed in table 7–6. To illustrate the spatial distribution, example maps of the GHG fluxes in 2005 are presented in figure 7–7.

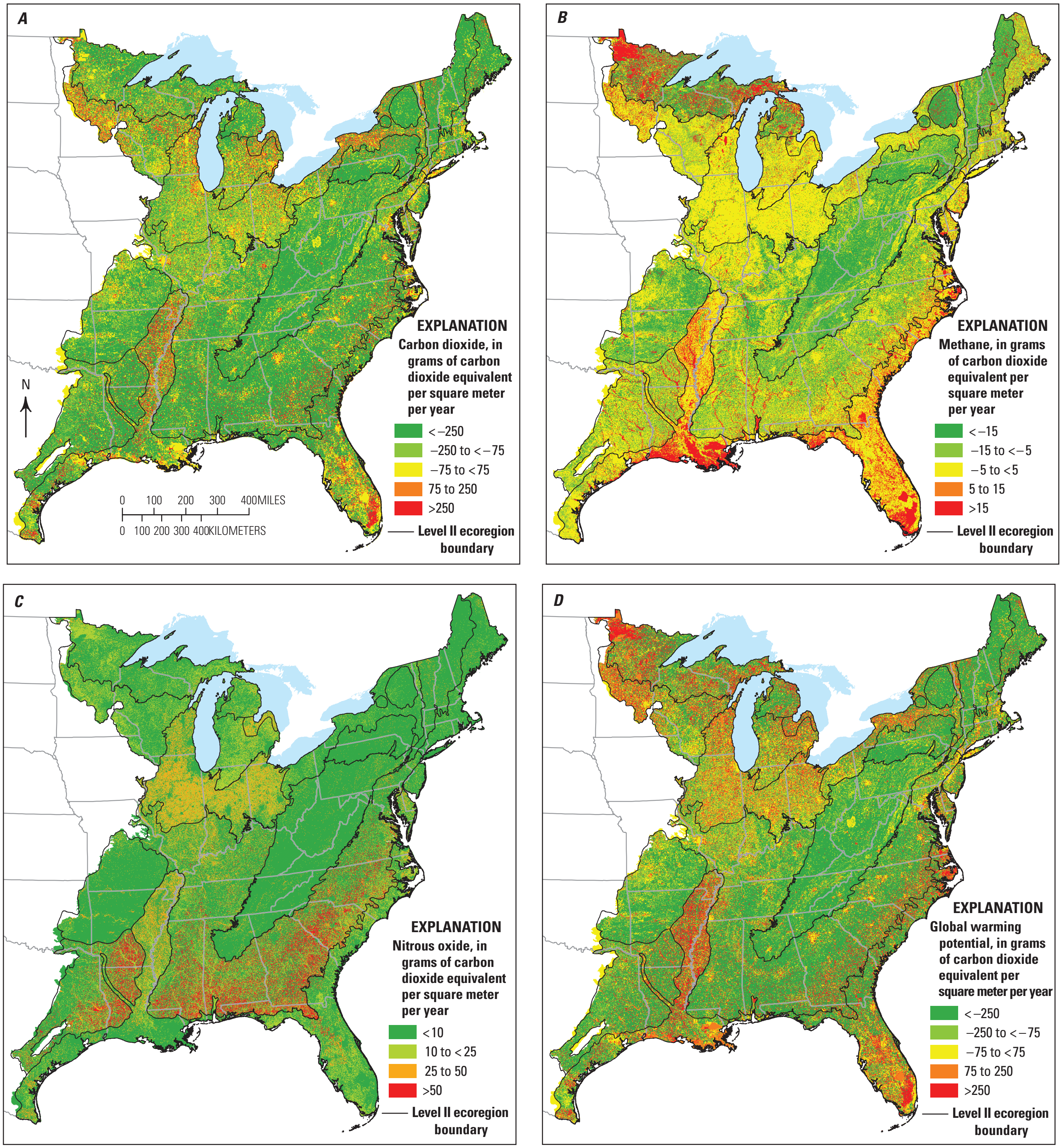


Figure 7–7. Maps showing the spatial distribution of the average annual carbon dioxide, methane, and nitrous oxide fluxes and the total global warming potential from 2001 through 2005 in the Eastern United States. Level II ecoregions are shown in figure 1–1.

Overall, the Eastern United States served as a GHG sink at an average rate of –656.9 $TgCO_2$-eq/yr (ranging from –1,122.3 to –41.3 $TgCO_2$-eq/yr across the three models). On average, the net CO_2 sink strength was –1,024.6 $TgCO_2$-eq/yr. However, the CO_2 sink was partially offset by N_2O and CH_4 emissions with averages of 174.7 $TgCO_2$-eq/yr and 193 $TgCO_2$-eq/yr, respectively. Among all ecosystems, forest was the largest sink of GHG (–776.6 $TgCO_2$-eq/yr), whereas wetlands and cropland were net GHG sources emitting 69.6 $TgCO_2$-eq/yr and 45.9 $TgCO_2$-eq/yr, respectively. Forest and cropland were major sources of N_2O with average annual contributions of 76.4 $TgCO_2$-eq/yr and 74.7 $TgCO_2$-eq/yr, respectively. Wetlands contributed the highest amount of CH_4 with 186.2 $TgCO_2$-eq/yr on emission, followed by cropland with 12.9 $TgCO_2$-eq/yr, but forests took up CH_4 with an average rate of –23.2 $TgCO_2$-eq/yr.

7.4.4. Projected Future Carbon Stock Distributions

A total of 21 maps resulted from the 21 simulation model runs described in the “Ensemble Modeling” and “Output and Further Processing” sections, which depict the spatial patterns of carbon storage in 2050 (the end year of the scenario period), were produced for the Eastern United States. The maps showing the average and standard deviation of the 21 simulation model runs are shown in figure 7–8. Similar to the baseline carbon stock maps (fig. 7–5), the projected future carbon stock maps show that forest ecosystems have the highest carbon density (that is, carbon storage per unit area), and grass/shrublands and agricultural lands have the lowest carbon densities. The spatial pattern of carbon storage in 2050 is in general agreement with that in 2005.

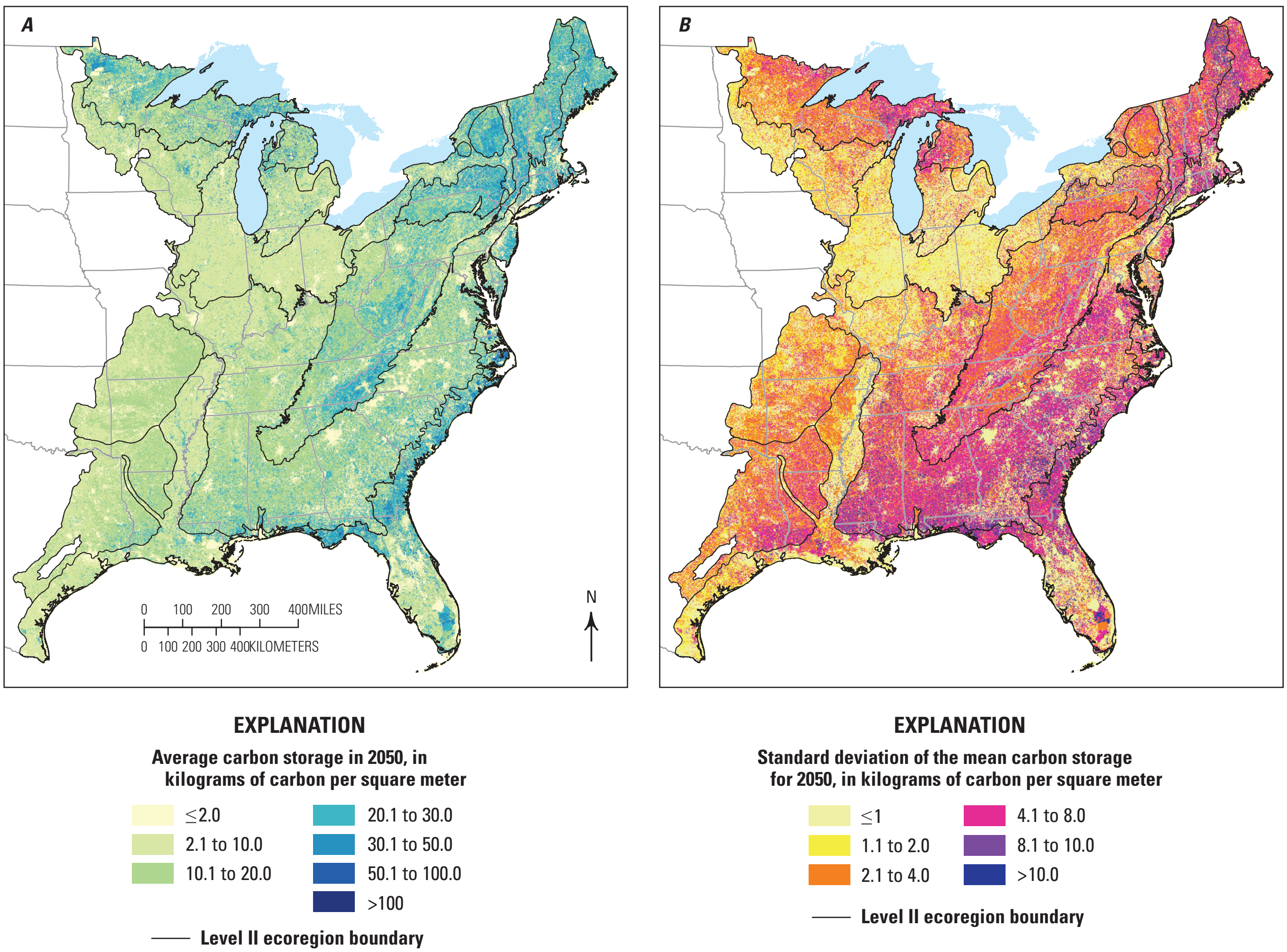


Figure 7–8. Maps showing the projected *A*, average amount and *B*, standard deviation of carbon stored in the Eastern United States in 2050. Projected average carbon stored in 2050 was derived from 21 simulation model runs using biogeochemical models Land GHG Accounting Tool, Century, and Erosion Deposition Carbon Model under Intergovernmental Panel on Climate Change Special Report on Emissions Scenarios (Nakićenović and others, 2000) scenarios A1B, A2, and B1 and general circulation models Third Generation Coupled Global Climate Model of the Canadian Centre for Climate Modelling and Analysis, Australia’s Commonwealth Scientific and Industrial Research Organisation Mark 3.0, and Model for Interdisciplinary Research on Climate 3.2, medium resolution. Level II ecoregions are shown in figure 1–1.

Table 7–6. Annual fluxes and total global warming potential from 2001 through 2005 in the Eastern United States.

[Data are by greenhouse-gas type for each ecosystem in each ecoregion. Estimates of methane (CH_4) and nitrous oxide (N_2O) were generated by the land GHG accounting tool. Carbon dioxide (CO_2) was calculated using net ecosystem carbon balance values from table 7–5. Global warming potential is the sum of CO_2, CH_4, and N_2O. $TgCO_2$-eq/yr, teragrams (or 10^{12} grams) of carbon dioxide equivalent per year]

Ecoregion	Ecosystem	Area, in km²	CO_2, in $TgCO_2$-eq/yr			N_2O, in $TgCO_2$-eq/yr		
			Min	Max	Average	Min	Max	Average
Mixed Wood Shield	Forests	110,556	–45.47	–17.2	–35.6	0.5	0.5	0.5
	Grass/shrub	3,796	–1.5	–0.7	–1.1	0.3	0.3	0.3
	Agriculture	20,986	–1.5	1.5	0.0	1.5	1.6	1.5
	Wetlands	57,336	–19.4	–6.2	–16.5	2.9	2.9	2.9
	Other	22,926	–0.4	0.4	0.0	0.1	0.1	0.1
	Total	**215,599**	**–68.2**	**–23.1**	**–53.2**	**5.2**	**5.2**	**5.2**
Atlantic Highlands	Forests	154,954	–100.8	–56.1	–88.7	1.8	1.8	1.8
	Grass/shrub	306	–0.4	0.0	–0.4	0.0	0.0	0.0
	Agriculture	18,194	–0.4	1.8	0.7	1.2	1.2	1.2
	Wetlands	5,123	–2.6	–1.1	–2.2	0.3	0.3	0.3
	Other	8,973	–0.4	0.4	0.0	0.2	0.2	0.2
	Total	**187,550**	**–104.9**	**–55.0**	**–90.6**	**3.5**	**3.5**	**3.5**
Mixed Wood Plains	Forests	147,983	–82.9	–49.5	–76.6	1.5	1.5	1.5
	Grass/shrub	2,247	–0.7	–0.4	–0.4	0.0	0.0	0.0
	Agriculture	159,756	1.1	9.5	5.5	9.7	9.7	9.7
	Wetlands	24,231	–8.8	–5.5	–7.7	1.5	1.5	1.5
	Other	54,639	–4.8	0.4	–2.6	1.1	1.1	1.1
	Total	**388,858**	**–96.1**	**–45.5**	**–82.1**	**13.8**	**13.9**	**13.8**
Central USA Plains	Forests	23,787	–11.0	–7.7	–9.9	0.8	0.8	0.8
	Grass/shrub	1,175	0.0	0.4	0.0	0.0	0.0	0.0
	Agriculture	185,336	–10.3	–1.5	–5.9	26.4	27.2	26.7
	Wetlands	4,675	–1.8	–1.1	–1.5	0.3	0.3	0.3
	Other	24,055	–4.0	–0.7	–2.2	0.2	0.2	0.2
	Total	**239,027**	**–27.1**	**–10.6**	**–19.1**	**27.8**	**28.5**	**28.1**
Southeastern USA Plains	Forests	550,022	–519.6	–138.3	–342.5	59.9	60.7	60.3
	Grass/shrub	11,262	–3.7	0.4	–2.2	0.5	0.5	0.5
	Agriculture	306,678	–54.6	11.7	–17.2	20.7	21.4	20.9
	Wetlands	60,762	–64.2	–18.0	–46.2	3.5	3.5	3.5
	Other	65,622	–5.9	–0.4	–3.3	3.4	3.4	3.4
	Total	**994,346**	**–648.0**	**–144.5**	**–411.4**	**87.9**	**89.5**	**88.6**
Ozark, Ouachita-Appalachian Forests	Forests	372,212	–286.0	–114.0	–212.7	11.2	11.2	11.2
	Grass/shrub	3,903	–1.1	0.0	–0.7	0.2	0.2	0.2
	Agriculture	117,760	–19.1	3.3	–6.6	5.4	5.5	5.4
	Wetlands	2,592	–2.2	–0.4	–1.5	0.1	0.1	0.1
	Other	24,020	–1.8	0.0	–1.1	1.4	1.4	1.4
	Total	**520,486**	**–310.2**	**–111.5**	**–222.6**	**18.2**	**18.3**	**18.3**
Mississippi Alluvial and Southeast USA Coastal Plains	Forests	101,944	–98.3	–9.5	–63.8	0.5	0.5	0.5
	Grass/shrub	28,618	–5.5	0.0	–3.3	1.4	1.4	1.4
	Agriculture	143,291	–40.3	4.8	–18.3	8.7	9.8	9.2
	Wetlands	116,763	–81.8	–16.1	–55.7	6.0	6.0	6.0
	Other	116,144	–6.6	–1.8	–4.4	0.1	0.1	0.1
	Total	**506,760**	**–232.5**	**–22.7**	**–145.6**	**16.6**	**17.8**	**17.2**
Eastern United States	Forests	1,461,458	–1,144.1	–392.4	–829.8	76.0	76.8	76.4
	Grass/shrub	51,306	–12.8	–0.4	–8.1	2.4	2.5	2.4
	Agriculture	952,000	–125.0	31.2	–41.8	73.6	76.3	74.7
	Wetlands	271,482	–180.8	–48.4	–131.3	14.6	14.6	14.6
	Other	316,380	–23.8	–1.8	–13.6	6.5	6.5	6.5
	Total	**3,052,626**	**–1,487.0**	**–412.9**	**–1,024.6**	**173.1**	**176.6**	**174.7**

Table 7–6. Annual fluxes and total global warming potential from 2001 through 2005 in the Eastern United States.—Continued

[Data are by greenhouse-gas type for each ecosystem in each ecoregion. Estimates of methane (CH_4) and nitrous oxide (N_2O) were generated by the land GHG accounting tool. Carbon dioxide (CO_2) was calculated using net ecosystem carbon balance values from table 7–5. Global warming potential is the sum of CO_2, CH_4, and N_2O. $TgCO_2$-eq/yr, teragrams (or 10^{12} grams) of carbon dioxide equivalent per year]

Ecoregion	Ecosystem	Area, in km²	CH_4, in $TgCO_2$-eq/yr			GWP, in $TgCO_2$-eq/yr		
			Min	Max	Average	Min	Max	Average
Mixed Wood Shield	Forests	110,556	–1.7	–1.6	–1.6	–46.7	–18.4	–36.8
	Grass/shrub	3,796	0.0	0.0	0.0	–1.2	–0.5	–0.9
	Agriculture	20,986	0.0	0.0	0.0	0.0	3.0	1.5
	Wetlands	57,336	47.1	47.2	47.1	30.5	43.8	33.5
	Other	22,926	2.2	2.2	2.2	1.9	2.6	2.3
	Total	**215,599**	**47.5**	**47.6**	**47.6**	**–15.5**	**29.7**	**–0.4**
Atlantic Highlands	Forests	154,954	–3.1	–3.1	–3.1	–102.2	–57.4	–90.1
	Grass/shrub	306	0.0	0.0	0.0	–0.4	0.0	–0.4
	Agriculture	18,194	0.0	0.0	0.0	0.8	3.0	1.9
	Wetlands	5,123	3.6	3.6	3.6	1.3	2.8	1.7
	Other	8,973	0.6	0.6	0.6	0.4	1.1	0.8
	Total	**187,550**	**1.0**	**1.0**	**1.0**	**–100.4**	**–50.5**	**–86.0**
Mixed Wood Plains	Forests	147,983	–0.9	–0.9	–0.9	–82.3	–49.0	–76.1
	Grass/shrub	2,247	0.0	0.0	0.0	–0.7	–0.4	–0.4
	Agriculture	159,756	–0.3	–0.3	–0.3	10.5	19.0	14.9
	Wetlands	24,231	19.5	19.5	19.5	12.2	15.5	13.3
	Other	54,639	2.7	2.7	2.7	–1.0	4.2	1.2
	Total	**388,858**	**20.9**	**20.9**	**20.9**	**–61.4**	**–10.7**	**–47.4**
Central USA Plains	Forests	23,787	–0.5	–0.5	–0.5	–10.6	–7.3	–9.5
	Grass/shrub	1,175	0.0	0.0	0.0	0.0	0.4	0.0
	Agriculture	185,336	–0.1	–0.1	–0.1	16.1	25.6	20.8
	Wetlands	4,675	3.3	3.3	3.3	1.7	2.5	2.1
	Other	24,055	0.6	0.6	0.6	–3.2	0.1	–1.4
	Total	**239,027**	**3.3**	**3.3**	**3.3**	**4.0**	**21.2**	**12.3**
Southeastern USA Plains	Forests	550,022	–6.6	–6.5	–6.5	–466.3	–84.1	–288.7
	Grass/shrub	11,262	–0.1	–0.1	–0.1	–3.2	0.8	–1.7
	Agriculture	306,678	–0.1	0.1	0.0	–34.1	33.2	3.7
	Wetlands	60,762	43.4	43.9	43.7	–17.3	29.5	1.0
	Other	65,622	2.1	2.1	2.1	–0.4	5.1	2.2
	Total	**994,346**	**39.0**	**39.5**	**39.2**	**–521.1**	**–15.4**	**–283.6**
Ozark, Ouachita–Appalachian Forests	Forests	372,212	–9.9	–9.9	–9.9	–284.8	–112.8	–211.4
	Grass/shrub	3,903	0.0	0.0	0.0	–0.9	0.2	–0.6
	Agriculture	117,760	–0.1	0.3	0.1	–13.8	9.0	–1.1
	Wetlands	2,592	1.7	1.7	1.7	–0.4	1.5	0.4
	Other	24,020	0.9	0.9	0.9	0.4	2.2	1.1
	Total	**520,486**	**–7.4**	**–7.1**	**–7.3**	**–299.4**	**–100.2**	**–211.6**
Mississippi Alluvial and Southeast USA Coastal Plains	Forests	101,944	–0.7	–0.7	–0.7	–98.5	–9.8	–64.1
	Grass/shrub	28,618	–0.2	–0.2	–0.2	–4.3	1.2	–2.1
	Agriculture	143,291	12.5	14.6	13.3	–19.2	29.2	4.2
	Wetlands	116,763	67.3	67.5	67.4	–8.5	57.4	17.7
	Other	116,144	8.4	8.4	8.4	1.9	6.7	4.1
	Total	**506,760**	**87.3**	**89.7**	**88.2**	**–128.5**	**84.7**	**–40.2**
Eastern United States	Forests	1,461,458	–23.3	–23.2	–23.2	–1,091.4	–338.7	–776.6
	Grass/shrub	51,306	–0.3	–0.3	–0.3	–10.7	1.8	–5.9
	Agriculture	952,000	11.8	14.5	12.9	–39.6	121.9	45.9
	Wetlands	271,482	185.8	186.7	186.2	19.6	152.9	69.6
	Other	316,380	17.3	17.4	17.4	0.0	22.0	10.3
	Total	**3,052,626**	**191.7**	**195.0**	**193.0**	**–1,122.3**	**–41.3**	**–656.9**

The projected minimum, maximum, and average amounts of stored carbon from the 21 simulation model runs are listed in table 7–7 and are by carbon pool, ecosystem, and ecoregion in the Eastern United States for 2050. The overall carbon stored in all seven ecoregions was projected to be 37,083 TgC, averaged across all scenarios, GCMs, and models used. The variability ranged from 25,513 to 46,002 TgC across all 21 model simulations, which was considerably wider than the range of 25,069 to 28,497 TgC for the baseline period. Among the ecoregions, the Southeastern USA Plains ecoregion was projected to have the most carbon stored by 2050, accounting for about 31 percent of the total carbon stored in the Eastern United States in terms of the average estimates, followed by the Ozark, Ouachita-Appalachian Forests (18 percent of the total), Mississippi Alluvial and Southeast USA Coastal Plains (14 percent), Mixed Wood Plains (13 percent), Atlantic Highlands (10 percent), Mixed Wood Shield (9 percent), and Central USA Plains (5 percent) ecoregions. Among the different ecosystems, forests were projected to store the most carbon (69 percent) in terms of total amount in the Eastern United States, followed by wetlands (16 percent) and agricultural lands (13 percent). About 48 percent and 37 percent of the total carbon stock were projected to be allocated to the live biomass and SOC pools, respectively, and the remaining 15 percent was projected to be stored in dead biomass (such as forest litter and dead, woody debris). Compared with the baseline period, the projected allocation indicates that the carbon stock in the live biomass pools grew a little faster than the SOC pools.

The average carbon density of the Eastern United States was projected to be about 12.2 kgC/m^2. However, by ecosystems, the projected average future carbon densities varied substantially (fig. 7–8; table 7–7), as follows: wetlands (21.8 kgC/m^2), forests (18.7 kgC/m^2), grasslands/shrublands (5.7 kgC/m^2), agricultural lands (5.1 kgC/m^2), and other lands (1.2 kgC/m^2). Geographically, the projected average future carbon density in forests varied among the Atlantic Highlands (23.7 kgC/m^2), Mississippi Alluvial and Southeast USA Coastal Plains (22.5 kgC/m^2), Mixed Wood Plains (22.2 kgC/m^2), Central USA Plains (18.6 kgC/m^2), Ozark, Ouachita-Appalachian Forests (17.6 gC/m^2), Southeast USA Coastal Plains (16.9 kgC/m^2), and Mixed Wood Shield (16 kgC/m^2) ecoregions. For grasslands/shrublands, the highest carbon density was projected to be found in the Central USA Plains ecoregion (9.1 kgC/m^2) and the lowest carbon density was projected to be found in the Atlantic Highlands ecoregion (4.9 kgC/m^2).

7.4.4.1. Mixed Wood Shield

The total carbon stored in the Mixed Wood Shield was projected to range between 2,512 and 3,783 TgC in 2050 across 21 model simulations used in this assessment (table 7–7). Live biomass, soil organic carbon (SOC), and dead biomass were projected to store an average of 40 percent, 43.5 percent, and 16.5 percent, respectively, of the total carbon. Among the different ecosystems, forests were projected to store the most carbon (average of 50.7 percent of the total) followed by wetlands (44 percent) and agricultural lands (4.2 percent). The projected allocation of carbon varied substantially between the three carbon pools (live biomass, SOC, and dead biomass) across ecosystems. Live biomass was projected to account for 44.4 percent of the total carbon stored in forests, whereas SOC was projected to be the dominant storage pool for other lands (92.1 percent), agricultural lands (82.9 percent), and grassland/shrubland (78.9 percent) in 2050.

7.4.4.2. Atlantic Highlands

The estimated carbon stored in the Atlantic Highlands in 2050 was projected to range from 2,875 to 4,401 TgC across 21 model simulations used in this assessment (table 7–7). Live biomass and SOC were projected to contain 51.5 percent and 31.1 percent, respectively, of this total amount. This being a predominantly forested region, forests were projected to store the most carbon (93.2 percent of the projected total carbon), followed by wetlands (3.4 percent) and agricultural lands (2.8 percent). The live biomass carbon pool was projected to contain the most carbon in wetlands, accounting for 49 percent, whereas the SOC pool was projected to be the largest for agricultural lands, other lands ecosystems, and grasslands/shrublands, accounting for 85.1 percent, 80.9 percent, and 73.3 percent, respectively, in 2050.

7.4.4.3. Mixed Wood Plains

The estimated carbon stored in the Mixed Wood Plains ecoregion was projected to range from 3,401 to 5,426 TgC in 2050 across 21 model simulations used in this assessment (table 7–7). Live biomass and SOC were projected to contain 40.1 percent and 45 percent, respectively, of this total amount. Forests were projected to serve as the primary carbon storage pool (66.2 percent), followed by agricultural lands (21 percent) and wetlands (10.2 percent). The total percentage of carbon stored in grasslands/shrublands and other lands was projected to be less than 3 percent. Live biomass was projected to serve as the major carbon pool in forests (52.6 percent of the total forests), but for the other ecosystems, most carbon was projected to be stored in the SOC pool, ranging from 45 percent (for wetlands) to 90.7 percent (for other lands).

7.4.4.4. Central USA Plains

For the Central USA Plains ecoregion, the projected total carbon ranged from 1,464 to 2,055 TgC from the 21 model simulations used in this assessment (table 7–7). Unlike in the Mixed Wood Shield, Atlantic Highlands, and Mixed Wood Plains ecoregions, SOC was projected to be the primary carbon pool in the Central USA Plains ecoregion, by storing 69.9 percent of the total carbon, and live biomass was projected to store only 19.1 percent in this agricultural ecoregion. Croplands were projected to store the most carbon (67.4 percent of the total), followed by forests (22.8 percent) and other lands (5.3 percent).

Live biomass was projected to account for 56.3 percent of the total carbon stock in forests, and SOC was projected to be the primary pool in grasslands/shrublands (85.3 percent), agricultural lands (84.7 percent), and others lands (93.4 percent).

7.4.4.5. Southeastern USA Plains

For the Southeastern USA Plains ecoregion, the total carbon stored in 2050 was projected to range from 6,863 to 15,311 TgC by the 21 model simulations used in this assessment (table 7–7). Live biomass was projected to be the primary carbon pool (storing 53.5 percent of the total carbon) and SOC was projected to store 30.7 percent. The majority of the stored carbon was projected to be in forests (75.4 percent of the total), followed by wetlands (11.8 percent) and agricultural lands (11.1 percent). Live biomass was projected to be the primary carbon pools for forests and wetlands, accounting for 60.1 percent and 62.9 percent of their totals, whereas in other ecosystems, most carbon was projected to be stored in the SOC pool, ranging from 60.9 percent in grasslands/shrublands to 80.8 percent in other lands.

7.4.4.6. Ozark, Ouachita-Appalachian Forests

The estimated carbon stored in the Ozark, Ouachita-Appalachian Forests ecoregion was projected to range from 4,847 to 8,328 TgC in 2050 according to the 21 model simulations used in this assessment (table 7–7). Live biomass carbon was projected to be the primary carbon pool (accounting for 56.8 percent of the projected total amount of carbon), followed by SOC (27.6 percent). Forests were projected to serve as the primary carbon storage pool (91.2 percent), followed by agricultural lands (7.3 percent). The total percentage of carbon stored in grasslands/shrublands, wetlands, and other lands was projected to be less than 2 percent. Live biomass was projected to serve as the major carbon pool in forests (61.5 percent of the total carbon in forests) and wetlands (56.5 percent of the total carbon in wetlands), but for the other ecosystems, most carbon was projected to be stored in the SOC pool, ranging from 79 percent (for grasslands/shrublands) to 82.4 percent (for agricultural lands).

7.4.4.7. Mississippi Alluvial and Southeast USA Coastal Plains

The total carbon stored in the Mixed Wood Shield was projected to range between 3,549 and 6,698 TgC in 2050 according to the 21 model simulations used in this assessment (table 7–7). Live biomass, SOC, and dead biomass were projected to store an average of 44.4 percent, 43.6 percent, and 12 percent, respectively, of the total carbon. Among the different ecosystems, wetlands were projected to store the most carbon (average of 44.2 percent of the total), followed by forests (36.6 percent) and agricultural lands (14.2 percent). The carbon stored in grasslands/shrublands and other lands (combined) was projected to be the remaining 5 percent of the total carbon. The projected allocation of carbon varied substantially between the three pools (live biomass, SOC, and dead biomass) across ecosystems. Live biomass was projected to account for 60.2 percent of the total carbon stored in forests, whereas SOC was projected to be the dominant storage pool for other lands (87.9 percent), agricultural lands (82.1 percent), and grasslands/shrublands (68.5 percent) in 2050.

7.4.5. Projected Future Carbon Flux Estimates

The projected average annual NECB and the standard uncertainty between 2006 and 2050 are shown in figure 7–9. The average annual NECB and standard deviation were calculated from all 21 simulation model runs. The projected high carbon sequestration rates (fig. 7–9, negative NECB, shown by green hues on the map) were strongly associated with the presence of forest ecosystems; the simulated disturbances, such as clearcutting, were projected to be responsible for a large number of carbon-release hot spots (fig. 7–9, positive NECB, indicated by red hues on the map). Carbon sequestration was also projected to occur in the agricultural lands. The standard deviation map, as shown in figure 7–9, was spatially similar to the pattern of the average annual NECB, suggesting the spread of NECB estimates was projected to be generally greater in areas experiencing large changes in carbon storage.

The projected minimum, maximum, and average of average annual net carbon fluxes—from the 21 simulations and averaged annually between 2006 and 2050—are listed in table 7–8 by carbon pool, ecosystem, and ecoregion in the Eastern United States. The annual NECB estimates were projected to vary between −403.7 and 1.4 TgC/yr across 21 simulations in the Eastern United States with an average value of −224.9 TgC/yr.

As shown in table 7–8, the average annual NECB in the ecoregions of the Eastern United States was projected to be highly variable, although all ecoregions within the Eastern United States were projected to be carbon sinks on average. Among the seven ecoregions, the Southeast USA Coastal Plains ecoregion was projected to be the greatest carbon sink with an average of −79.4 TgC/yr, followed by the Ozark, Ouachita-Appalachian Forests (−44.2 TgC/yr), Mississippi Alluvial and Southeast USA Coastal Plains (−32.2 TgC/yr), Atlantic Highlands (−23.5 TgC/yr), Mixed Wood Plains (−23.4 TgC/yr), Mixed Wood Shield (−16.3 TgC/yr), and Central USA Plains (−5.8 TgC/yr) ecoregions. Among all ecosystems, forests were projected to remain strong terrestrial carbon sinks, accounting for approximately 70 percent of the projected total average NECB. The other ecosystems were also projected to have the potential to sequester carbon, but the interannual variability was high. Wetlands were projected to have the highest average annual NECB per unit of area (−150.5 $gC/m^2/yr$), compared with forests (−115.6 $gC/m^2/yr$),

Table 7–7. Projections of carbon stored in the Eastern United States in 2050.

[Results are based on 21 simulation model runs and are listed by ecosystem and ecoregion. Only soil organic carbon (SOC) in the top 20 centimeters of the soil layer was calculated. Data may not add to totals shown due to independent rounding. km^2, square kilometers; max, maximum; min, minimum; TgC, teragrams (or 10^{12} grams) of carbon]

Ecoregion	Ecosystem	Area, in km^2	Biomass, in TgC			SOC, in TgC		
			Min	Max	Average	Min	Max	Average
Mixed Wood Shield	Forests	105,593	421.4	988.9	750.3	498.5	670.0	594.4
	Grass/shrub	3,822	1.4	4.5	2.5	18.0	23.5	22.0
	Agriculture	23,888	0.1	9.3	4.1	78.5	148.9	115.5
	Wetlands	58,742	334.4	682.6	577.4	656.9	739.1	707.7
	Other	23,554	0.0	0.3	0.1	2.4	30.5	8.2
	Total	**215,599**	**757.3**	**1,685.6**	**1,334.5**	**1,254.4**	**1,612.0**	**1,447.7**
Atlantic Highlands	Forests	151,901	1,352.3	2,252.9	1,923.1	802.9	1,264.0	1,041.2
	Grass/shrub	304	0.0	1.0	0.3	1.0	1.7	1.1
	Agriculture	19,145	0.1	7.1	2.7	54.9	145.3	92.7
	Wetlands	5,124	42.2	75.1	64.8	43.0	55.8	49.0
	Other	11,076	0.0	3.1	0.8	5.8	44.0	16.5
	Total	**187,550**	**1,394.6**	**2,339.2**	**1,991.7**	**907.6**	**1,510.8**	**1,200.5**
Mixed Wood Plains	Forests	137,258	1,037.1	1,958.0	1,602.1	723.3	1,125.4	927.9
	Grass/shrub	2,049	0.5	2.4	1.2	10.2	12.8	11.9
	Agriculture	160,383	0.2	74.6	40.0	651.3	1,016.3	826.7
	Wetlands	23,494	136.3	232.1	201.0	185.5	230.8	209.2
	Other	65,674	0.0	8.7	3.4	45.8	230.8	96.4
	Total	**388,857**	**1,174.1**	**2,275.8**	**1,847.7**	**1,616.1**	**2,616.0**	**2,072.1**
Central USA Plains	Forests	21,621	195.9	253.2	225.7	83.0	143.0	112.6
	Grass/shrub	827	0.0	0.8	0.4	4.2	7.8	6.4
	Agriculture	177,774	0.1	125.3	62.7	864.6	1,155.1	1,004.3
	Wetlands	4,658	32.4	53.8	43.9	34.2	41.4	38.2
	Other	34,147	0.0	11.1	3.5	27.4	156.6	68.1
	Total	**239,027**	**228.4**	**444.2**	**336.2**	**1,013.3**	**1,504.1**	**1,229.7**
Southeastern USA Plains	Forests	507,236	3,369.8	6,851.9	5,149.8	981.5	2,786.5	2,019.2
	Grass/shrub	10,377	12.0	20.7	16.3	20.0	47.3	38.0
	Agriculture	313,514	1.4	123.6	60.8	616.1	1,504.3	1,001.4
	Wetlands	63,410	551.8	955.7	846.3	219.1	405.7	335.9
	Other	99,809	0.0	22.9	9.1	69.4	189.6	100.3
	Total	**994,346**	**3,934.9**	**7,974.8**	**6,082.3**	**1,906.1**	**4,933.4**	**3,494.9**
Ozark, Ouachita-Appalachian Forests	Forests	352,049	2,939.7	4,689.9	3,803.0	777.6	1,595.7	1,402.1
	Grass/shrub	3,804	1.2	4.1	2.2	9.4	17.8	15.0
	Agriculture	130,834	0.5	37.5	18.5	254.8	605.6	410.1
	Wetlands	2,671	17.1	26.7	24.0	7.6	14.8	12.9
	Other	31,128	0.0	5.8	2.2	17.0	64.2	31.7
	Total	**520,486**	**2,958.4**	**4,763.9**	**3,850.0**	**1,066.4**	**2,298.1**	**1,871.9**
Mississippi Alluvial and Southeast USA Coastal Plains	Forests	87,495	581.6	1,463.9	1,183.3	359.3	612.2	495.8
	Grass/shrub	26,811	21.6	34.6	28.1	77.7	107.3	96.0
	Agriculture	139,412	0.3	45.6	22.8	453.1	846.7	623.9
	Wetlands	113,617	643.9	1,353.4	1,146.5	948.7	1,094.1	1,012.9
	Other	139,424	0.0	17.9	6.7	48.6	311.0	114.4
	Total	**506,758**	**1,247.4**	**2,915.5**	**2,387.4**	**1,887.5**	**2,971.4**	**2,343.1**
Eastern United States	Forests	1,363,153	9,897.8	18,458.6	14,637.3	4,226.2	8,196.8	6,593.2
	Grass/shrub	47,992	36.7	68.0	51.0	140.5	218.2	190.5
	Agriculture	964,948	2.6	423.0	211.6	2,973.3	5,422.4	4,074.6
	Wetlands	271,717	1,758.1	3,379.4	2,904.0	2,094.9	2,581.8	2,365.9
	Other	404,813	0.0	69.8	26.0	216.4	1,026.6	435.6
	Total	**3,052,623**	**11,695.2**	**22,399.0**	**17,829.8**	**9,651.3**	**17,445.7**	**13,659.8**

Table 7–7. Projections of carbon stored in the Eastern United States in 2050.—Continued

[Results are based on 21 simulation model runs and are listed by ecosystem and ecoregion. Only soil organic carbon (SOC) in the top 20 centimeters of the soil layer was calculated. Data may not add to totals shown due to independent rounding. km², square kilometers; max, maximum; min, minimum; TgC, teragrams (or 10^{12} grams) of carbon]

Ecoregion	Ecosystem	Area, in km²	Others, in TgC			Total, in TgC		
			Min	Max	Average	Min	Max	Average
Mixed Wood Shield	Forests	105,593	254.1	390.5	345.8	1,174.1	1,929.0	1,690.5
	Grass/shrub	3,822	0.0	5.1	3.4	22.5	30.4	27.9
	Agriculture	23,888	0.0	37.0	19.8	93.3	184.6	139.4
	Wetlands	58,742	154.5	197.9	179.5	1,218.7	1,608.3	1,464.7
	Other	23,554	0.0	1.5	0.6	3.1	30.5	8.9
	Total	**215,599**	**408.6**	**631.9**	**549.2**	**2,511.8**	**3,782.9**	**3,331.4**
Atlantic Highlands	Forests	151,901	543.4	690.1	638.9	2,699.8	4,023.7	3,603.2
	Grass/shrub	304	0.0	0.2	0.1	1.1	2.7	1.5
	Agriculture	19,145	0.0	36.7	13.6	61.9	182.5	108.9
	Wetlands	5,124	16.9	21.0	18.3	103.7	148.1	132.1
	Other	11,076	0.0	9.2	3.1	8.3	44.0	20.4
	Total	**187,550**	**560.4**	**757.2**	**674.0**	**2,874.8**	**4,401.0**	**3,866.1**
Mixed Wood Plains	Forests	137,258	410.2	588.1	515.3	2,170.7	3,469.8	3,045.3
	Grass/shrub	2,049	0.0	2.6	1.7	12.5	16.9	14.8
	Agriculture	160,383	0.0	176.9	100.5	778.3	1,192.5	967.2
	Wetlands	23,494	48.9	70.5	59.7	386.3	516.4	469.8
	Other	65,674	0.0	14.9	6.5	53.3	230.8	106.3
	Total	**388,857**	**459.1**	**853.0**	**683.6**	**3,401.0**	**5,426.4**	**4,603.4**
Central USA Plains	Forests	21,621	53.5	74.3	62.8	332.6	460.3	401.0
	Grass/shrub	827	0.0	1.1	0.6	4.8	9.6	7.5
	Agriculture	177,774	0.0	168.9	119.1	1,019.0	1,324.2	1,186.2
	Wetlands	4,658	9.4	12.9	10.9	79.5	104.0	92.9
	Other	34,147	0.0	3.0	1.2	28.0	156.6	72.9
	Total	**239,027**	**62.8**	**260.2**	**194.6**	**1,463.9**	**2,054.7**	**1,760.5**
Southeastern USA Plains	Forests	507,236	811.0	1,976.3	1,407.2	5,162.3	11,613.9	8,576.2
	Grass/shrub	10,377	0.0	15.3	8.1	32.0	78.6	62.4
	Agriculture	313,514	0.0	410.7	199.6	697.0	1,919.5	1,261.8
	Wetlands	63,410	115.3	211.7	162.3	886.2	1,510.0	1,344.6
	Other	99,809	0.0	30.7	14.8	85.5	189.6	124.2
	Total	**994,346**	**926.4**	**2,644.7**	**1,791.9**	**6,863.1**	**15,311.4**	**11,369.1**
Ozark, Ouachita-Appalachian Forests	Forests	352,049	753.8	1,222.3	975.9	4,471.0	7,450.3	6,181.1
	Grass/shrub	3,804	0.0	2.8	1.7	13.5	22.9	19.0
	Agriculture	130,834	0.0	134.9	69.3	312.1	742.2	497.9
	Wetlands	2,671	4.3	7.4	5.6	29.0	48.6	42.5
	Other	31,128	0.0	10.3	4.7	21.8	64.2	38.6
	Total	**520,486**	**758.0**	**1,377.8**	**1,057.2**	**4,847.3**	**8,328.1**	**6,779.1**
Mississippi Alluvial and Southeast USA Coastal Plains	Forests	87,495	156.7	396.2	288	1,097.6	2,472.3	1,967.1
	Grass/shrub	26,811	0	28.8	16.1	108.1	169.7	140.2
	Agriculture	139,412	0	231.4	113.4	487.9	1,079.6	760.1
	Wetlands	113,617	137.3	291.8	216.6	1,799.1	2,665.1	2,376.0
	Other	139,424	0	20.7	9	56.9	311	130.2
	Total	**506,758**	**294**	**968.9**	**643.1**	**3,549.6**	**6,697.7**	**5,373.6**
Eastern United States	Forests	1,363,153	2,982.6	5,337.8	4,233.9	17,108.1	31,419.3	25,464.3
	Grass/shrub	47,992	0	55.9	31.7	194.6	330.8	273.3
	Agriculture	964,948	0	1,196.40	635.2	3,449.5	6,625.0	4,921.4
	Wetlands	271,717	486.5	813.3	652.8	4,502.4	6,600.5	5,922.7
	Other	404,813	0	90.3	39.9	256.9	1,026.6	501.5
	Total	**3,052,623**	**3,469.2**	**7,493.7**	**5,593.5**	**25,511.6**	**46,002.2**	**37,083.2**

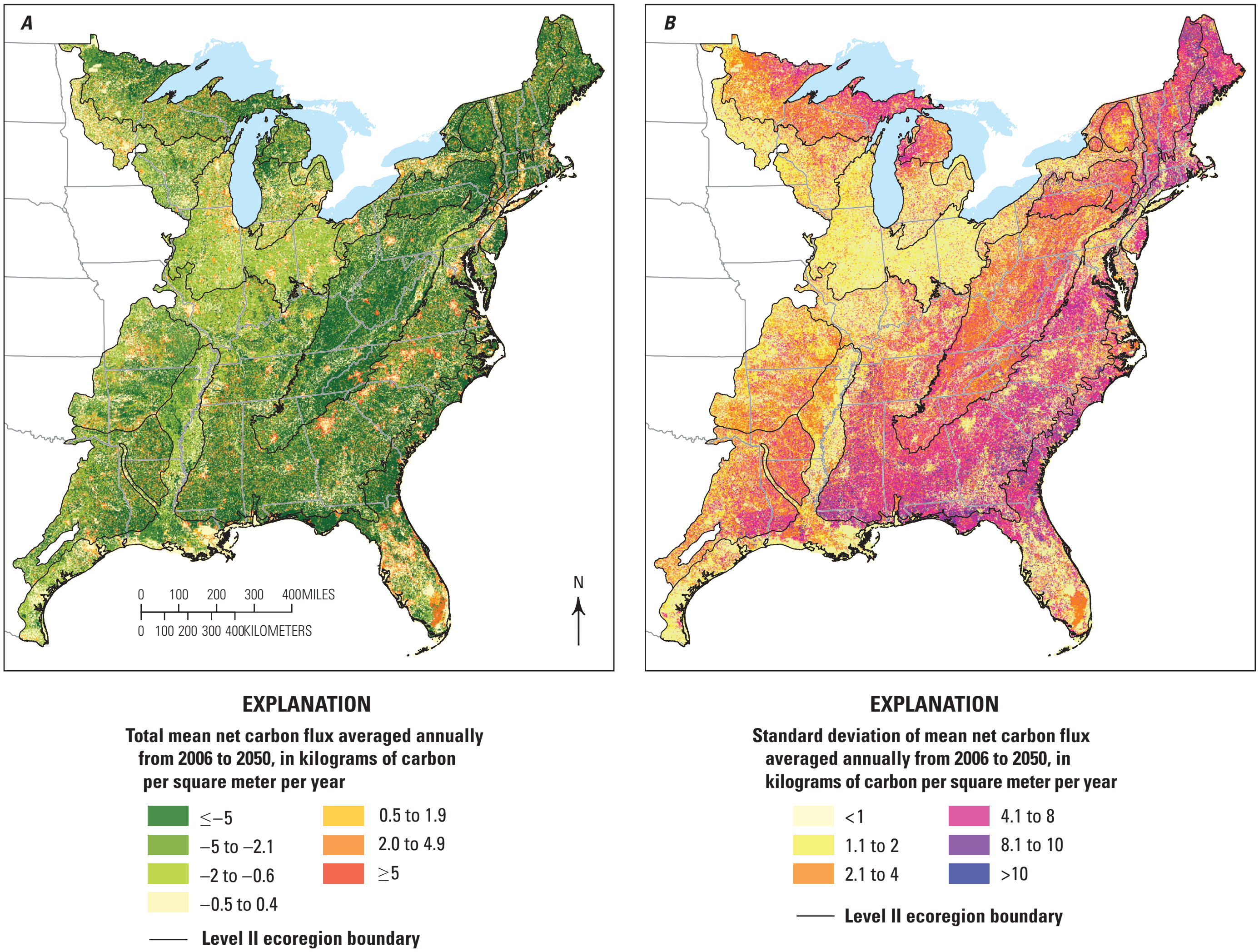


Figure 7–9. Maps showing the projected *A*, average annual and *B*, standard deviation of net ecosystem carbon balance (NECB) in the Eastern United States, averaged annually from 2006 to 2050. Projected average annual NECB was derived from 21 simulation model runs using biogeochemical models Land GHG Accounting Tool, Century, and Erosion Deposition Carbon Model, Intergovernmental Panel on Climate Change Special Report on Emissions Scenarios (Nakićenović and others, 2000) scenarios A1B, A2, and B1, and general circulation models Third Generation Coupled Global Climate Model of the Canadian Centre for Climate Modelling and Analysis, Australia's Commonwealth Scientific and Industrial Research Organisation Mark 3.0, and Model for Interdisciplinary Research on Climate 3.2, medium resolution. Negative average annual NECB values indicate projected carbon sinks or carbon gains by terrestrial ecosystems, and positive values denote projected carbon losses. Level II ecoregions are shown in figure 1–1.

agricultural lands (−22 $gC/m^2/yr$), grasslands/shrublands (−16.7 $gC/m^2/yr$), and other lands (−11.1 $gC/m^2/yr$). On average, about 64.3 percent of the total carbon was projected to accumulate in live biomass, 20.3 percent in soil organic carbon, and about 15.4 percent in dead biomass (forest litter and dead, woody debris). Forests were projected to be the primary carbon sink with −157.6 TgC/yr in the Eastern United States in the future.

7.4.5.1. Mixed Wood Shield

In the Mixed Wood Shield ecoregion, the projected mean annual net ecosystem carbon balance (NECB) values between 2006 and 2050 of the 21 model simulations used in this assessment ranged from −26 to 0.6 TgC/yr , depending on land-use and land-cover scenario, climate-change projection, and biogeochemical model (table 7–8). On average, this ecoregion can be a carbon sink with the sequestration rate of −16.3 TgC/yr. Among the different ecosystems, wetlands were projected to gain −8.1 TgC/yr (49.7 percent of the total) averaged across all model runs, followed by forests with an average of −7.3 TgC/yr (44.8 percent of the total), agricultural lands with an average of −0.8 TgC/yr (4.9 percent of the total), and the sum of the rest of the ecosystems averaging −0.2 TgC/yr (less than 1 percent of the total).

7.4.5.2. Atlantic Highlands

The projected mean annual NECB values in the Atlantic Highlands ecoregion between 2006 and 2050 ranged from −34.8 to −1.8 TgC/yr across 21 model simulations used in this assessment (table 7–8) with an average of −23.5 TgC/yr. The projected mean annual NECB for forests in this ecoregion was –22.1 TgC/yr (or 94 percent of the total) across all model runs, followed by wetlands (3.8 percent of the total) and agricultural lands (1.3 percent of the total).

7.4.5.3. Mixed Wood Plains

The projected mean annual NECB values in the Mixed Wood Plains between 2006 and 2050 ranged from −41.7 to 2.5 TgC/yr across all 21 model simulations used in this assessment (table 7–8). The projected mean annual NECB for forests (–18 TgC/yr) in this ecoregion accounted for 76.9 percent of the total, followed by wetlands (12 percent of the total) and agricultural lands (8.1 percent of the total).

7.4.5.4. Central USA Plains

The projected means of annual NECB in the Central USA Plains ecoregion between 2006 and 2050 ranged from −11.7 to 0.6 TgC/yr (table 7–8) across all 21 model simulations used in this assessment. Generally, this ecoregion was projected to be a carbon sink, with a mean carbon sequestration rate of −5.8 TgC/yr. The dominant ecosystem in the ecoregion, agricultural lands, was projected to contribute about 50 percent of the total carbon sequestration, followed by forests (31 percent of the total), other lands (10.4 percent), and wetlands (8.6 percent).

7.4.5.5. Southeastern USA Plains

The projected means of annual NECB in the Southeastern USA Plains ecoregion between 2006 and 2050 ranged from −157.3 to 5 TgC/yr according to 21 model simulations used in this assessment. The projected average NECB of −79.4 TgC/yr makes this ecoregion the greatest carbon sink in the Eastern United States. Among different ecosystems, forests were projected to accumulate the most carbon (70.7 percent of the total), followed by wetlands (17.1 percent), agricultural lands (10.2 percent), and grasslands/shrublands (0.4 percent). The total carbon sequestration the rest ecosystems contributed about 2 percent.

7.4.5.6. Ozark, Ouachita-Appalachian Forests

In the Ozark, Ouachita-Appalachian Forests ecoregion, the projected means of annual NECB between 2006 and 2050 as simulated by the 21 model runs used in this assessment ranged from −76.9 to −5.7 TgC/yr (table 7–8) with an average estimate of −44.2 TgC/yr, which makes this ecoregion the second largest carbon sink in the Eastern United States. Among the different ecosystems, forests were projected to gain −40 TgC/yr, which contributed 90.1 percent of the total carbon sequestration, and agricultural lands, which accounted for about 7.5 percent.

7.4.5.7. Mississippi Alluvial and Southeast USA Coastal Plains

In the Mississippi Alluvial and Southeast USA Coastal Plains ecoregion, the projected meansof annual NECB between 2006 and 2050 representing the 21 model simulations used in this assessment ranged from −55.3 to 0.2 TgC/yr. Of this total, wetlands were projected to accumulate the most carbon (45.3 percent of the total), followed by forests (37.9 percent) and agricultural lands (12.1 percent). Grasslands/shrublands and other lands were projected to account for about 4.7 percent of the total mean annual NECB in this ecoregion.

7.4.6. Projected GHG Fluxes

The projected minimum, maximum, and average of annual GHG fluxes from 2006 to 2050 are listed by ecoregion and ecosystem in table 7–9. Temporal trends of the projected future fluxes of the three GHG between 2000 and 2050 are shown in figure 7–10. The projected future GHG fluxes for CO_2, N_2O, and CH_4 averaged –824.6 $TgCO_2$-eq/yr, 174.7 $TgCO_2$-eq/yr, and 198.71 $TgCO_2$-eq/yr, respectively. The overall GWP from 2006 through 2050 averaged −451.2 $TgCO_2$-eq/yr.

7.5. Discussion

7.5.1. Effects of Uncertainty of Models, LULC Scenarios, and GCMs on Carbon Sequestration Estimates

Table 7–10 lists the projected estimates of average carbon stocks in 2050, average annual NECB from 2006 to 2050, and corresponding relative variability (variability index, as described in the Definitions of Carbon Stocks and Fluxes and Uncertainty section) by model, LULC scenario, and GCM. The variability index of the carbon stocks and NECB estimated by the three models indicates the uncertainty introduced by these models. Among the three biogeochemical models for the Eastern United States, the Century model and the LGAT gave a highest and lowest projected estimates, respectively, whereas the projection by the EDCM model fell generally in the middle although a lot closer to that of the Century model. For simulating carbon stock, the models performed differently across ecoregions with the smallest discrepancy found in the Central USA Plains ecoregion (15.1 percent variability across three models), and the highest, in the Southeastern USA Plains ecoregion (49.1 percent). For

Table 7–8. Projected net ecosystem carbon balance values simulated in 21 model runs and averaged between 2006 and 2050 in the Eastern United States.

[Negative net ecosystem carbon balance (NECB) values indicate carbon uptake or sequestration by ecosystems. Only soil organic carbon (SOC) in the top 20 cm of the soil layer was calculated. Data may not add to totals shown due to independent rounding. km², square kilometers; max, maximum; min, minimum; TgC, teragrams (or 10^{12} grams) of carbon]

Ecoregion	Ecosystem	Area, in km²	Biomass, in TgC/yr			SOC, in TgC/yr		
			Min	Max	Average	Min	Max	Average
Mixed Wood Shield	Forests	105,593	–10.1	1.9	–4.9	–1.5	0.8	–0.7
	Grass/shrub	3,822	0.0	0.0	0.0	–0.1	0.0	–0.1
	Agriculture	23,888	–0.1	0.0	0.0	–1.2	0.2	–0.5
	Wetlands	58,742	–8.4	–2.1	–6.6	–0.4	0.5	–0.1
	Other	23,554	0.0	0.0	0.0	–0.1	0.0	0.0
	Total	**215,599**	**–18.6**	**–0.1**	**–11.5**	**–3.3**	**1.6**	**–1.3**
Atlantic Highlands	Forests	151,901	–23.3	–2.6	–15.2	–6.1	0.7	–3.0
	Grass/shrub	304	0.0	0.0	0.0	0.0	0.0	0.0
	Agriculture	19,145	–0.1	0.0	0.0	–1.2	0.6	–0.1
	Wetlands	5,124	–0.9	–0.3	–0.7	–0.2	0.0	–0.1
	Other	11,076	–0.1	0.0	0.0	–0.4	0.1	–0.1
	Total	**187,550**	**–24.3**	**–2.8**	**–15.9**	**–7.9**	**1.5**	**–3.3**
Mixed Wood Plains	Forests	137,258	–22.2	–1.4	–13.9	–4.0	2.4	–1.1
	Grass/shrub	2,049	0.0	0.0	0.0	0.0	0.0	0.0
	Agriculture	160,383	–0.3	0.0	–0.1	–4.6	2.5	–0.7
	Wetlands	23,494	–2.7	–0.8	–2.2	–0.6	0.2	–0.2
	Other	65,674	–0.1	0.0	–0.1	–1.5	0.1	–0.6
	Total	**388,857**	**–25.3**	**–2.2**	**–16.2**	**–10.8**	**5.3**	**–2.7**
Central USA Plains	Forests	21,621	–2.2	–0.6	–1.5	–0.6	0.3	–0.1
	Grass/shrub	827	0.0	0.0	0.0	0.0	0.0	0.0
	Agriculture	177,774	–0.4	0.1	0.0	–4.7	1.3	–1.9
	Wetlands	4,658	–0.6	–0.2	–0.5	–0.1	0.0	0.0
	Other	34,147	–0.2	0.0	–0.1	–1.6	0.2	–0.5
	Total	**239,027**	**–3.4**	**–0.6**	**–2.0**	**–7.1**	**1.8**	**–2.5**
Southeastern USA Plains	Forests	507,236	–73.0	3.0	–36.6	–27.7	3.6	–12.0
	Grass/shrub	10,377	–0.2	0.1	–0.1	–0.4	0.1	–0.2
	Agriculture	313,514	–0.9	0.0	–0.3	–15.2	2.4	–5.7
	Wetlands	63,410	–11.9	–4.2	–10.1	–3.3	–0.1	–2.1
	Other	99,809	–0.4	0.0	–0.2	–1.9	–0.2	–1.0
	Total	**994,346**	**–86.4**	**–1.1**	**–47.3**	**–48.5**	**5.7**	**–21.0**
Ozark, Ouachita-Appalachian Forests	Forests	352,049	–47.2	–6.5	–27.4	–11.7	1.6	–7.4
	Grass/shrub	3,804	0.0	0.0	0.0	–0.1	0.0	–0.1
	Agriculture	130,834	–0.3	0.0	–0.1	–6.0	0.4	–2.4
	Wetlands	2,671	–0.3	–0.1	–0.3	–0.1	0.0	–0.1
	Other	31,128	–0.1	0.0	0.0	–0.6	0.1	–0.3
	Total	**520,486**	**–48.0**	**–6.6**	**–27.9**	**–18.6**	**2.1**	**–10.2**
Mississippi Alluvial and Southeast USA Coastal Plains	Forests	87,495	–15.8	0.6	–10.5	–3.0	1.9	–0.4
	Grass/shrub	26,811	–0.2	0.1	–0.1	–0.4	0.2	–0.2
	Agriculture	139,412	–0.2	0.0	–0.1	–7.2	1.2	–2.9
	Wetlands	113,617	–16.4	–3.9	–12.9	–2.1	1.2	–0.1
	Other	139,424	–0.4	0.0	–0.1	–2.4	–0.1	–1.0
	Total	**506,758**	**–33.1**	**–3.3**	**–23.7**	**–15.1**	**4.4**	**–4.5**
Eastern United States	Forests	1,363,153	–193.8	–5.7	–110.0	–54.7	11.3	–24.8
	Grass/shrub	47,992	–0.5	0.2	–0.1	–1.0	0.3	–0.6
	Agriculture	964,948	–2.2	0.2	–0.6	–40.2	8.5	–14.1
	Wetlands	271,717	–41.2	–11.6	–33.2	–6.8	1.9	–2.6
	Other	404,813	–1.3	0.0	–0.5	–8.6	0.2	–3.5
	Total	**3,052,623**	**–239.0**	**–16.8**	**–144.5**	**–111.3**	**22.3**	**–45.6**

Table 7–8. Projected net ecosystem carbon balance values simulated in 21 model runs and averaged between 2006 and 2050 in the Eastern United States.—Continued

[Negative net ecosystem carbon balance (NECB) values indicate carbon uptake or sequestration by ecosystems. Only soil organic carbon (SOC) in the top 20 cm of the soil layer was calculated. Data may not add to totals shown due to independent rounding. km², square kilometers; max, maximum; min, minimum; TgC, teragrams (or 10^{12} grams) of carbon]

Ecoregion	Ecosystem	Area, in km²	Others, in TgC/yr			Total, in TgC/yr		
			Min	Max	Average	Min	Max	Average
Mixed Wood Shield	Forests	105,593	–3.5	0.9	–1.8	–14.0	3.7	–7.3
	Grass/shrub	3,822	0.0	0.0	0.0	–0.1	0.0	–0.1
	Agriculture	23,888	–0.6	0.0	–0.3	–1.7	0.1	–0.8
	Wetlands	58,742	–2.0	–0.8	–1.4	–10.1	–3.2	–8.1
	Other	23,554	0.0	0.0	0.0	–0.1	0.0	–0.1
	Total	**215,599**	**–6.1**	**0.1**	**–3.5**	**–26.0**	**0.6**	**–16.3**
Atlantic Highlands	Forests	151,901	–6.4	–0.3	–3.9	–31.2	–2.2	–22.1
	Grass/shrub	304	0.0	0.0	0.0	0.0	0.0	0.0
	Agriculture	19,145	–0.6	0.0	–0.2	–1.8	0.6	–0.3
	Wetlands	5,124	–0.2	–0.1	–0.1	–1.1	–0.3	–0.9
	Other	11,076	–0.2	0.0	–0.1	–0.6	0.0	–0.2
	Total	**187,550**	**–7.4**	**–0.3**	**–4.2**	**–34.8**	**–1.8**	**–23.5**
Mixed Wood Plains	Forests	137,258	–5.3	0.1	–3.0	–29.7	1.1	–18.0
	Grass/shrub	2,049	0.0	0.0	0.0	–0.1	0.0	0.0
	Agriculture	160,383	–2.3	0.0	–1.1	–6.9	2.1	–1.9
	Wetlands	23,494	–0.7	–0.2	–0.4	–3.6	–0.8	–2.8
	Other	65,674	–0.2	0.0	–0.1	–1.5	0.0	–0.7
	Total	**388,857**	**–8.6**	**–0.1**	**–4.6**	**–41.7**	**2.5**	**–23.4**
Central USA Plains	Forests	21,621	–0.5	–0.1	–0.2	–3.0	–0.3	–1.8
	Grass/shrub	827	0.0	0.0	0.0	0.0	0.1	0.0
	Agriculture	177,774	–1.6	0.0	–1.0	–6.3	0.9	–2.9
	Wetlands	4,658	–0.1	0.0	–0.1	–0.7	–0.2	–0.5
	Other	34,147	0.0	0.0	0.0	–1.6	0.1	–0.6
	Total	**239,027**	**–2.2**	**–0.1**	**–1.3**	**–11.7**	**0.6**	**–5.8**
Southeastern USA Plains	Forests	507,236	–16.6	1.5	–7.4	–117.2	8.1	–56.1
	Grass/shrub	10,377	–0.1	0.0	0.0	–0.7	0.1	–0.3
	Agriculture	313,514	–5.3	0.0	–2.2	–20.6	2.4	–8.1
	Wetlands	63,410	–1.9	–0.8	–1.4	–16.8	–5.1	–13.6
	Other	99,809	–0.4	0.0	–0.1	–2.0	–0.5	–1.3
	Total	**994,346**	**–24.3**	**0.8**	**–11.2**	**–157.3**	**5.0**	**–79.4**
Ozark, Ouachita–Appalachian Forests	Forests	352,049	–10.1	–0.7	–5.1	–67.7	–5.7	–40.0
	Grass/shrub	3,804	0.0	0.0	0.0	–0.1	0.0	–0.1
	Agriculture	130,834	–1.8	0.0	–0.9	–7.8	0.0	–3.3
	Wetlands	2,671	–0.1	0.0	0.0	–0.5	–0.1	–0.4
	Other	31,128	–0.1	0.0	–0.1	–0.7	0.0	–0.4
	Total	**520,486**	**–12.1**	**–0.7**	**–6.1**	**–76.9**	**–5.7**	**–44.2**
Mississippi Alluvial and Southeast USA Coastal Plains	Forests	87,495	–2.8	0.4	–1.3	–21.7	2.8	–12.2
	Grass/shrub	26,811	–0.1	0.0	0.0	–0.6	0.2	–0.3
	Agriculture	139,412	–2.5	0.0	–1.0	–9.8	1.1	–3.9
	Wetlands	113,617	–2.5	–0.7	–1.6	–20.9	–3.7	–14.6
	Other	139,424	–0.4	0.0	–0.1	–2.4	–0.2	–1.2
	Total	**506,758**	**–8.3**	**–0.3**	**–4.0**	**–55.3**	**0.2**	**–32.2**
Eastern United States	Forests	1,363,153	–45.2	1.9	–22.8	–284.5	7.5	–157.6
	Grass/shrub	47,992	–0.2	0.1	–0.1	–1.6	0.5	–0.8
	Agriculture	964,948	–14.6	0.0	–6.5	–54.9	7.4	–21.2
	Wetlands	271,717	–7.5	–2.6	–5.1	–53.7	–13.4	–40.9
	Other	404,813	–1.4	0.0	–0.5	–9.0	–0.5	–4.5
	Total	**3,052,623**	**–68.9**	**–0.7**	**–34.9**	**–403.7**	**1.4**	**–224.9**

Table 7–9. Projected average annual nutrient fluxes and total global warming potential (GWP), averaged from 2006 to 2050, in the Eastern United States.

[Nutrient fluxes are for carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). Projected fluxes of methane and nitrous oxide were estimated by the land GHG accounting tool (LGAT), and projected flux of carbon dioxide was calculated using net ecosystem carbon balance (NECB) values from table 7–8. $TgCO_2$-eq, teragrams (or 10^{12} grams) of carbon dioxide equivalent per year]

Ecoregion	Ecosystem	Area, in km²	CO_2, in $TgCO_2$-eq/yr			N_2O, in $TgCO_2$-eq/yr		
			Min	Max	Average	Min	Max	Average
Mixed Wood Shield	Forests	105,593	–51.3	13.6	–26.8	0.4	0.5	0.4
	Grass/shrub	3,822	–0.4	0.0	–0.4	0.3	0.3	0.3
	Agriculture	23,888	–6.2	0.4	–2.9	1.5	1.9	1.6
	Wetlands	58,742	–37.0	–11.7	–29.7	2.9	3.0	2.9
	Other	23,554	–0.4	0.0	–0.4	0.1	0.1	0.1
	Total	**215,599**	**–95.3**	**2.2**	**–59.8**	**5.2**	**5.6**	**5.4**
Atlantic Highlands	Forests	151,901	–114.4	–8.1	–81.0	1.6	1.8	1.7
	Grass/shrub	304	0.0	0.0	0.0	0.0	0.0	0.0
	Agriculture	19,145	–6.6	2.2	–1.1	1.0	1.6	1.3
	Wetlands	5,124	–4.0	–1.1	–3.3	0.3	0.3	0.3
	Other	11,076	–2.2	0.0	–0.7	0.2	0.2	0.2
	Total	**187,550**	**–127.6**	**–6.6**	**–86.2**	**3.3**	**3.8**	**3.5**
Mixed Wood Plains	Forests	137,258	–108.9	4.0	–66.0	1.2	1.5	1.4
	Grass/shrub	2,049	–0.4	0.0	0.0	0.0	0.0	0.0
	Agriculture	160,383	–25.3	7.7	–7.0	9.4	10.7	9.9
	Wetlands	23,494	–13.2	–2.9	–10.3	1.4	1.6	1.5
	Other	65,674	–5.5	0.0	–2.6	1.1	1.1	1.1
	Total	**388,857**	**–152.9**	**9.2**	**–85.8**	**13.6**	**14.6**	**13.9**
Central USA Plains	Forests	21,621	–11.0	–1.1	–6.6	0.7	0.9	0.8
	Grass/shrub	827	0.0	0.4	0.0	0.0	0.0	0.0
	Agriculture	177,774	–23.1	3.3	–10.6	27.1	29.1	28.0
	Wetlands	4,658	–2.6	–0.7	–1.8	0.3	0.3	0.3
	Other	34,147	–5.9	0.4	–2.2	0.2	0.2	0.2
	Total	**239,027**	**–42.9**	**2.2**	**–21.3**	**28.5**	**30.5**	**29.3**
Southeastern USA Plains	Forests	507,236	–429.7	29.7	–205.7	52.2	64.1	59.1
	Grass/shrub	10,377	–2.6	0.4	–1.1	0.5	0.6	0.5
	Agriculture	313,514	–75.5	8.8	–29.7	17.6	25.5	21.0
	Wetlands	63,410	–61.6	–18.7	–49.9	3.6	3.8	3.7
	Other	99,809	–7.3	–1.8	–4.8	3.4	3.6	3.4
	Total	994,346	–576.8	18.3	–291.1	83.2	90.4	87.7
Ozark, Ouachita-Appalachian Forests	Forests	352,049	–248.2	–20.9	–146.7	10.0	11.2	10.8
	Grass/shrub	3,804	–0.4	0.0	–0.4	0.2	0.2	0.0
	Agriculture	130,834	–28.6	0.0	–12.1	5.2	6.8	5.8
	Wetlands	2,671	–1.8	–0.4	–1.5	0.1	0.2	0.2
	Other	31,128	–2.6	0.0	–1.5	1.4	1.4	1.4
	Total	**520,486**	**–282.0**	**–20.9**	**–162.1**	**18.0**	**18.5**	**18.2**
Mississippi Alluvial and Southeast USA Coastal Plains	Forests	87,495	–79.6	10.3	–44.7	0.4	0.5	0.5
	Grass/shrub	26,811	–2.2	0.7	–1.1	1.3	1.4	1.4
	Agriculture	139,412	–35.9	4.0	–14.3	7.9	9.6	8.8
	Wetlands	113,617	–76.6	–13.6	–53.5	5.6	6.3	6.0
	Other	139,424	–8.8	–0.7	–4.4	0.1	0.1	0.1
	Total	**506,758**	**–202.8**	**0.7**	**–118.1**	**16.0**	**17.4**	**16.7**
Eastern United States	Forests	1,363,153	–1,043.2	27.5	–577.9	66.6	80.3	74.6
	Grass/shrub	47,992	–5.9	1.8	–2.9	2.2	2.5	2.4
	Agriculture	964,948	–201.3	27.1	–77.7	69.7	85.3	76.3
	Wetlands	271,717	–196.9	–49.1	–150.0	14.2	15.4	14.9
	Other	404,813	–33.0	–1.8	–16.5	6.5	6.7	6.5
	Total	**3,052,623**	**–1,480.2**	**5.1**	**–824.6**	**167.7**	**180.8**	**174.7**

Table 7–9. Projected average annual nutrient fluxes and total global warming potential (GWP), averaged from 2006 to 2050, in the Eastern United States.—Continued

[Nutrient fluxes are for carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). Projected fluxes of methane and nitrous oxide were estimated by the land GHG accounting tool (LGAT), and projected flux of carbon dioxide was calculated using net ecosystem carbon balance (NECB) values from table 7–8. $TgCO_2$-eq, teragrams (or 10^{12} grams) of carbon dioxide equivalent per year]

Ecoregion	Ecosystem	Area, in km²	CH_4, in $TgCO_2$-eq/yr			GWP, in $TgCO_2$-eq/yr		
			Min	Max	Average	Min	Max	Average
Mixed Wood Shield	Forests	105,593	–1.7	–1.5	–1.6	–52.6	12.6	–27.9
	Grass/shrub	3,822	0.0	0.0	0.0	–0.1	0.3	–0.1
	Agriculture	23,888	–0.1	0.0	0.0	–4.8	2.3	–1.3
	Wetlands	58,742	47.3	48.6	48.2	13.2	39.8	21.4
	Other	23,554	2.2	2.2	2.2	1.9	2.3	1.9
	Total	**215,599**	**47.8**	**49.1**	**48.7**	**–42.3**	**56.9**	**–5.7**
Atlantic Highlands	Forests	151,901	–3.1	–2.9	–3.0	–115.9	–9.2	–82.3
	Grass/shrub	304	0.0	0.0	0.0	0.0	0.0	0.0
	Agriculture	19,145	0.0	0.0	0.0	–5.6	3.8	0.1
	Wetlands	5,124	3.6	3.6	3.6	–0.1	2.8	0.6
	Other	11,076	0.6	0.6	0.6	–1.4	0.8	0.0
	Total	**187,550**	**1.0**	**1.3**	**1.1**	**–123.3**	**–1.6**	**–81.6**
Mixed Wood Plains	Forests	137,258	–0.9	–0.8	–0.9	–108.6	4.7	–65.5
	Grass/shrub	2,049	0.0	0.0	0.0	–0.3	0.0	0.0
	Agriculture	160,383	–0.3	–0.3	–0.3	–16.2	18.2	2.6
	Wetlands	23,494	18.3	19.7	19.2	6.5	18.3	10.5
	Other	65,674	2.7	2.7	2.7	–1.7	3.8	1.2
	Total	**388,857**	**19.8**	**21.2**	**20.7**	**–119.5**	**45.0**	**–51.2**
Central USA Plains	Forests	21,621	–0.5	–0.4	–0.4	–10.8	–0.6	–6.2
	Grass/shrub	827	0.0	0.0	0.0	0.0	0.4	0.0
	Agriculture	177,774	–0.1	–0.1	–0.1	3.9	32.4	17.3
	Wetlands	4,658	3.2	3.4	3.3	0.9	2.9	1.7
	Other	34,147	0.6	0.6	0.6	–5.1	1.2	–1.4
	Total	**239,027**	**3.3**	**3.4**	**3.3**	**–11.1**	**36.1**	**11.4**
Southeastern USA Plains	Forests	507,236	–6.8	–5.4	–6.2	–384.4	88.4	–152.8
	Grass/shrub	10,377	–0.1	–0.1	–0.1	–2.2	0.9	–0.7
	Agriculture	313,514	0.0	0.2	0.1	–58.0	34.5	–8.6
	Wetlands	63,410	44.6	47.5	46.0	–13.4	32.6	–0.2
	Other	99,809	2.1	2.2	2.2	–1.8	3.9	0.8
	Total	994,346	40.3	43.0	42.0	–453.3	151.8	–161.5
Ozark, Ouachita-Appalachian Forests	Forests	352,049	–9.9	–8.9	–9.5	–248.1	–18.6	–145.4
	Grass/shrub	3,804	0.0	0.0	–0.5	–0.2	0.2	–0.9
	Agriculture	130,834	–0.1	0.0	–0.1	–23.5	6.8	–6.4
	Wetlands	2,671	1.7	1.8	1.8	0.0	1.6	0.4
	Other	31,128	0.9	0.9	0.9	–0.3	2.3	0.8
	Total	**520,486**	**–7.4**	**–6.2**	**–7.0**	**–271.4**	**–8.7**	**–150.8**
Mississippi Alluvial and Southeast USA Coastal Plains	Forests	87,495	–0.8	–0.6	–0.7	–79.9	10.2	–45.0
	Grass/shrub	26,811	–0.2	–0.2	–0.2	–1.1	2.0	0.1
	Agriculture	139,412	13.7	15.2	14.3	–14.3	28.8	8.8
	Wetlands	113,617	63.2	71.3	67.9	–7.8	64.0	20.4
	Other	139,424	8.4	8.5	8.5	–0.3	7.9	4.2
	Total	**506,758**	**85.5**	**92.7**	**89.8**	**–101.2**	**110.8**	**–11.6**
Eastern United States	Forests	1,363,153	–23.6	–20.4	–22.3	–1,000.2	87.4	–525.5
	Grass/shrub	47,992	–0.3	–0.3	–0.3	–3.9	4.1	–0.8
	Agriculture	964,948	13.1	15.0	13.9	–118.5	127.4	12.4
	Wetlands	271,717	182.0	195.9	189.9	–0.8	162.1	54.9
	Other	404,813	17.4	17.6	17.5	–9.2	22.5	7.5
	Total	**3,052,623**	**190.4**	**204.5**	**198.7**	**–1,122.1**	**390.3**	**–451.2**

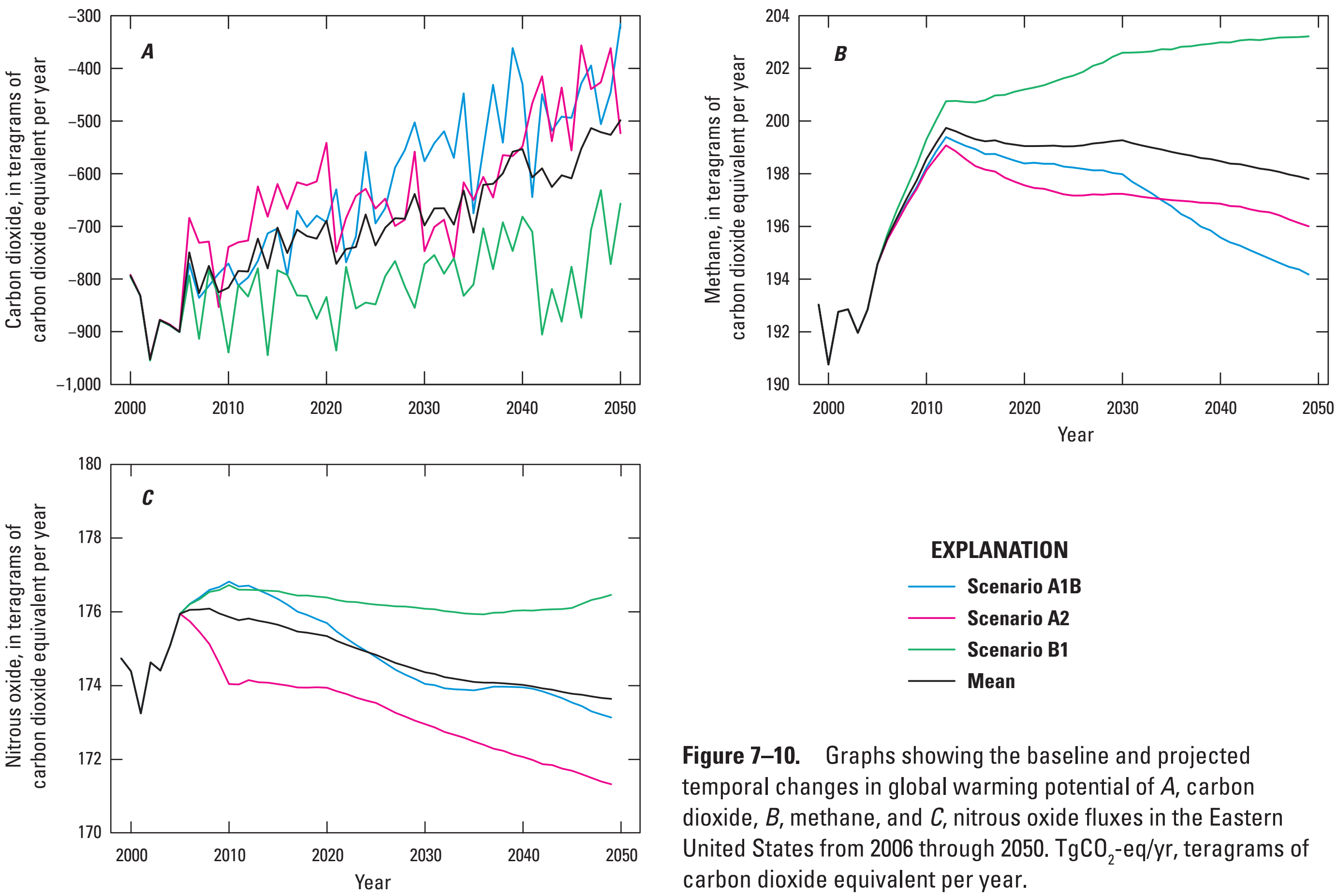


Figure 7–10. Graphs showing the baseline and projected temporal changes in global warming potential of *A*, carbon dioxide, *B*, methane, and *C*, nitrous oxide fluxes in the Eastern United States from 2006 through 2050. $TgCO_2$-eq/yr, teragrams of carbon dioxide equivalent per year.

the projected average annual NECB estimates, the Century model almost always yielded the highest estimates, followed by the EDCM and the LGAT. The relative variability among the models in projecting the average annual NECB was very high, ranging from 110.2 percent in the Mixed Wood Plains to 154.6 percent in the Central USA Plains.

The three LULC scenarios (A1B, A2, and B1) were adapted for the assessment based on social, economic, and biophysical conditions embedded in the SRES scenarios (chaps. 2 and 3). Among the three scenarios, the relative variability of the estimated carbon stock was small, ranging from 2.9 to 12.1 percent across the ecoregions. The relative variability of the projected average annual NECB under these scenarios, higher than that of carbon stock, ranged from 13.3 percent in the Central USA Plains to 32.5 percent in the Southeastern USA Plains ecoregion. The higher variability of the projected average annual NECB across scenarios in some ecoregions compared with the carbon stock variability did not necessarily indicate that there was a large difference among the results of the scenario modeling. The high variability may have been simply related to the low projected average annual NECB estimates and how the percent variability was defined.

The effect of climate uncertainty introduced by the GCMs on projected carbon sequestration is reflected by the variability of carbon estimates across GCMs. The relative variability that may be attributed to GCM uncertainty ranged from 1 to 4.1 percent for projected carbon stocks and from 7.9 to 15.9 percent for the projected average annual NECB across the ecoregions (table 7–10).

Comparing the relative variability or uncertainty of carbon estimates demonstrated by the models, LULC scenarios, and GCMs (table 7–10), the biogeochemical models introduced the highest relative uncertainty, varying from 110.2 to 148.8 percent, followed by LULC scenarios (from 13.3 to 32.5 percent) and GCMs (from 7.9 to 15.9 percent). The uncertainty of biogeochemical models overwhelmed the uncertainty from the other two.

7.5.2. Comparison of Results With Other Studies

On average, the terrestrial ecosystems (forests, agricultural lands, grasslands and shrublands, wetlands, and other lands) in the seven ecoregions of the Eastern United States stored a total 26,962 TgC (table 7–4) during the baseline period. Carbon in biomass pools (such as live and dead vegetative materials aboveground and belowground, except for those removed from agricultural fields and forests) accounted for 15,352 TgC (57 percent) of the total, and the rest was stored in the top 20 cm of the soil layer. Carbon stored in other pools (such as grain and woody biomass removed from the

Table 7–10. Comparison of projected average carbon stocks in 2050 and projected average annual net ecosystem carbon balance from 2006 to 2050 in the Eastern United States.

[Derived from combinations of three biogeochemical models, three land-use and land-change scenarios, and three general circulation models. The "variability index," which is also presented, was calculated as a percentage measure for each of the three subsets of the model runs by dividing the range of the minimum and maximum estimates of the subset by their average and multiplying by 100]

Source of data	Mixed Wood Shield	Atlantic Highlands	Mixed Wood Plains	Central USA Plains	Southeastern USA Plains	Ozark, Ouachita-Appalachian Forests	Mississippi Alluvial and Southeast USA Coastal Plains	Eastern United States
Projected average carbon stock in 2050, in teragrams of carbon								
Century	3,345.2	3,809.9	4,552.7	1,693.9	12,732.8	7,282.1	5,562.8	38,979.4
EDCM	3,505.4	4,147.0	4,835.8	1,868.4	11,115.2	6,696.7	5,597.2	37,765.7
Spreadsheet	2,693.3	3,040.4	3,922.4	1,607.8	7,592.2	5,138.3	3,982.9	27,977.4
Variability	25.5	30.2	20.6	15.1	49.1	33.6	32.0	31.5
Scenario A1B	3,254.4	3,775.1	4,534.7	1,730.2	10,719.6	6,522.5	5,165.5	35,702.0
Scenario A2	3,268.2	3,795.5	4,462.3	1,758.4	11,107.0	6,629.3	5,350.2	36,370.8
Scenario B1	3,439.6	3,962.7	4,755.0	1,780.5	12,088.9	7,023.1	5,540.0	38,589.8
Variability	5.6	4.9	6.4	2.9	12.1	7.4	7.0	7.8
CGCM3	3,223.4	3,727.7	4,488.3	1,732.5	10,641.9	6,526.4	5,098.0	35,438.2
CSIRO	3,129.6	3,594.7	4,367.8	1,715.4	10,489.6	6,328.2	5,082.3	34,707.6
MIROC	3,190.9	3,674.8	4,454.9	1,722.2	10,308.8	6,262.5	4,962.6	34,576.7
Variability	2.9	3.6	2.7	1.0	3.2	4.1	2.7	2.5
Projected average annual NECB from 2006 to 2050, in teragrams of carbon per year								
Century	–19.0	–26.2	–24.7	–3.9	–104.3	–55.7	–35.0	–268.8
EDCM	–17.7	–26.0	–27.1	–8.9	–74.8	–41.0	–37.3	–232.8
Spreadsheet	–2.6	–5.0	–5.9	–1.5	–10.3	–11.8	–5.9	–43.1
Variability	124.9	111.3	110.2	154.6	148.8	121.4	120.2	124.3
Scenario A1B	–12.3	–18.1	–18.6	–4.4	–54.4	–33.3	–23.2	–164.3
Scenario A2	–12.4	–18.4	–17.5	–4.9	–60.1	–34.9	–26.1	–174.3
Scenario B1	–14.7	–20.7	–21.6	–5.1	–74.9	–40.3	–29.0	–206.3
Variability	18.4	13.3	21.8	15.3	32.5	19.4	22.2	23.1
CGCM3	–14.0	–20.4	–20.3	–5.0	–66.5	–39.5	–27.1	–192.9
CSIRO	–11.9	–17.4	–17.7	–4.6	–63.1	–35.1	–26.8	–176.6
MIROC	–13.4	–19.3	–19.7	–4.8	–59.8	–34.0	–24.3	–175.2
Variability	15.9	15.5	13.9	7.9	10.7	15.2	11.1	9.7

landscape) was not estimated in this assessment, although its influx was calculated.

For the baseline period, the estimated forest live biomass carbon for the entire Eastern United States was 9,686 TgC on 1.461 Mkm^2 (146.1 million hectares (Mha)) of forested areas, which was lower than a recent Forest Service estimate of 11,249 TgC on a larger land base of 155.4 Mha (U.S. Department of Agriculture, 2008). In terms of carbon density, forest live biomass from this assessment (6.6 kgC/m^2) was about 10 percent lower than that of the Forest Service study at 7.3 kgC/m^2. The dead biomass (dead wood and forest floor) from this assessment was estimated to be 3,209 TgC (2.2 kgC/m^2), which was very close to the Forest Service estimate of 3,188 TgC (2.1 kgC/m^2).

The average carbon sequestration rate or NECB of all terrestrial ecosystems in the Eastern United States was estimated to decline from –279.4 TgC/yr during the baseline period to –224.9 TgC/yr during the projection period. The decrease of the carbon sink strength of Eastern United States over time may be attributed largely to potential forest aging and reduced soil organic carbon accumulation. Several studies have noted the maturity of recovered forest lands in the Eastern United States (particularly in the northeastern region) since the early 20th century, hence the reduced contribution of active carbon production by the forests. Major processes contributing to the reduced SOC accumulation in the Eastern United States may include (1) the re-equilibration of soils to the rates of addition of organic matter as soils slowly recover from the soil organic matter that was lost following abandonment of agriculture around the beginning of the 20th century, (2) acceleration of the waning of the sink strength due to climate warming (as soil temperatures and biological activities increase with climate warming, rates of soil organic matter decomposition increase northwards; Melvin and Goodale, 2013), and (3) genetic improvement of plants, especially crops, that will enhance organic matter production and therefore likely increase carbon storage in soils.

The average rate of sequestration by forests in the Eastern United States estimated in this assessment was –155 gC/m^2/yr (–226.2 TgC/yr on 146.1 Mha), including –36 gC/m^2/yr for soil carbon increase and –119 gC/m^2/yr for live and dead biomass carbon increase. By comparison, the Forest Service estimate (U.S. Department of Agriculture, 2008) estimated the forest sequestration rate in combined aboveground and belowground live and dead biomass pool to be –60 gC/m^2/yr (–93.3 TgC/yr on 155.4 Mha). Therefore, the per-unit-area estimate for carbon sequestration in the biomass pool is twice as large from this assessment compared with that from the Forest Service study. Causes to the difference in the estimates of carbon sequestration are many, including different forest areas, definitions, years of studies, and methods, and can be complex; the variability and associated uncertainties in many existing studies summarized in table 1–2 range from –82.8 gC/m^2/yr for major forest types in the Eastern United States (Williams and others, 2012) to –243 gC/m^2/yr for all forests in the Eastern United States (Turner and others, 1995). Carbon removals, especially clearcutting and thinning, are also critical components that affect the calculation of the rate of sequestration. The carbon removal amount (clear and partial cuttings) was estimated in this assessment to be 41 TgC/yr for the baseline period, which is significantly lower than in some earlier studies; for example, Williams and others (2012) estimated carbon removal to be about 100 TgC/yr in the Eastern United States.

NPP values from MODIS for 2001 through 2005 were used to constrain the spatial variability of GEMS NPP simulations. For the entire Eastern United States, the average baseline NPP was about 640 gC/m^2/yr, generally matching that of other regional studies. Mickler and others (2002) reported that forest NPP of the Southeastern United States was between 644 and 711 gC/m^2/yr (converted from biomass according to a standard conversion factor of 0.5 given by Eggleston and others (2006)). One challenge in validating NPP simulations is the scarcity of the NPP estimates compared with the aboveground NPP (ANPP) estimates because of the difficulties in measuring belowground NPP. In order to compare belowground NPP estimates with available ANPP estimates, ANPP from this assessment was estimated to be 448 gC/m^2/yr, using the forest NPP estimate of 640 gC/m^2/yr and a conversion factor of 0.7 from forest NPP to ANPP according to field studies (Whittaker and Woodwell, 1969; Harris and others, 1975; Benecke and Nordmeyer, 1982; Gholz and Fisher, 1982; Ryan and others, 1996, 1997; Curtis and others, 2002; Maier and others, 2004). This value for ANPP would agree well with other estimations generated using inventory or site-specific methods. For example, Brown and Schroeder (1999) reported that the ANPP in forests in the Eastern United States averaged 435 gC/m^2/yr and 485 gC/m^2/yr for hardwood and softwood types, respectively. Jenkins and others (2001) reported that the average forest ANPPs in the mid-Atlantic region were 393 gC/m^2/yr and 430 gC/m^2/yr for hardwood and softwood types, respectively.

Another comparison for ecosystem carbon sequestration may be made with CO_2 NEE for an entire ecosystem, estimated with the eddy covariance technique (table 7–11). The eddy covariance technique has been central to measuring the magnitude and variation of NEE in various ecosystems and the effects of disturbances and climate change (Loescher and others, 2006). Although NEE values listed in table 7–11 showed large variations across sites, most ecosystems showed

Table 7–11. Net ecosystem exchange of carbon dioxide measured in various ecosystems in the Eastern United States using eddy covariance techniques.

[Negative net ecosystem exchange (NEE) of carbon dioxide (CO_2) indicates carbon uptake by ecosystems. gC/m^2/yr, grams per square meter per year]

Forest ecosystem	NEE, in gC/m^2/yr	Location of site	Location	Reference
Deciduous broad-leaved forest	–370	Harvard Forest, Mass.	42°54'N,72°18'W	Wofsy and others (1993)
Deciduous broad-leaved forest	–140	Harvard Forest, Mass.	42°54N,72°18'W	Goulden and others (1996)
Slash pine plantation	–740	Gainesville, Fla.	29°44 N, 82°09' W	Clark and others (1999)
Scrub oak ecosystem	–287	Kissimmee-St. Cloud, Fla.	28°36'N, 80°42'W	Powell and others (2006)
Deciduous forest	–525	Oak Ridge, Tenn.	35°57'N, 84°17'W	Greco and Baldocchi (1996)
Deciduous broad-leaved forest	–574	Walker Branch Watershed, Tenn.	35°57'N, 84°17'W	Wilson and Baldocchi (2000)
Slash pine plantation	–425	Duke Forest, N.C.	35°98'N, 79°08'W	Oren and others (2006)
Mixed hardwood and boreal forests	–119	University of Michigan Biological Station, Mich.	45°35'N, 84°42'W	Curtis and others (2002)
Mix of upland forests and wetlands	–220	Willow Creek, Wisc.	45°47'N, 90°05'W	Curtis and others (2002)
Deciduous broad-leaved forest	–280	Harvard Forest, Mass.	42°54'N,72°17'W	Urbanski and others (2007)
Loblolly pine plantation	106	Southeast Tree Research and Education Site, Scotland County, N.C.	34°48'N, 79°12'W	Lai and others (2002)
Young loblolly pine plantation	–1,010	Scotland, N.C.	35°00'N, 79°00'W	Albaugh and others (1998)

carbon sequestration. For example, Wofsy and others (1993) reported an NEE of –370 gC/m^2/yr at the Harvard Forest. Goulden and others (1996) reported that the annual net uptake of CO_2 by a deciduous forest in New England (the Atlantic Highlands and Mixed Wood Plains ecoregions) ranged from –140 gC/m^2/yr to 280 gC/m^2/yr. Falge and others (2002) estimated the NEE of a temperate deciduous forest to be –181 gC/m^2/yr.

Bracho and others (2012) used eddy covariance and biometric approaches to measure carbon dynamics in two slash pine plantations (*Pinus elliottii* var. *elliottii* Englm) in northern Florida (in the Mississippi Alluvial and Southeast USA Coastal Plains ecoregion) over 9 years with frequent drought events and observed that the NEE magnitude fluctuated with environmental conditions (for example, drought events) from –800 to –400 gC/m^2/yr and documented a drought-induced reduction of 20 percent in NEE. Similarly, Clark and others (2010) reported that invasive insects led to defoliation in a mixed stand in New Jersey (in the Mississippi Alluvial and Southeast USA Coastal Plains ecoregion) from 2005 through 2007 and resulted in a 20 to 41 percent NEE reduction.

After analyzing a global database, Luyssaert and others (2007) found that the average NEP was –311 gC/m^2/yr ±38 gC/m^2/yr for temperate humid deciduous forests. In addition, the study found that the global pattern for NEP was insensitive to climate and was mainly determined by nonclimatic conditions, such as successional stage, site management, site history, and site disturbance.

In the USGS assessment of the Eastern United States, the average forest carbon sequestration in the baseline period was –155 gC/m^2/yr, with soil carbon change contributing –36 gC/m^2/yr and the live and dead biomass carbon increase representing –119 gC/m^2/yr. This average value was in the lower range of the measurements made by eddy covariance in the Eastern United States (table 7–11). With support of data obtained from 128 cold temperate and boreal forests across the United States, Reich (2012) found that stand-scale forest productivity is a function of leaf area index and canopy nitrogen concentration, which together explain more than 75 percent of the variation in ANPP among forests.

7.5.3. Soil Carbon Sequestration Measurements in Agricultural Ecosystems

The agricultural soils were estimated to be a small SOC sink at an average rate of –4 gC/m^2/yr (derived from table 7–5) ranging from a small source of 10 gC/m^2/yr to a sink of –21 gC/m^2/yr for the baseline years. The average value is somewhat smaller than the observed values reported by Tan and others (2006) and Franzluebbers (2010) but shows a relatively higher uncertainty than the reported field measurements. These estimated rates from previous studies came with an assumption that all cropped lands were under conservation tillage, but in reality only about 70 percent of all cropped soils were managed with conservation practices (Conservation Technology Information Center, 2012). The estimated values from this assessment included cropped soils that would be managed with conventional tillage, which likely led to higher SOC carbon source estimates (West and Post, 2002). Projected average net carbon flux in SOC pool for the agricultural lands was a SOC sink at –15 gC/m^2/yr, ranging from an almost neutral state to a moderate SOC sink of –36 gC/m^2/yr.

7.5.4. Carbon Removal From Forest Harvesting

Carbon removal from clearcutting and partial forest cuts was estimated to be 41 TgC/yr from 2001 through 2005, which was lower than an estimate by the Forest Service (Adams and others, 2006) that showed about 110 to 120 TgC/yr of clearcutting and partial forest cuts by the end of the 1990s. Comparing annual harvest statistics from 2001 through 2005 between the Forest Service RPA studies (Smith and others, 2004, 2009) for the north and south regions of the Forest Service and this assessment (table 7–12) clearly indicates that the issue was the difference in estimating areas of harvesting.

Although forest areas used in the two studies were similar, annual areas harvested were quite different, with Smith and others (2009) reporting approximately 2.5 times the harvest area in this assessment. Area affected from clearcutting and partial cutting in the RPA was reported as 38,091 km^2 or 2.45 percent of the total forest area, whereas it was 15,037 km^2 or 1.03 percent of the total forest area used in this assessment. Both clear cutting and partial cutting were more than twice as high in the RPA study as in this assessment. The RPA study relied on the approach of forest inventory to estimate harvesting area (Smith and others, 2009), whereas this assessment used datasets derived from remote sensing techniques as described in chapter 3 of this report.

Carbon removal rates, on the other hand, were similar between the RPA study and this assessment at 2.8 kilograms of carbon per square meter per event (kgC/m^2/event) and 2.7 kgC/m^2/event, respectively. The RPA study used 3.6 kgC/m^2/event and 2.3 kgC/m^2/event for clearcutting and partial cutting, compared with 3.8 kgC/m^2/event and 1.8 kgC/m^2/event used in this assessment.

As the result, using the approach described in McKinley and others (2011) and the data from the RPA (Smith and others, 2009), the total carbon removal from the RPA study would be approximately 108 TgC/yr for the two Forest Service regions in the Eastern United States, compared with 41 TgC/yr reported in this assessment. The magnitude of difference is similar for both clearcutting and partial cutting (table 7–12).

Evidence from this assessment shows that the effect of discrepancies in estimating areas of forest cutting (clearcutting and partial cutting) on estimating net forest carbon flux is substantial. Current efforts that merge remotely sensed spatial forest cutting footprints with estimates derived from forest inventories have shown promising results (Hicke and others, 2007; Goward and others, 2008; Huang and others, 2010;

Table 7–12. Annual average forest harvests from 2001 through 2005 in the Eastern United States.

[Comparison of forest harvest results between the Forest Service Resource Planning Act (RPA) results reported in Smith and others (2004; 2009) for the Forest Service north and south regions and produced for the U.S. Geological Survey (USGS) assessment. km², square kilometers; gC/m²/event, grams of carbon per square meter per event; TgC/yr, teragrams of carbon per year]

Forest harvest variable	RPA	USGS assessment
Forest area, in km²	1,555,163	1,461,458
Clearcut and partial cut area, in km²	38,091	15,037
Forest area clearcut and partial cut, in percent	2.45	1.03
Clearcut area, in km²	14,810	6,683
Forest area clearcut, in percent	0.95	0.46
Partial cut area, in km²	23,280	8,354
Forest area partial cut, in percent	1.50	0.57
Carbon removal from clearcut and partial cut, in TgC/yr	108	41.4
Carbon removal from clearcut, in TgC/yr	54.0	25.4
Carbon removal from partial cut, in TgC/yr	54.0	15.6
Rate of carbon removal from clearcut and partial cut, in gC/m² per event	2,830	2,750
Rate of carbon removal from clearcut, in gC/m² per event	3,640	3,800
Rate of carbon removal from partial cut, in gC/m² per event	2,320	1,800

Turner and others, 2011; Williams and others, 2012). The combined approach is one that was used for this assessment (described in chapter 3 of this report). Both remotely sensed products and ground-based estimation carry uncertainties in their results. This kind of uncertainty is one of the major areas that deserve much attention to reduce the uncertainty in estimating carbon dynamics over large areas (Liu and others, 2012b; Kasischke and others, 2013).

7.5.5. Summary of Baseline Carbon Fluxes in the Assessment of the Eastern United States

On average, the terrestrial ecosystems (forests, croplands, grasslands, shrublands, wetlands, and other lands) in the seven ecoregions of the Eastern United States stored a total of 26,962 TgC during the baseline period (2001–2005). Carbon in biomass pools (such as live and dead vegetative materials aboveground and belowground, except for those removed from agricultural fields and forests) accounted for 15,352 TgC (57 percent) of the total, and the rest was stored in the top 20 cm of the soil layer. Carbon stored in other pools (such as grain and woody biomass removed from the landscape) was not estimated in this assessment, although the influx of carbon from these sources was calculated. The regional NECB was estimated to be –288.6 TgC/yr, including NECB from lacustrine systems (9.2 TgC/yr) in the Eastern United States. This estimate represented the sum of carbon sequestered in terrestrial pools and in sediments in aquatic ecosystems in this region; however, carbon removal from rivers and coastal waters was not included in this assessment. Of the total NECB in the region, the terrestrial ecosystems were responsible for an average of –279.4 TgC/yr, including –214 TgC/yr and –65.4 TgC/yr in biomass and soils, respectively (fig. 7–11).

Carbon fluxes and burials from major terrestrial sources (this chapter) and in inland waters and coastal waters (chaps. 5 and 6) for baseline years are summarized together in figure 7–11. For simplicity, the estimated carbon stocks in all terrestrial ecosystems are lumped together in this diagram within two carbon pools: one for biomass carbon and one for soil organic carbon. The baseline years varied for different components of the assessment as limited by available input data (chap. 1). As the result, figure 7–11 should be interpreted as a composite representation of contemporary carbon cycle processes in the region estimated using different methods described in various chapters of this report. The common time period for all the components was from 2001 to 2005, which is the nominal baseline period for this assessment.

Among the various fluxes, the largest were NPP and heterotrophic respiration of the terrestrial ecosystems (fig. 7–11). The NPP and heterotrophic respiration were 1,690.1 TgC/yr and 1,369.1 TgC/yr, respectively. About 16.5 percent of the annual NPP was sequestered in biomass and soils. The amount of carbon removed by grain harvesting from agricultural lands was 103.8 TgC/yr. The amount of carbon removed by timber harvesting from forest lands was 41.4 TgC/yr. Wildland fires also emitted an average of 1.6 TgC/yr from ecosystems in the Eastern United States. On the aquatic side, rivers and streams transported an average of 36.5 TgC/yr through various ecosystems in the Eastern United States, and 51.3 TgC/yr was emitted from all inland water bodies.

7.5.6. Limitation of This Assessment and Future Directions

For this assessment, efforts were made to process and produce spatially and temporally explicit input data of LULC (chaps. 2 and 3), wildland fire (chap. 4), and land management activities (this chapter) and to include the effects of these processes in carbon estimates presented in this chapter. Nevertheless, only a partial attribution analysis was produced on effects of controlling processes (for example, effects of wildland fire (chap. 4), effects of timber production (this chapter), general attribution of LULC change (chap. 3 and this chapter), and uncertainty contribution from the three biogeochemical models, LULC scenarios, and GCMs (this chapter).

Other ecosystem processes and land-use activities not included in this assessment could also potentially introduce uncertainties in the results. Although carbon fluxes related to timber and grain harvesting were estimated, the offsite

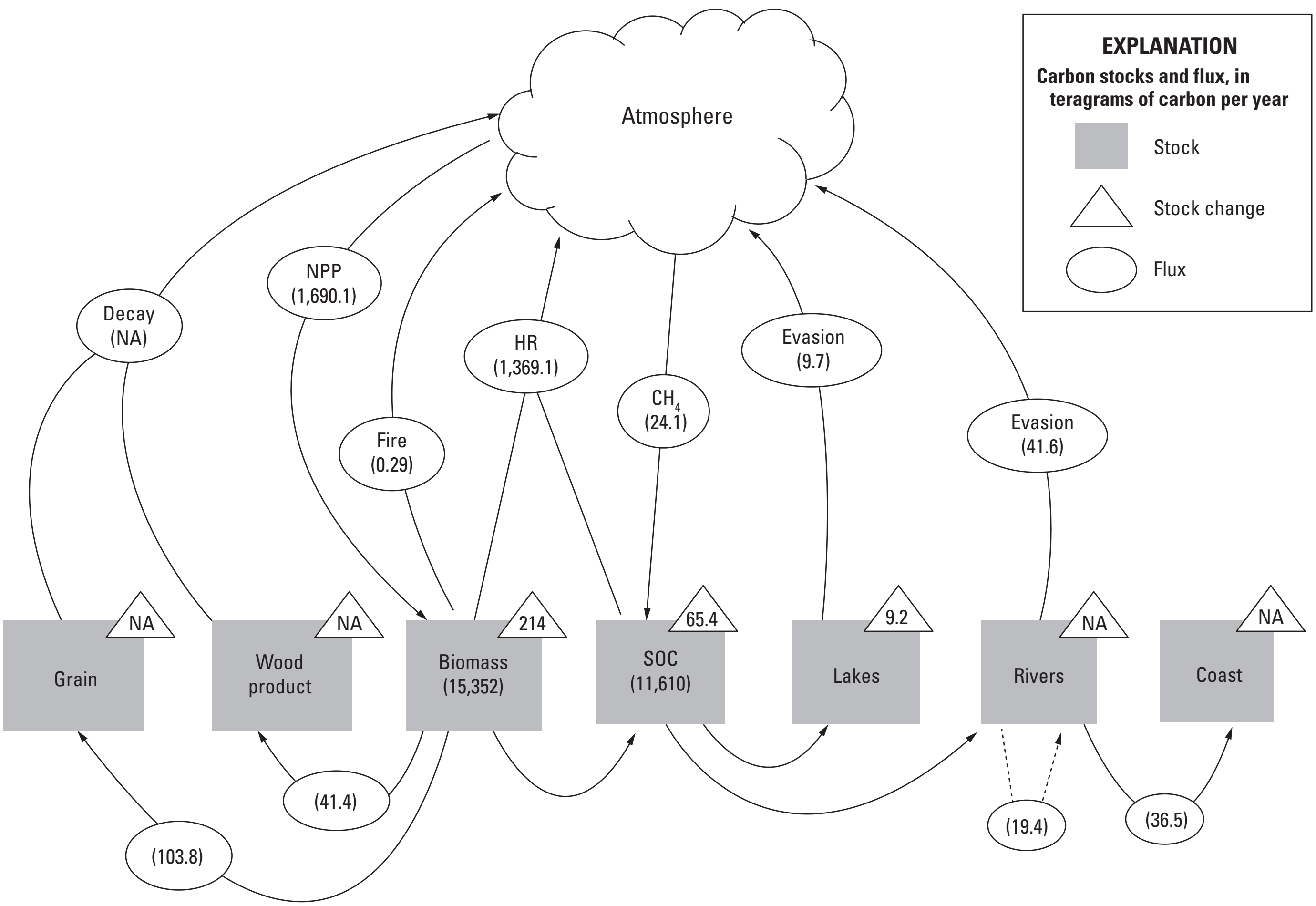


Figure 7–11. Flow diagram showing average carbon stocks and fluxes and changes in average carbon stock for primary carbon pools in the Eastern United States during the baseline years (2001 through 2005). Only those carbon stocks and fluxes that were examined in the assessment are shown. Changes in carbon storage rates in lacustrine systems (lakes and reservoirs) and in coastal waters (by burial in sediment) were included, but the carbon stocks in these ecosystems were not included. In quantifying the changes in average carbon stocks of soils and biomass (all dead and live biomass), carbon combustion by fire and transfer to products by harvesting were considered, but not their export to the aquatic ecosystems. There was no coupling between the estimates of carbon stocks in the terrestrial and aquatic systems. Positive carbon stock change indicates a carbon storage increase and therefore represents carbon sequestration. The arrow with the dashed line under the "Rivers" box indicates the lateral flux of carbon within the streams and rivers. CH_4, methane; HR, heterotrophic respiration of terrestrial ecosystems; NA, not applicable, due to either a lack of input data or the choice of methods; NPP, net primary production of terrestrial ecosystems; SOC, soil organic carbon.

dynamics of timber and grain products were not accounted in this assessment because no life-cycle analysis was conducted to evaluate the long-term decomposition rates of the harvests. Also not explicitly included in this assessment were the carbon implications of other ecosystem disturbances, such as the carbon fluxes related to the temporal dynamics of forest defoliation and mortality from insects and windstorm-caused mortalities, particularly in the Great Lake and southern States. The dynamics of these land-management activities and natural disturbances, although highly relevant to the carbon cycle in the Eastern United States, were not supported with sufficient input data and scientific understanding. As a result, their exclusion introduced uncertainty in the assessment.

Results of this assessment suggested a wide range of uncertainty in the estimated carbon sequestration rates across models, LULC scenarios, and GCM projections in ecoregions and in the Eastern United States. In addition, the results showed that the uncertainty from models dominated the uncertainties from LULC and GCMs. These results are important but they are high-level observations without a detailed cause-and-effect analysis, which require a further effort to explain the differences among models, LULC scenarios, and GCM projections.

It should be recognized that the uncertainty analysis presented in this chapter is partial and conditional to the methods and input data used, specifically, the three biogeochemical models, climate projections of the three GCMs, and the three LULC scenarios. For example, the general analysis did not include uncertainties from input data layers and model parameters. Model simulations were constrained by nationally consistent ground-based measurements and census data (for example, forest inventory data from FIA and grain yield and crop management practices from the USDA) and satellite-derived estimates of processes such as NPP and disturbances. The development of additional data layers should be beneficial in constraining model simulations. For example, GEMS models should be calibrated and validated, with measures of parameter uncertainty, at site scales, using various measurements collected from diverse ecosystems and are available from FLUXNET (*http://fluxnet.ornl.gov/*). Developing additional data layers from FIA data through collaboration with the Forest Service and from literature review and meta-analysis may help reduce uncertainties in the data. It is also important to develop a scheme that can improve the understanding and quantification of the export of carbon from terrestrial to aquatic systems using the law of mass conservation, which was not implemented in this assessment. A continuing national effort should be undertaken to add more data streams and fields to constrain GEMS model behavior more tightly and therefore improve the understanding and quantification of the carbon cycle and reduce the uncertainty of the estimated carbon sources and sinks over large areas in the United States.

This assessment has created a nationwide and consistent framework capacity for quantifying carbon dynamics and GHG emissions under the effects of LULC, disturbances, and climate for the Eastern United States at 250-m resolution. Future efforts should be orchestrated around the following major themes to strengthen this capacity: (1) improving understanding and quantification of the carbon cycle at landscape to national scales, as described earlier in this section, with fundamental advancement in process understanding, and (2) transitioning GEMS into a real-time carbon dynamics monitoring system for the country and the ecoregions. With regard to the second theme, efforts should replace part of the databases developed in this assessment. Specifically, the model simulated dynamics of climate, land use, and disturbances from 2006 to present (part of the projection period in the assessment) should be replaced with real observations.