North American Carbon Program (NACP) Interim Synthesis Project: Regional Forward Model Intercomparison

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Introduction

Our understanding of how carbon is exchanged between terrestrial ecosystems and the atmosphere is gained from direct observations and experiments, as well as through modeling activities. Terrestrial biosphere models (TBMs) have become an integral tool for extrapolating local observations and understanding to larger regions. Although models vary in their specific goals and approaches, their central role within carbon cycle research is to provide a better understanding of the mechanisms currently controlling carbon exchange. Recently, the North American Carbon Program (NACP) organized several interim-synthesis activities to evaluate and inter-compare models and observations at local to continental scales for the time period of 2000 through 2005. Here, we present the results from the TBMs collected as part of the regional and continental interim-synthesis (RCIS) activities. (http://nacp.ornl.gov/ int_synthesis.shtml)

Objectives

The primary objective of this work is to synthesize and compare 19 TBMs to assess current understanding of the terrestrial carbon cycle in North America. Thus, the RCIS focuses on model simulations and data currently available from analyses that have been completed by ongoing NACP projects and other recently published studies. Bringing model estimates (and available data) together that incorporate a wide range of modeling approaches provides a valuable assessment of the current state of understanding of regional carbon flux across North America.

Models Participating in the NACP Regional Interim Synthesis

Model	Native Temporal Resolution	NEP	External Factors Influencing NEP: Land-use/Land Cover Change	External Factors Influencing NEP: Fire	External Factors Influencing NEP: Transient Forcings	Formulations: Photo-synthesis	Formulations: Soil Carbon Decomp.
Prognostic Models							
Can-IBIS	30 min	GPP - (Ra+Rh)		prescribed	CO_2, Ndep	EK	1st order
CLM-CASA'	20 min		prescribed land-use		CO_2	EK	1st order
CLM-CN				prognostic	CO_2, Ndep	EK	1st order with N
DLEM	Daily			prescribed		EK	1st order with N
ISAM	Weekly	NPP - Rh				LUE	1st order with N
LPJ-wsl	Daily	GPP - (Ra+Rh)			CO_2	EK	1st order
MC1	Monthly		prescribed land-use, prognostic forest harvest	prognostic	CO_2, Ndep	Statistical	1st order with N
ORCHIDEE	30 min			prognostic	CO_2	EK	1st order with N
SiB3.1	Hourly					EK	Zero order
TEM6	Monthly		prescribed land-use, and forest harvest	prescribed	CO_2, Ndep	EK	1st order with N
VEGAS2	Daily			prognostic	CO_2	LUE	1st order
Diagnostic Models							
BEPS	Hourly	GPP - (Ra+Rh)	prescribed[1]	prescribed[1]	CO_2	EK	1st order with N
CASA-TransCom	Monthly	GPP - Re				LUE	1st order
NASA-CASA		GPP - (Ra+Rh)	prescribed land-use		CO_2, Ndep	LUE	1st order with N
CASA GFEDv2		GPP - Re		prescribed		LUE	1st order
EC-LUE	Weekly					LUE	
EC-MOD	Daily	-NEE				LUE	Zero order
MODIS	8-Day					LUE	
MOD17+	Daily	GPP - (Ra+Rh)				LUE	Zero order

[1]Biomass in BEPS is calculated from annual LAI which implies all disturbances that impact LAI will result in biomass changes.

Methods

The TBM flux estimates are evaluated over different land cover regions of North America, and with respect to model type (i.e., prognostic versus diagnostic), temporal resolution, photosynthetic formulation, soil carbon dynamics, and whether they included impacts from land-cover / land-use change and transient forcings, such as changes in atmospheric carbon dioxide (CO_2) and nitrogen (N) deposition.

Model estimates were also compared to spatially explicit inventory-based estimates of cropland productivity.

REFERENCES

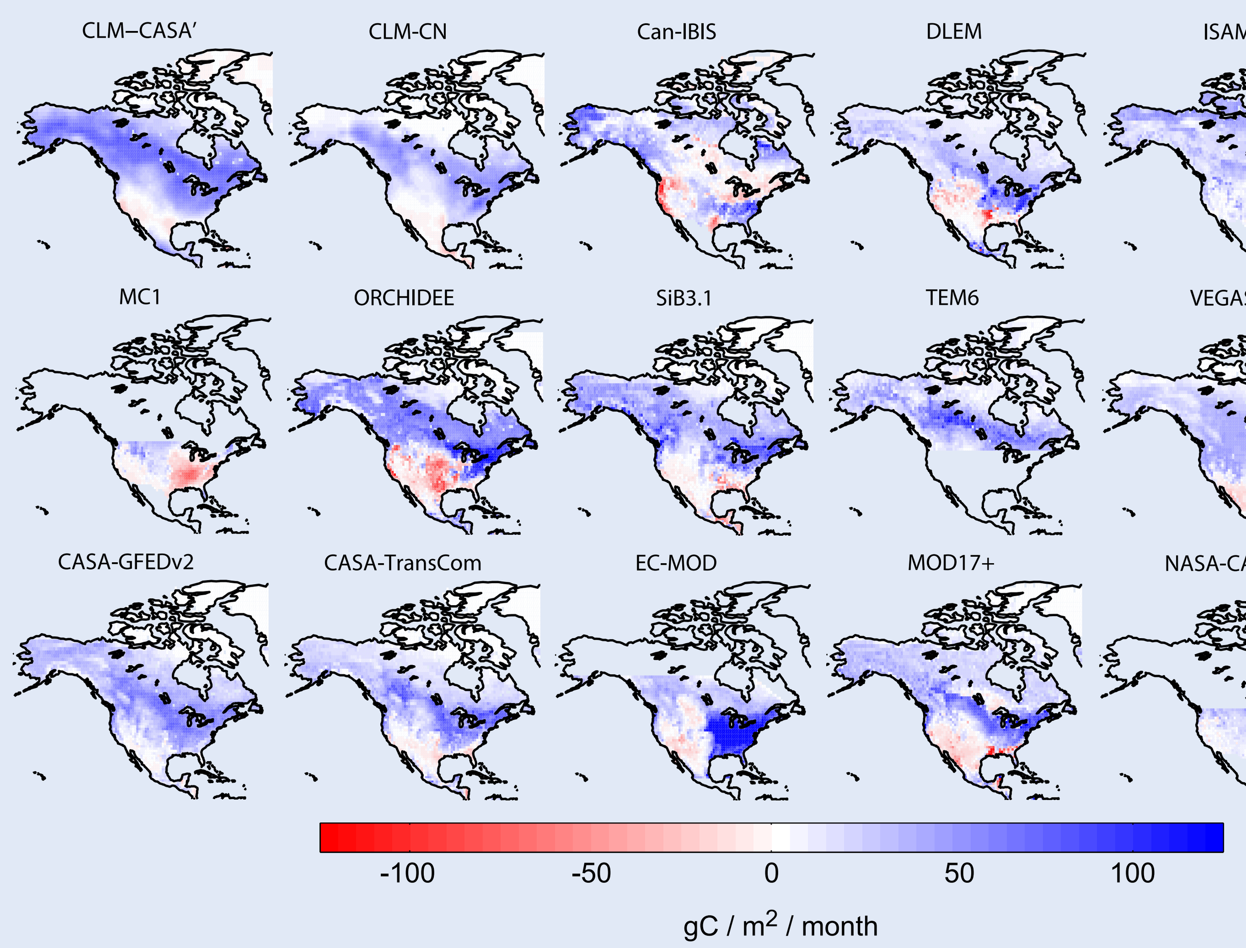
Olson, D. M., et al. (2001), Terrestrial ecoregions of the worlds: A new map of life on Earth, Bioscience, 51(11), 933-938.

Taylor, K. E. (2001), Summarizing multiple aspects of model performance in a single diagram, Journal of Geophysical Research-Atmospheres, 106(D7), 7183-7192.

West, T. O., et al. (2010), Cropland carbon fluxes in the United States: Increasing geospatial resolution of inventory-based carbon accounting., Ecological Applications, 20(4), 1074-1086.

Variability in Surface Flux Distribution

Long-Term Mean Summer (June, July, August) Net Ecosystem Productivity (NEP)



(+) Denotes net carbon uptake by land from atmosphere

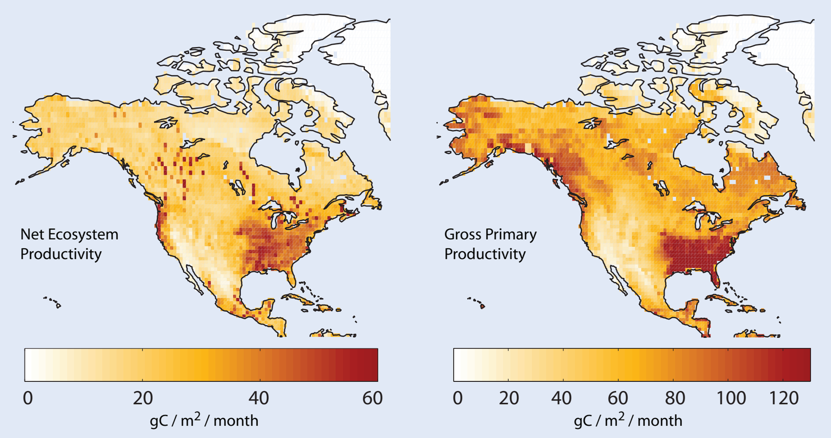
(-) Denotes net release of carbon from land to atmosphere

During the growing season, the magnitude and distribution of fluxes vary significantly among the models. Some models show strong carbon sources in the midwest and southern portions of the U.S., (e.g., MC1, LPJ-wsl), central plains, west, and southwest (ORCHIDEE, LPJ-wsl, MOD17+), while others estimate large sinks (e.g., BEPS, EC-MOD) particularly in the southeast.

In the boreal regions of North America there appears to be more consistency among the models, with most models showing an overall sink of carbon during the summer months. The strength of that sink, however, varies across models.

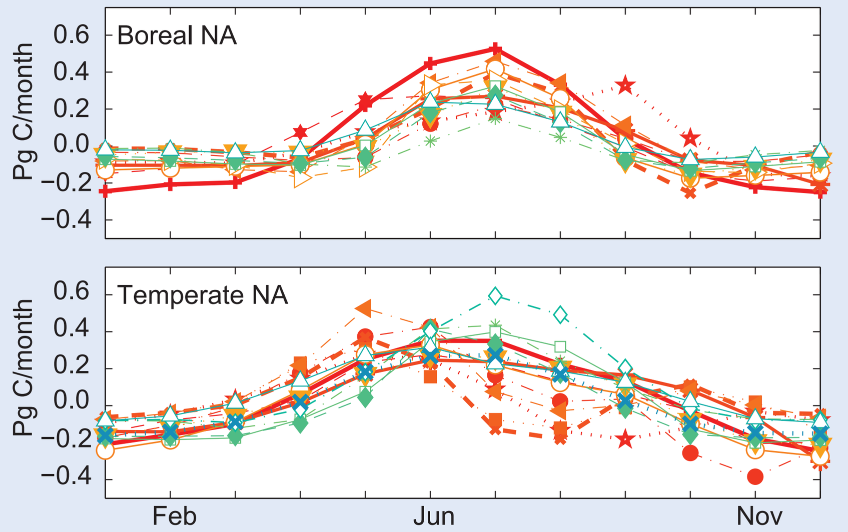
Much of the variability in summertime NEP in the southeast is driven by variability in predicted GPP.

Across-Model Standard Deviation in Long-Term Mean Summer Net Ecosystem Productivity (NEP)

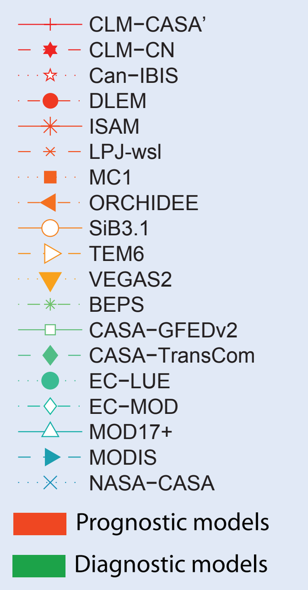


Seasonal Cycle

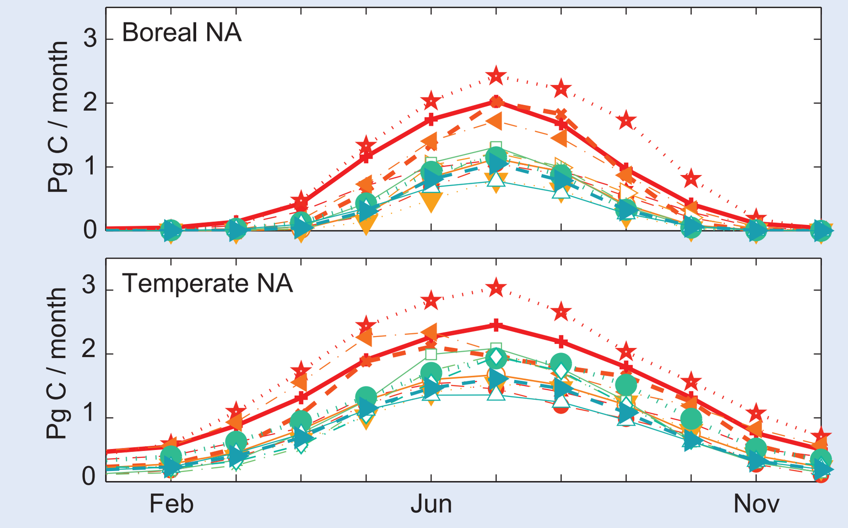
NEP Long-Term Mean Seasonal Cycle



The models vary significantly in their estimates of the depth and timing of the seasonal cycle.

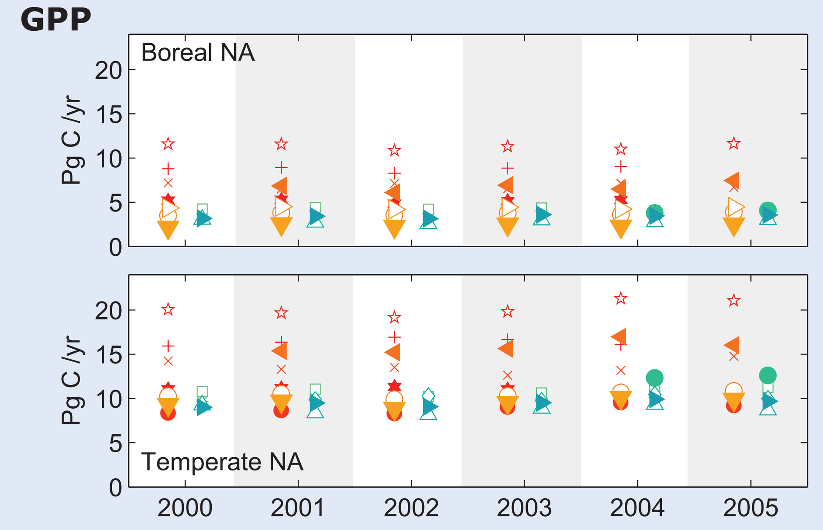


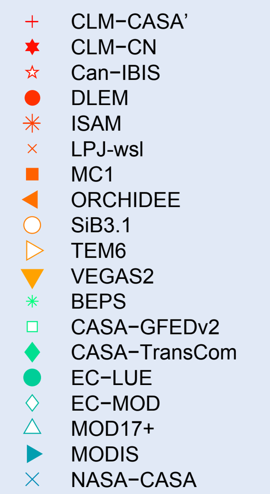
GPP Long-Term Mean Seasonal Cycle



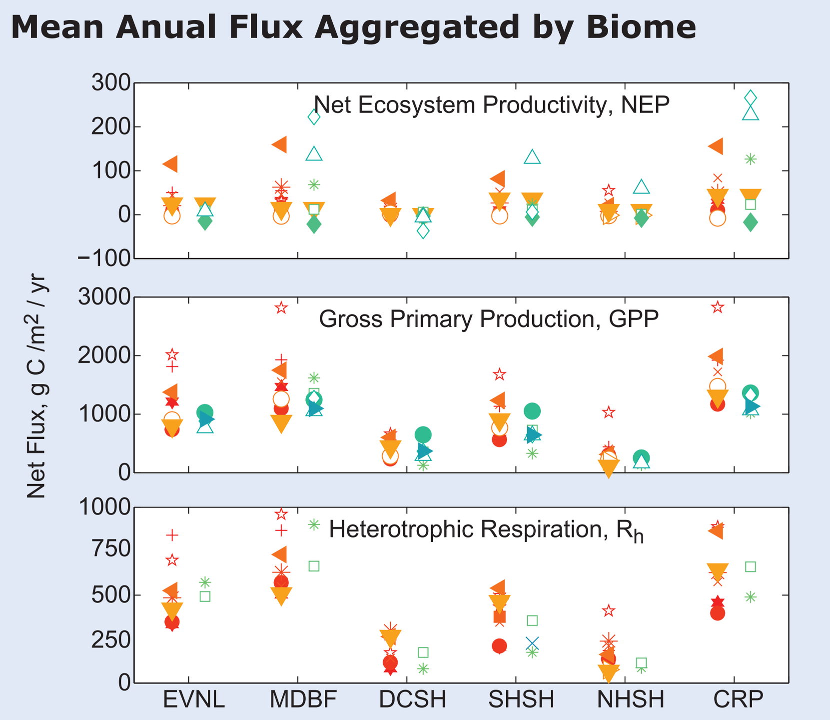
Prognostic models tend to have greater variability among their estimates and a larger peak GPP than diagnostic models.

Net Annual Carbon Flux

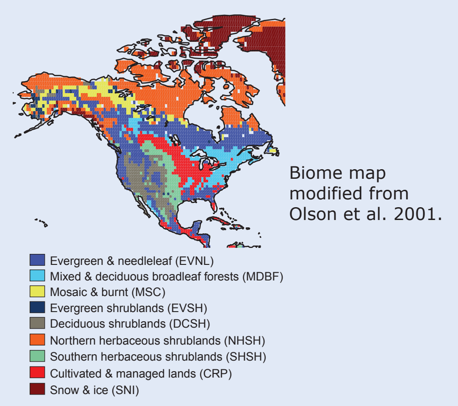




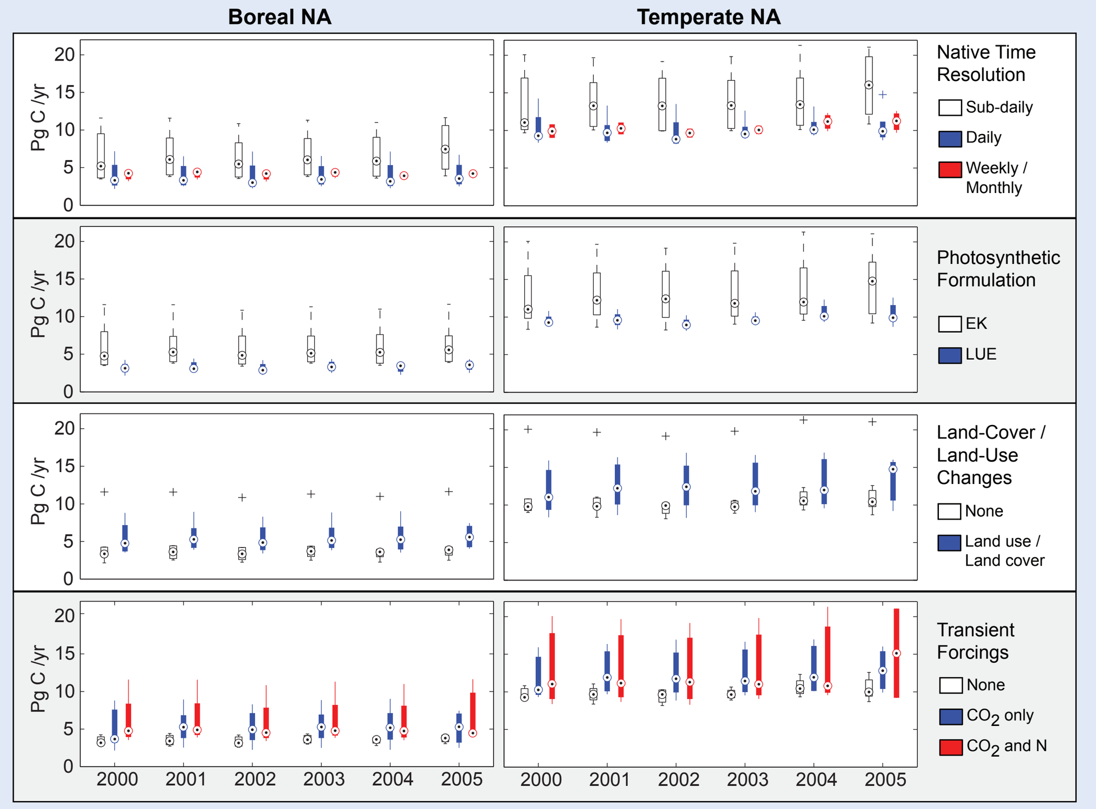
Mean Anual Flux Aggregated by Biome



Fluxes aggregated spatially to both TransCom regions (above) and spatially contiguous regions of similar landcover (left)



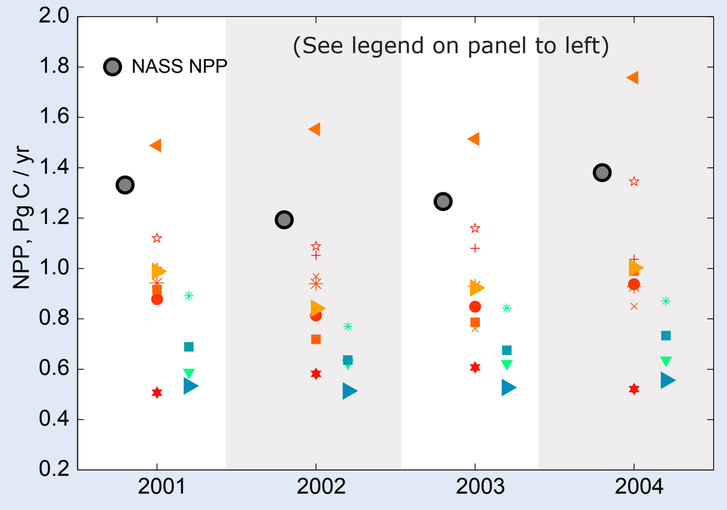
Grouping Models by Other Factors

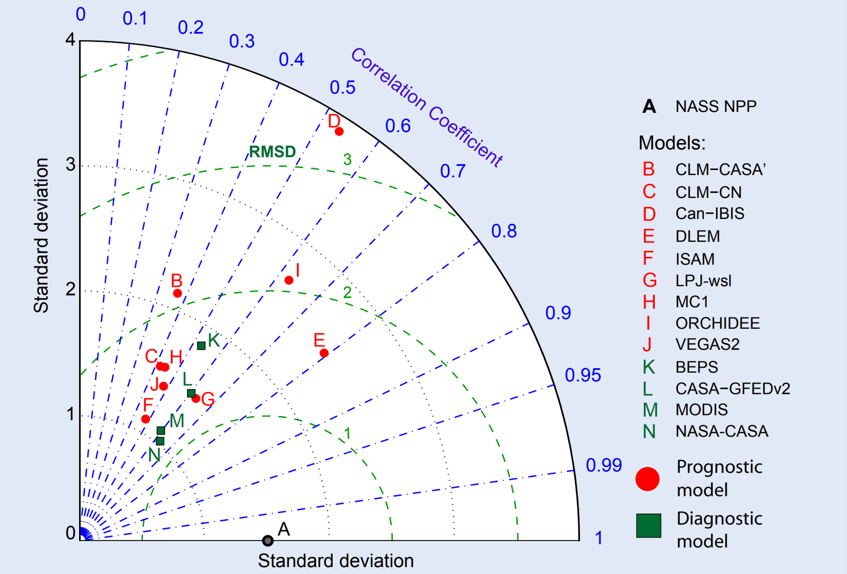


Grouping models by different formulation types/classes is a useful means of comparison. It highlights difference in flux that would be difficult to see otherwise. However, many other factors may influence flux estimates among the models (e.g., environmental driving variables, initial conditions, spin-up, land-cover type). Formal model simulations conducted with a detailed protocol and standardized drivers are needed to properly evaluate the influence of model formulation, structure, and assumptions on flux estimations.

Comparing Models to Inventory-Based Estimates

Model estimates of annual NPP are compared to inventory-based cropland NPP estimates derived from NASS yield data [West et al., 2010] for predominant agricultural areas within the United States. Most models do not actually model agricultural ecosystems, and those that do, often do so simply (e.g., as a fertilized C3 or C4 grassland). In general, the models predict lower NPP than the inventory data. Prognostic models tend to predict great NPP than diagnostic models.





Taylor Diagram's (above, right) [Taylor, 2001] are useful for evaluating multiple models against a chosen dataset or reference. Models that closely match the spatial pattern of the NASS inventory data will have a small centered root mean squared difference (RMSD), a correlation coefficient close to 1, and a standard deviation similar to the NASS inventory.

Conclusions

There is significant disagreement among the models in their estimates of flux, both in terms of the net carbon uptake and the timing and depth of their estimated seasonal cycles. The range in estimates from the models appears to be driven by a combination of factors, including how the model represents photosynthesis, the source of environmental driver data, temporal resolution, as well as whether land-cover use and/change and/or transient forcings such as increased atmospheric carbon dioxide and nitrogen deposition are included in the model. The results of this study highlight the disagreement in current estimates of carbon flux across North America. The results also highlight the need for further analysis through the use of formal model intercomparisons that include a detailed model simulation protocol in order to isolate the influence of model formulation, structure, and assumptions on flux estimations (e.g., http://nacp.ornl.gov/MsTMIP.shtml).