The North American Carbon Program
Regional Interim Synthesis Project

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and many modeling teams

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Introduction
The North American Carbon Program (NACP) has organized a synthesis project to compare inverse and forward model estimates of North American CO_2 exchange over the period 2000-2005. This regional synthesis project has posed five scientific questions:

1. What is the spatial pattern and magnitude of interannual variation in carbon fluxes during 2000-2005?
2. What are the components of carbon fluxes and pools that contribute to this variation?
3. Do model results and observations show consistent spatial patterns in response to the 2002 drought in North America?
4. From measurements and ecosystem models, can we infer what processes were affected by the 2002 drought?
5. What are the magnitudes and spatial distribution of carbon sources and sinks, and their uncertainties, during 2000-2005?

The present analysis attempts to address some of these questions. We compare 22 forward (mechanistic, bottom-up) models with 24 inverse (top-down) models to evaluate the extent of agreement regarding interannual variability of carbon exchange over North America.

Comparison of Net Ecosystem Exchange

The net ecosystem exchange (NEE) of CO_2 between the terrestrial biosphere and the atmosphere, including the effects of photosynthesis, respiration, and disturbance*, is directly simulated by forward (bottom-up) models and inferred by atmospheric transport inversions (top-down models). NEE fluxes from forward and inverse models are integrated across two large continental-scale regions (see figure at right). Time series of the regional fluxes are compared below.

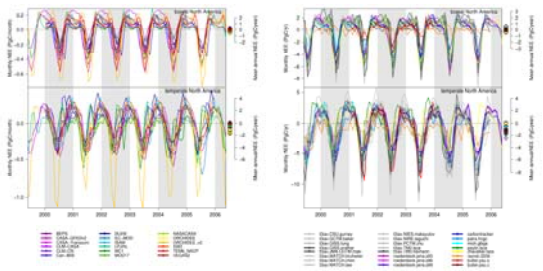
* Not all models simulate fire emissions, and some only provide fire emissions on annual time scales. Forward model NEE here excludes fire emissions, which are estimated to range from 10-90 TgC/yr in the boreal zone and 20-40 TgC/yr in the temperate zone.

Transcom regions

Boreal North America

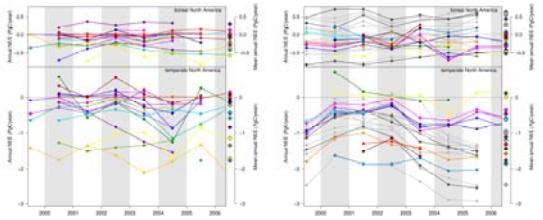
Temperate North America

Forward Models | Inverse Models

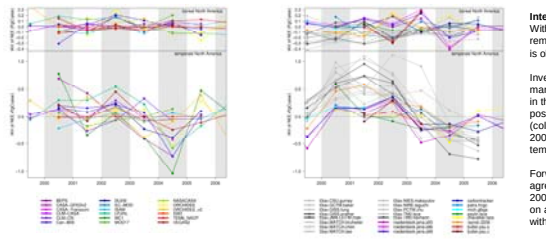


Full monthly time series
Significant model-model differences, especially among forward models.

Shapes and depths of seasonal cycle vary considerably among models. Inversions tend to have sharper peak uptake.



Annual total time series
Models each estimate a different mean uptake (diamonds on the right margins of each figure). From a mechanistic perspective, NEE is the sum of two large, nearly-balanced fluxes. Their tight linkage drives many forward models to have small NEE.



Interannual Variability
With each model's mean NEE removed, the time series of IAV is obtained.

Inverse models suggest a marked decadal-scale variability in the temperate region. Many post-Transcom inversions (colored lines) manifest a clear 2002 drought signal in the temperate region.

Forward models show less agreement, but most have a 2002 drought anomaly imposed on a longer-term trend consistent with the inversions.

Summary of NEE statistics for Temperate North America

Forward models

	25th percentile	central value	75th percentile
Uptake	0.1	0.3	0.8
IAV peak-to-peak	0.3	0.6	0.8
IAV (sd)	0.1	0.2	0.3

Inverse models

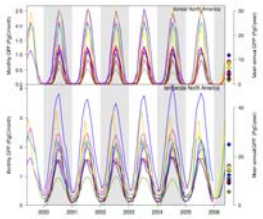
	25th percentile	central value	75th percentile
Uptake	0.6	1.1	1.4
IAV peak-to-peak	0.7	1,1	1,5
IAV (sd)	0.2	0.3	0.4

All units PgC/yr for Temperate North America. Positive uptake is negative NEE.

Forward model Gross Primary Production (GPP)

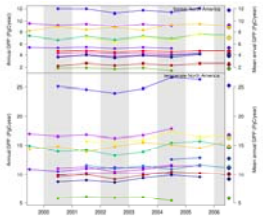
Full monthly time series
It is immediately evident from the monthly time series at right that there are significant discrepancies among forward models' estimates of photosynthetic uptake. The amplitudes of seasonal cycles, and consequently the long-term mean GPPs (shown as diamonds in the right-hand margin of this plot) vary by as much as a factor of 7.

Compared to the complexities of representing ecosystem respiration, the physiology of photosynthesis is relatively well understood. That models can disagree to this extent about GPP suggests that significant work remains to be done to pin down the magnitudes of gross fluxes.



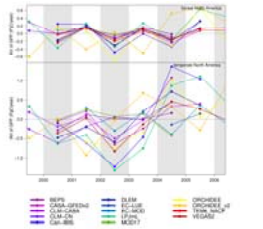
Annual time series
As expected, models with large amplitude seasonal cycles have large annual GPP. However, the curves at right show no signs that larger mean GPP yields larger interannual variability (IAV) of GPP. The parallel dips and rises are indicators that despite the diversity of model formulations, meteorological drivers, and in some cases remotely-sensed forcing fields, some agreement about variability does exist.

Note that despite the larger seasonal cycle in the southern, temperate region, across-model differences in estimates of the long-term mean GPP are comparable between the two regions.

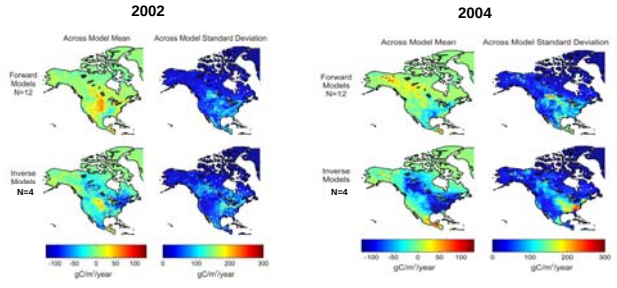


Interannual variability
A great deal of coherence emerges once the model-specific mean GPP is removed. Agreement in the boreal zone is particularly striking. Both temperate and boreal regions exhibit significant dips in GPP during the 2002 drought.

The temperate zone shows a trend toward increasing gross uptake in the latter half of the time series, consistent with interannual variability of NEE diagnosed from atmospheric inversions (see box at left, lower figures).



Spatial analysis



While 2002 was a drought year in North America, 2004 was a highly productive year. Analysis of across-model mean and across-model variability shows interesting differences between inverse and forward estimates of NEE. Inversions localized the 2002 drought to a smaller area than forward models. Inversions manifest very strong uptake in the U.S. southeast during 2004, although significant inter-inversion variability indicates that agreement is weak. Forward models identify a region in central Canada for which there is high uncertainty, both in 2002 and in 2004.

Conclusions and Next Steps

The NACP regional interim synthesis gathered "off-the-shelf" model results in order to make a quick assessment of the state of agreement among carbon models, and between models and observations. A significant effort has been made to assemble observational constraints against which regional-scale models can be evaluated, but this analysis is ongoing and results are not yet available. Current results suggest that while forward and inverse models show significant differences in mean uptake, encouraging signs of agreement in the magnitude and timing of interannual variability are emerging.

Future work will focus on indentifying mechanisms of interannual variability in forward models and in comparing model results to observational constraints. A formal model intercomparison project, the Multi-scale Terrestrial Model Intercomparison Project (MsTMIP) has also been proposed. This effort will formalize the ability to "grade" model results against available observational constraints, and provide uniform driver datasets for modeling teams.

Acknowledgments

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