Towards Well-Constrained Continental Flux Estimates: Progress in the North American Carbon Program


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Outline

- Background
- Methods
- Results to date
- Conclusions
Background: The North American Carbon Program (NACP)
NACP Questions

1. What is the carbon balance of North America and adjacent oceans? What are the geographic patterns of fluxes of CO$_2$, CH$_4$, and CO? How is the balance changing over time? ("Diagnosis")

2. What processes control the sources and sinks of CO$_2$, CH$_4$, and CO, and how do the controls change with time? ("Attribution")

3. Are there potential surprises (could sources increase or sinks disappear)? ("Prediction")

4. How can we enhance and manage long-lived carbon sinks ("sequestration"), and provide resources to support decision makers? ("Decision support")

Denning et al, 2005
US Carbon Cycle Science Plan Goals, 1999

1. Quantify and understand the Northern Hemisphere terrestrial carbon sink. ORIGIN OF THE NACP

2. Quantify and understand the uptake of anthropogenic CO₂ in the ocean.

3. Determine the impacts of past and current land use on the carbon budget.

4. Provide greatly improved projections of future atmospheric concentrations of CO₂.

5. Develop the scientific basis for societal decisions about management of CO₂ and the carbon cycle.

Sarmiento and Wofsy, 1999
Motivation

1. Curiosity
2. Climate and carbon management
   - Reduce the uncertainty in current and future carbon fluxes to inform policy.
3. Regulatory support
   - Provide an operational analysis system that can quantify regional carbon emissions.
   - Provide tools for evaluating potential carbon management strategies (potential storage, stability of storage).
   - Provide tools for verifying sequestration of carbon.
Pre-NACP results

- Coarse temporal (multi-year) and spatial (continental) resolution.
- Consistency in N. American net CO$_2$ flux among methods (order 0.5 PgC yr$^{-1}$) at these resolutions.
- “Large” uncertainty in the N. American CO$_2$ balance (few tenths of a PgC yr$^{-1}$) at these resolutions.


Can we reduce this uncertainty, and move to finer spatial (ecoregions, political units) and temporal resolution (individual years, maybe months)?
Methods
Interim syntheses underway

• Regional/continental comparison
  – Atmospheric inversions, biogeochemical or “forwards” models, biomass inventories.
  – Part or all of N. America.

• Site-based model-data comparison
  – Flux towers, biogeochemical models.
  – Flux tower sites.

• Midcontinent intensive regional synthesis
  – Atmospheric inversions, biogeochemical models, biomass inventories.
  – “Greater Iowa” region.

• Non-CO$_2$ greenhouse gas synthesis
• Coastal ocean carbon cycle synthesis
Methods

Biomass inventory

Atmospheric inversion

Regional interim synthesis

Midcontinent regional intensive study

Ecosystem model

Time Scale

- year
- month
- day
- hour

Spatial Scale

- (1 m)^2 = 10^-4 ha
- (1 km)^2 = 10^2 ha
- (10 km)^2 = 10^4 ha
- (100 km)^2 = 10^6 ha
- (1000 km)^2 = 10^8 ha

(Davis, 2008)
Why “interim” syntheses?

• NACP investigators (and many international colleagues - thank you!) have generated many parallel estimates of the N. American CO2 balance.

• We (the NACP research community) wished to:
  – create a benchmark for the future, and to
  – exercise our ability to synthesize results from multiple models and methods.

• The results to date imply that we aren’t “finished.” (half-empty?)
Atmospheric inversion example - NOAA’s Carbon Tracker

Annual NEE (gC m^{-2} yr^{-1}) for 2000-2005 (left).
Summer NEE for 2002, 2004 (above).
Peters et al, 2007, PNAS
Biogeochemical or “forwards” model example: Potter et al., 2007: CASA

Figure 8. Annual NEP.
Flux tower upscaling example

XIAO ET AL, 2008, AGR. AND FOREST MET.
Overall goals of the NACP interim syntheses

• Evaluate current ability to 
  diagnose carbon fluxes at site and continental scales using multiple methods.

• Provide a benchmark for future progress.

(Temporal focus: 2000-2005)
Results to date

• Regional synthesis
  – Aggregated continental-scale fluxes (Jacobson)
  – Spatial patterns (Huntzinger)
  – Inventory comparison (Hayes)

• Site synthesis
  – Interannual, seasonal and diurnal cycles (Ricciuto, Schaeffer, Thornton, Raczka)
  – Link to regional synthesis (Raczka)

• Midcontinent intensive
  – Promise of well-constrained inversions (Miles, Butler)
Regional interim synthesis results

See also:
Jacobson, T2-045
Huntzinger, T2-077
Fall 2009 AGU session, interim syntheses
Model runs are “out of the box.” Driver data (e.g. meteorology) will differ across models.

Annual NEE is not necessarily comparable across models as models differ in processes simulated (e.g. SiB3 annual NEE is set to zero).

Large variability exists across models in both monthly and annual NEE.

(Half empty? - variance.
Half full? - ‘out of the box’ + comparison)
Gray lines are TRANSCOM results. Colored lines are more recent inversions (also “out of the box”).

More coherence among inversions as compared to forwards models?

LOTS of models! (half full!)
"Forwards" models - annual NEE

Half ____ ?

- boreal North America
- temperate North America
Annual NEE is highly variable across inversions.

Evidence of covariance in boreal vs. temperate N. America?

0.5 PgC yr-1 uncertainty bound may be optimistic?

Evidence of coherence in the interannual variability.
“Forwards” models vs. Inverse models - interannual variability

Encouraging coherence across models, and across forwards vs. inverse models.  
Half-full! (3/4 full?)
Incredibly(?) large range of GPP estimates across forwards models. Factor of 4. (half empty?)
Impressive degree of coherence across models, especially in boreal N. America and for 2002 vs. 2004 in temperate N. America.

(half full!)

Similar to the coherence found in NEE for both forwards and inverse models.
Annual NEE - forwards and inverse models - 2002

Drought year


Smaller impact of drought in inverse estimates.
Annual NEE - forwards and inverse models - 2004

Productive year

Larger productivity in inverse estimates.

High uncertainty in central Canada in forwards models, in SE in inverse estimates.

Modest coherence across methods.
Which fluxes are correct?
What is our reference for ground-truthing? Calibration?
(half empty!)

Try as reference points:
- biomass inventories
- flux towers
The NACP Regional Interim Synthesis “Fast-Track Analysis”

- examining the ability of forward and inverse models to identify sources and sinks of C for the North American continent by comparing model estimates with inventory-based estimates of forest C stocks and crop yields
NACP Model – Inventory Comparison

Change in Total Forest Sector C Stocks from Inventory-based Estimates

Mean Model Estimates for Forest Sector Net C Exchange (NEE)

Avg. Annual Flux (TgC yr⁻¹), 2000 - 2006

* negative values represent a land-based C sink
NACP Model – Inventory Comparison

Forest Sector NEE, Canada

Agricultural Sector NEE, U.S.

Forwards models more similar in annual NEE to inventory estimates?
Site interim synthesis results
Flux Tower Sites

NACP Interim Site Synthesis
First Priority Sites

- Initial 10
- First Priority
Participating Models

• BEPS
• CNCLASS
• ISOLSM
• TECO
• ecosys
• SiBCASA
• SiB
• DLEM
• ED2
• LOTECE_DA

• DNDC
• SiBCrop
• can-ibis
• EDCM
• ORCHIDEE
• LPJ
• BIOME-BGC
• SSiB2
• TRIPLEX
• AgroIBIS

• Results from >20 models
• Order 10+ simulations per site
• Common driver data used for all models
• Many models participating in both regional and site syntheses
• Models are not formally optimized to fluxes save for LOTECE_DA
NEE seasonal mean diurnal cycle
(Howland forest example)
GPP seasonal mean diurnal cycle (Howland forest example)

Recall “forwards” model GPP results.

Model mean close to true GPP?
NEE multi-year mean seasonal cycle (Howland example)

Spread:  
Half - empty?  
Comparison:  
Half-full!
GPP multi-year mean seasonal cycle (Howland forest example)

Model mean close to truth?
Respiration multi-year mean seasonal cycle
(Howland Forest example)
Inter-annual variability in annual NEE Site and regional model runs.

Correlation coefficient:

Regional model “extracts” show little correlation with flux tower observations.

Site level model runs show weak correlation with tower observations.
Inter-annual variability in annual NEE Site and regional model runs.

**Magnitude of IAV:**

Regional model runs tend to underpredict IAV as compared to flux towers.

Site model runs show IAV that is similar in magnitude to the flux tower observations.

(just a product of spatial averaging in regional model “extracts?”)
Imminent improvements in atmospheric inversions due to increased data density?
CO$_2$ Concentration Network: 2000
CO₂ Concentration Network: 2004

Legend: Sampling Platform
- Green: Surface-layer tower
- Blue: Mixed-layer (tall) tower
- Red: Complex terrain
- Yellow: Aircraft Profile

Colors Denote Operator
- Blue: NOAA ESRL
- Green: Canadian Carbon Program
- Red: Other (PSU, ORST, Harvard, NCAR)
- Yellow: MCI Ring of Towers 2 (PSU)
CO₂ Concentration Network: 2005

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CO$_2$ Concentration Network: 2007
CO₂ Concentration Network: 2008

See Butler, T4-032 for impact on TRANSCOM-style inversion. See Friday morning session for a block of MCI talks.

Half-full: Greatly improved data density.

Half-empty: Partly due to a “coop” of short-term funding and multiple PIs. Not all a stable, centrally-supported network.
MCI region CO$_2$ seasonal cycle

- Large(!) amplitude seasonal cycle across stations
- Strong impact of the corn belt - similarity of signal across groups of sites suggests sampling density needed for well-constrained atmospheric inversions?

Miles, Richardson, Andrews
Conclusions

• Vigorous comparison of multiple models at multiple scales is underway.
• Encouraging coherence in interannual variability in continental annual NEE across models.
• Flux tower and biomass inventory data show promise for providing “ground truth.”
• Increased atmospheric CO2 data density over N. America likely to have a large impact on atmospheric inversions post 2005.

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