PENNSTATE

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

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13-19 September, 2009

NACP

United States Carbon Cycle Science Program
An Interagency Partnership

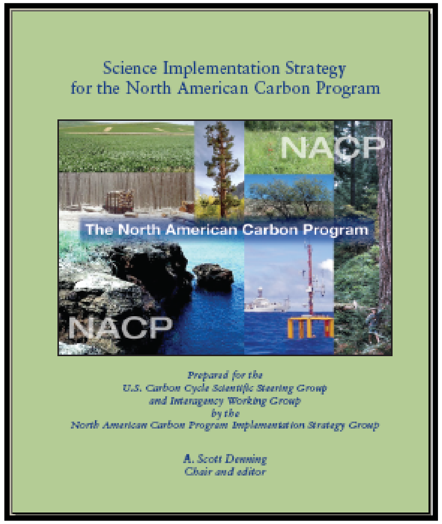
Outline

- 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***")



NACP Implementation Strategy, 2005

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 CO_2 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 CO_2.
5. Develop the scientific basis for societal decisions about management of CO_2 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.

Pacala et al (2001); Gurney et al (2002); SOCCR report (2007).

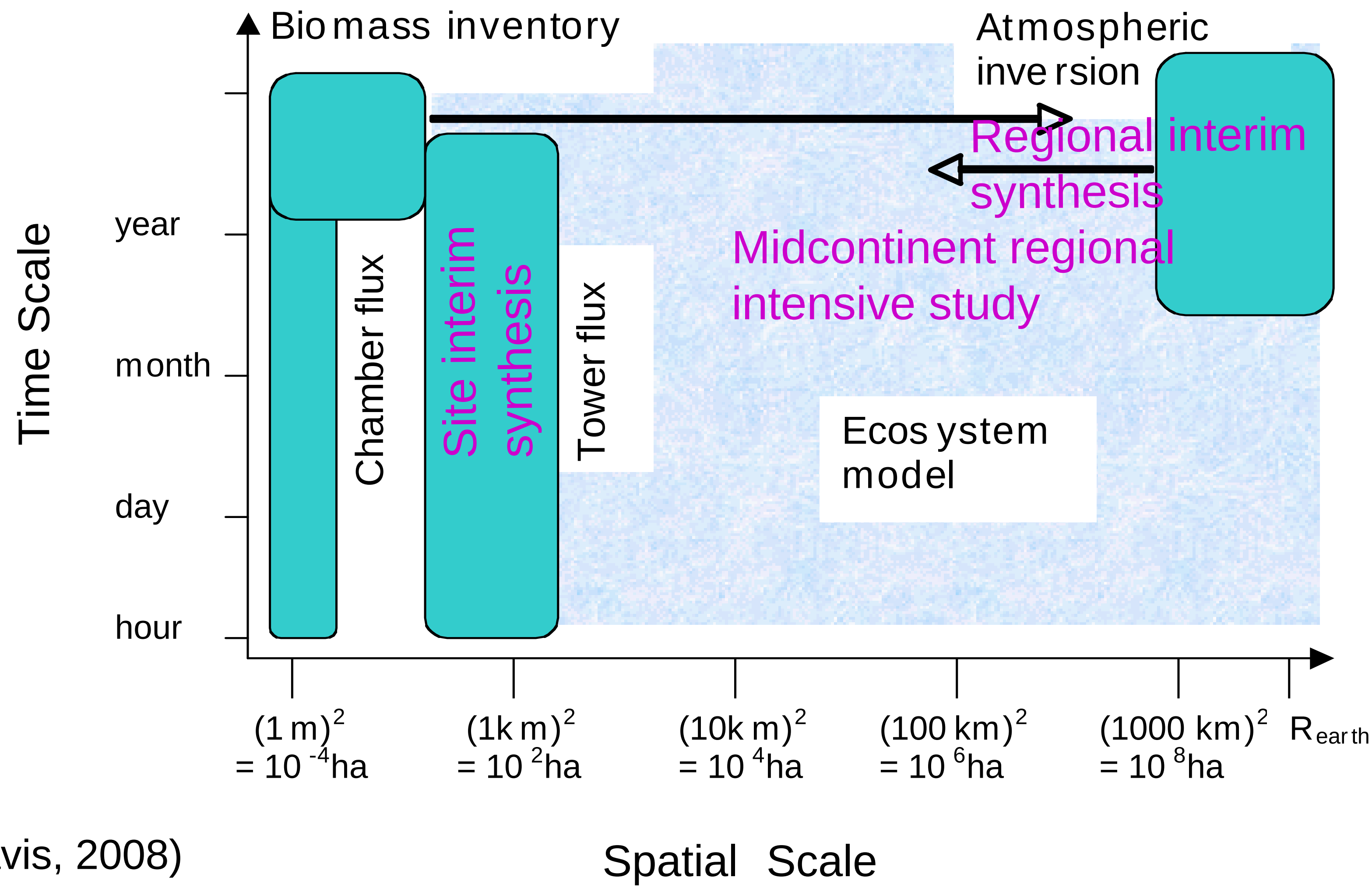
Can we reduce this uncertainty, and move to finer spatial (ecoregions, political units) and temporal resolution (individual years, maybe months)?

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

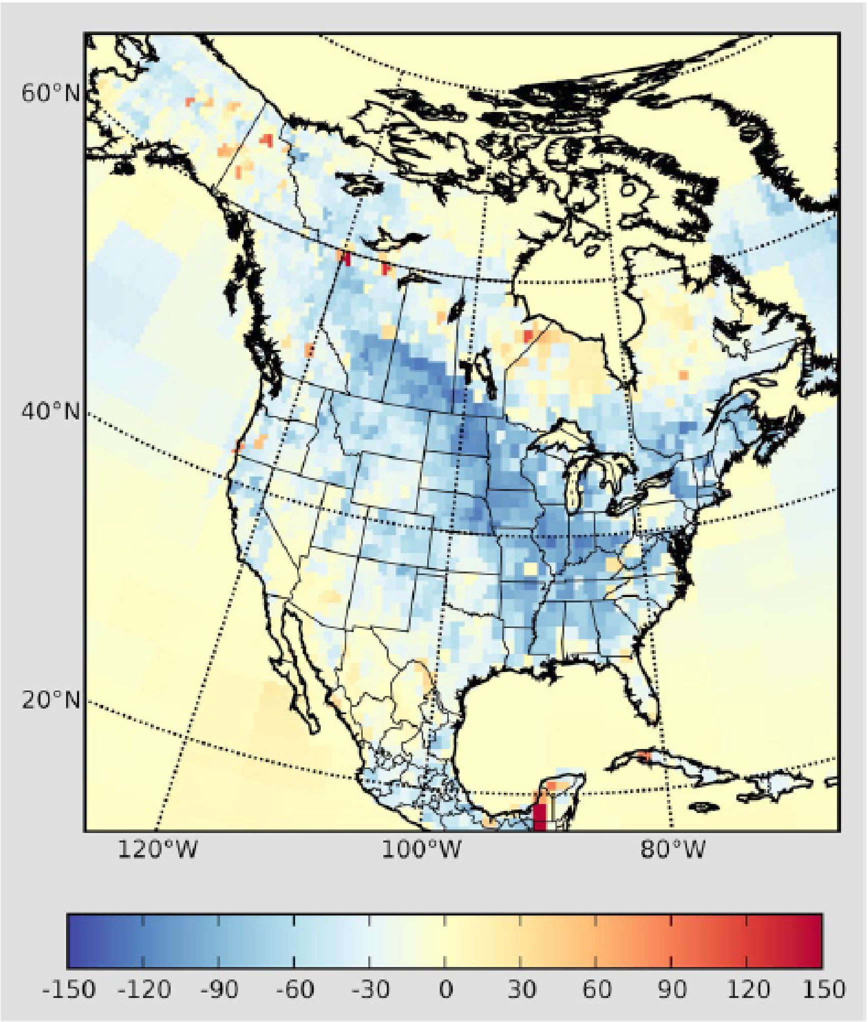


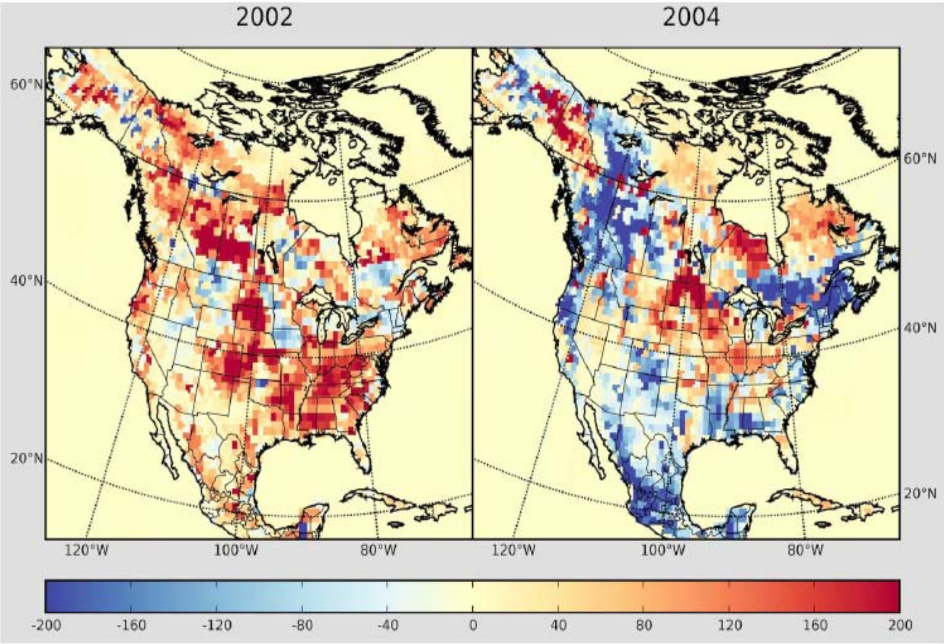
(Davis, 2008)

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

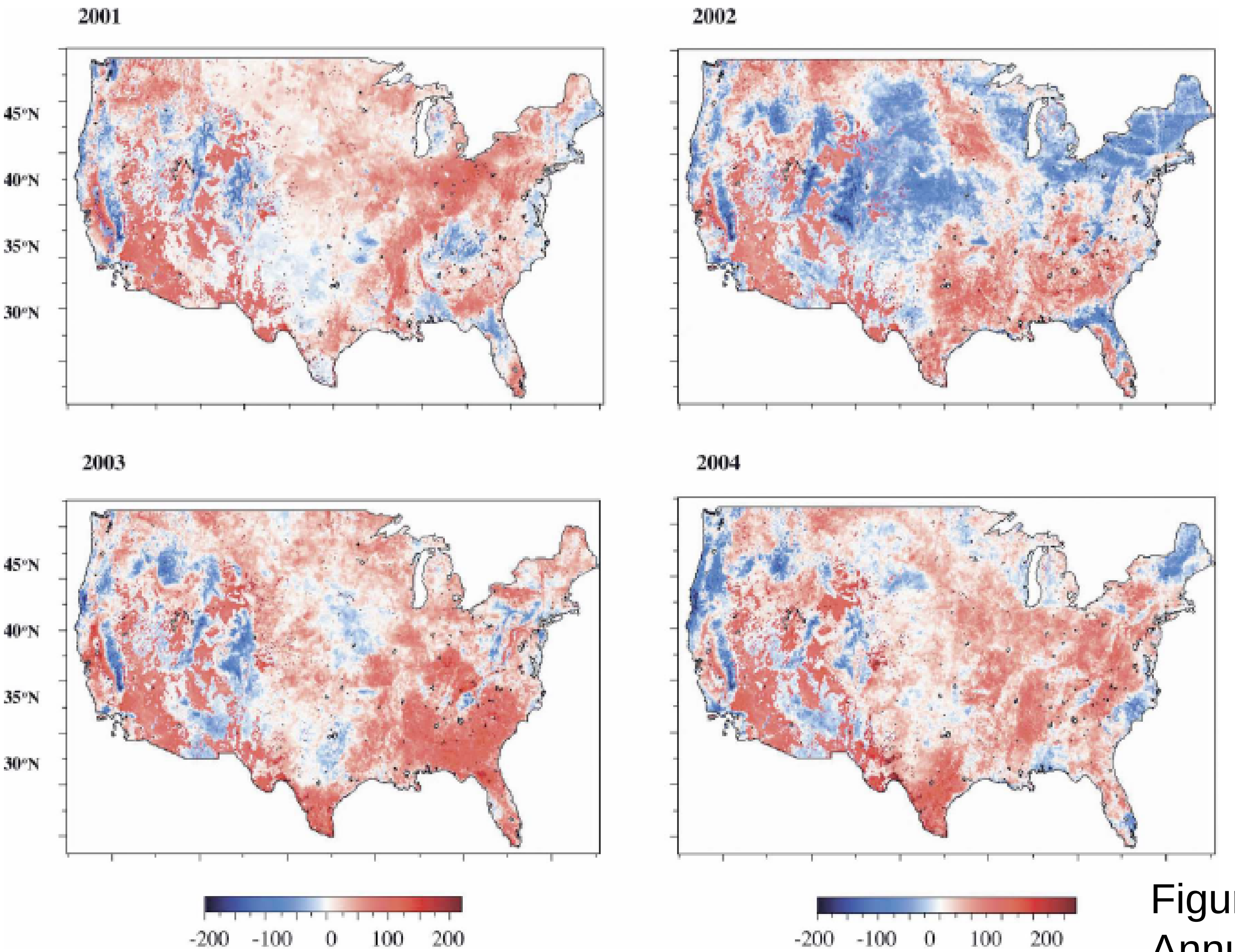
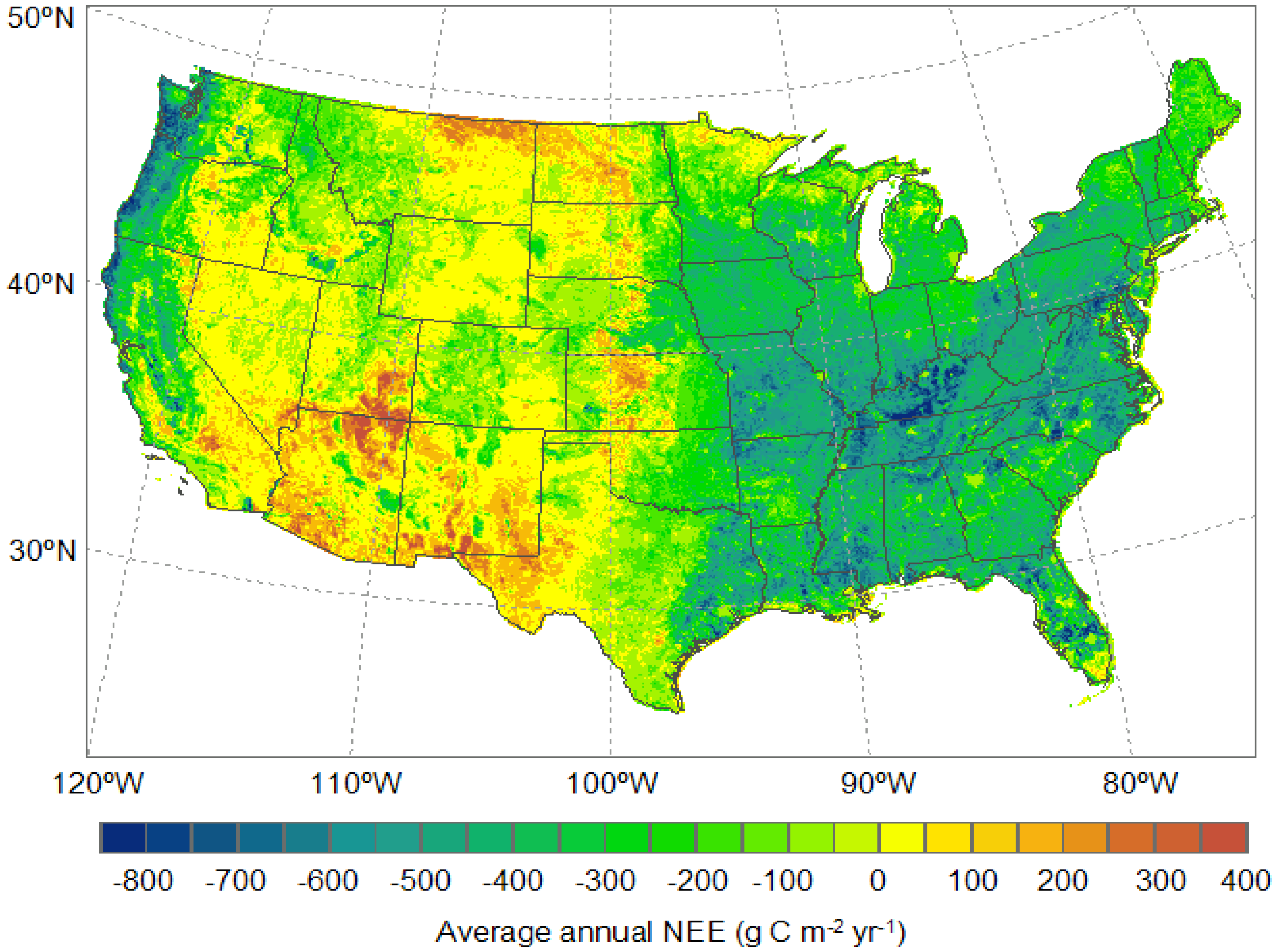


Figure 8. Annual NEP.

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)

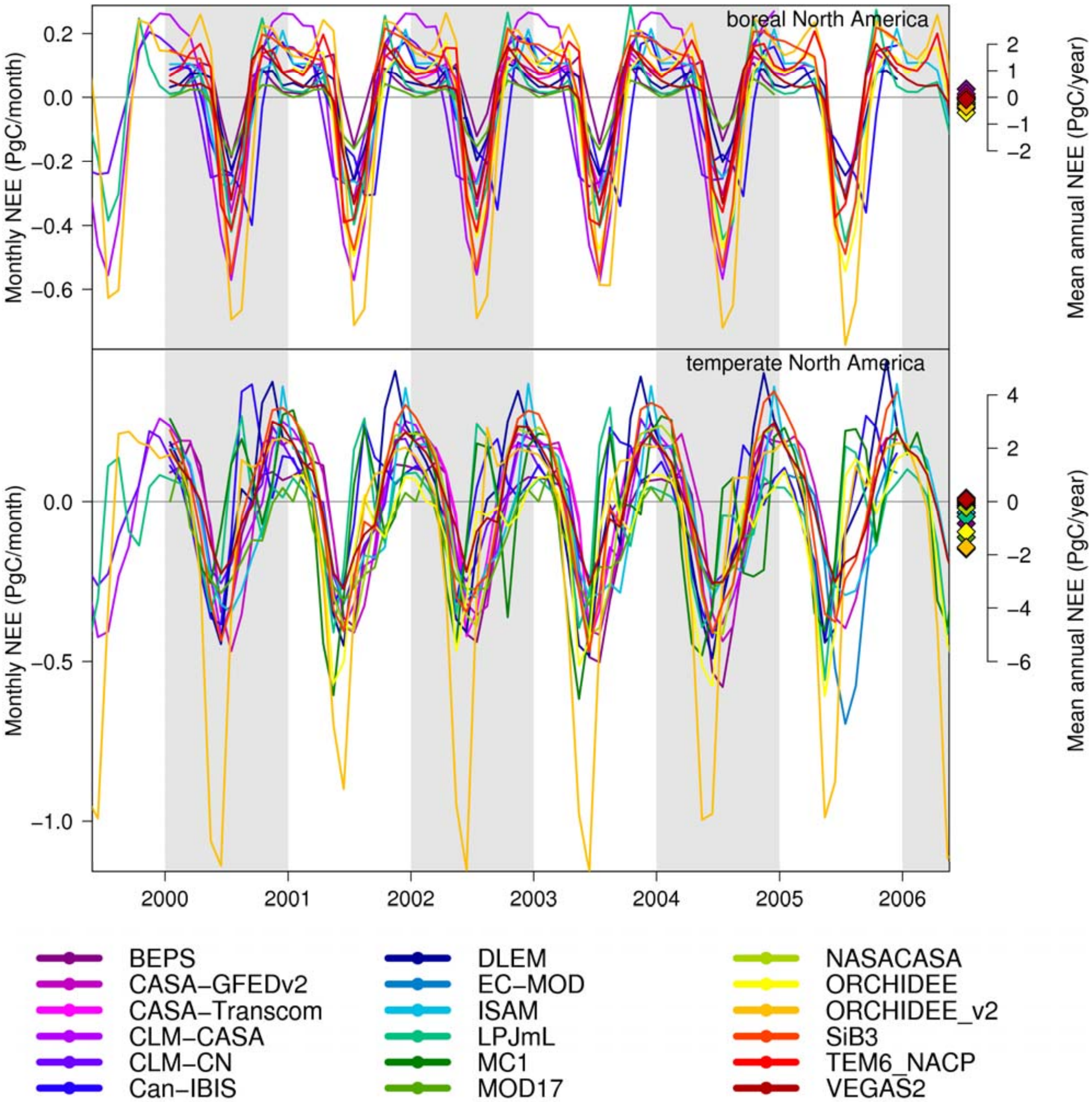
Results to date

- 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

"Forwards" models - monthly NEE



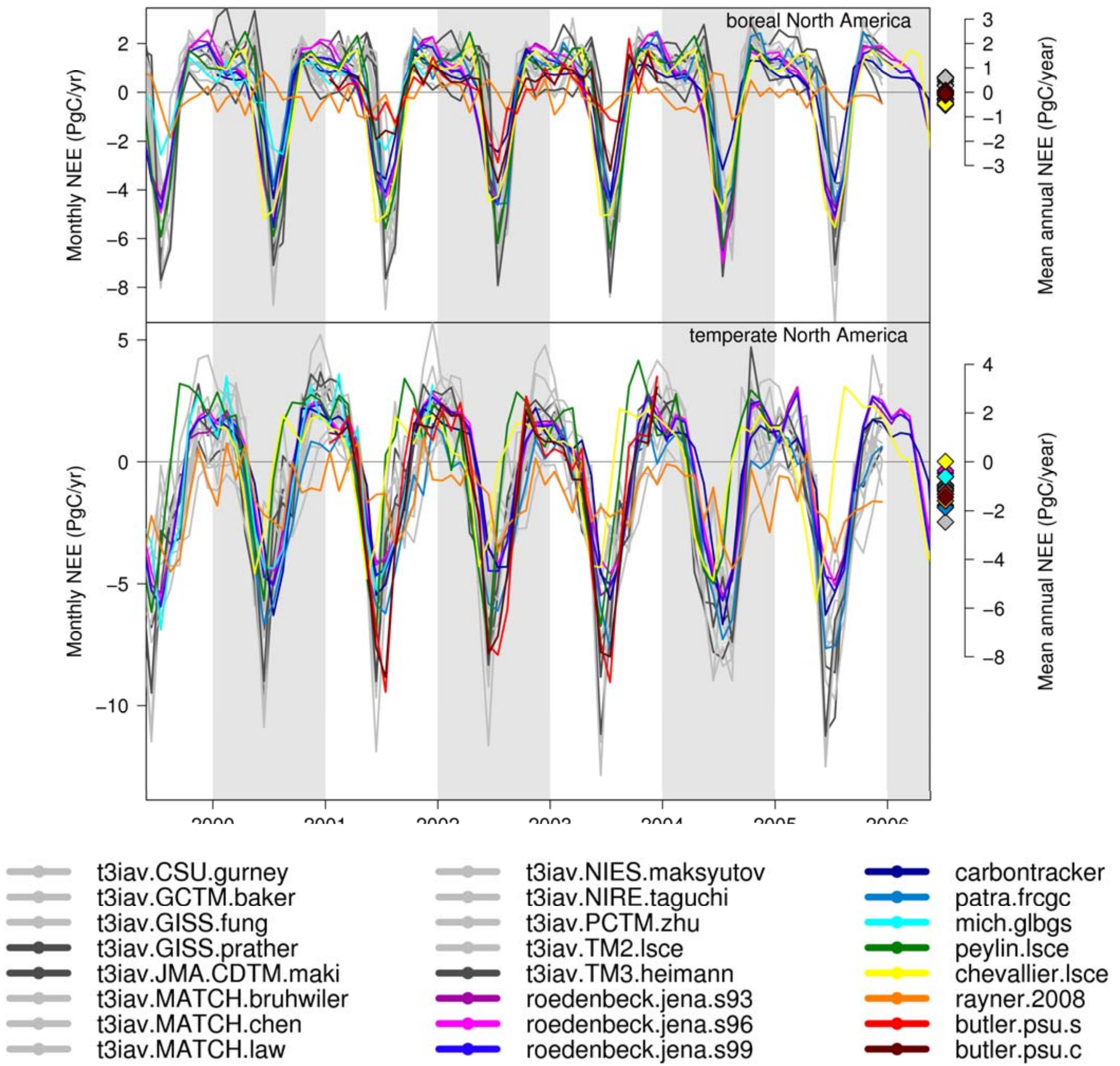
Model runs are "out of the box." Driver data (e.g. meteorology) will differ across models.

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)

“Inverse” models - monthly NEE



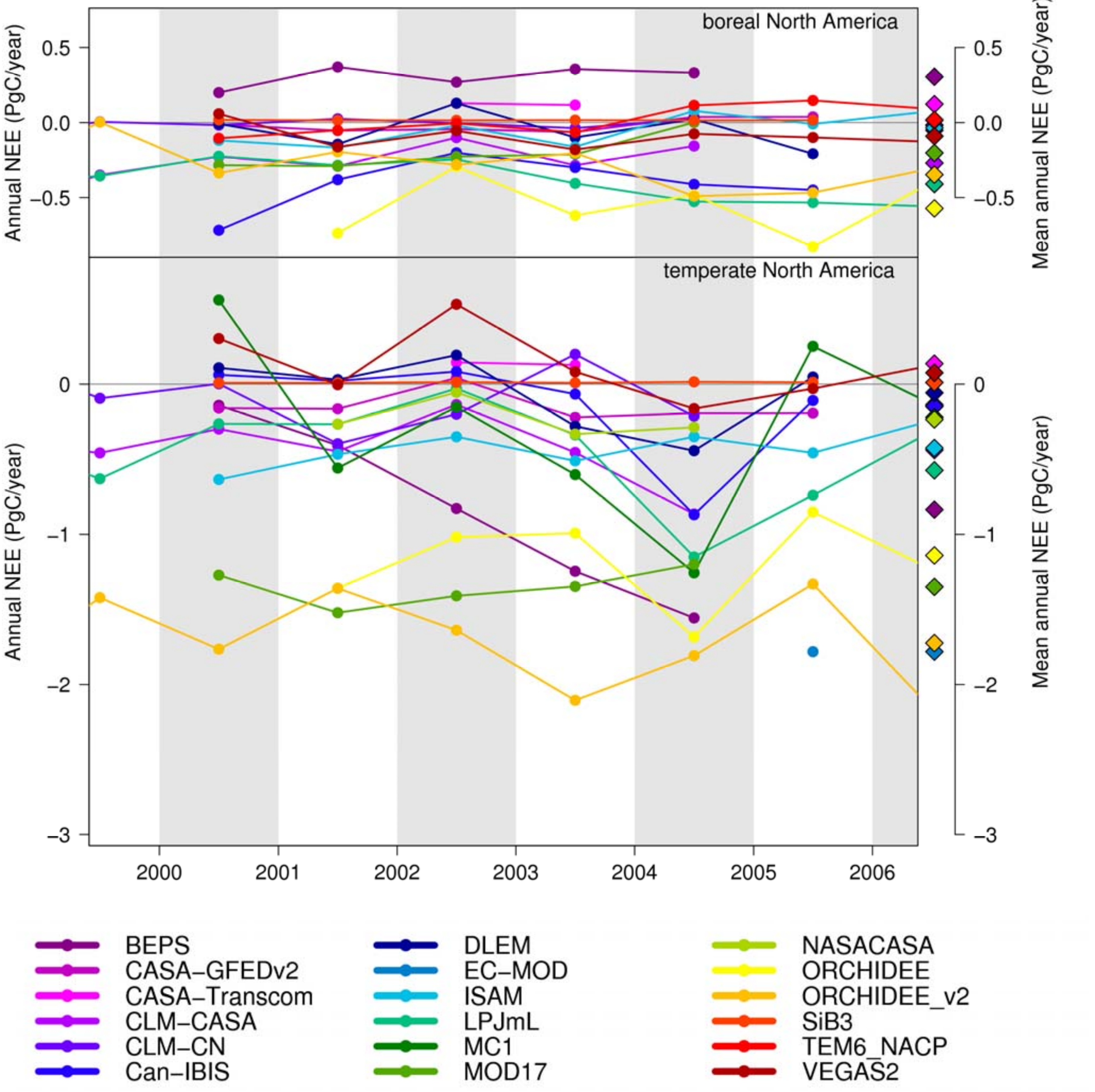
Gray lines are TRANSCOM results. Colored lines are more recent inversions (also “out of the box”).

More coherence among inversions as compared to forwards models?

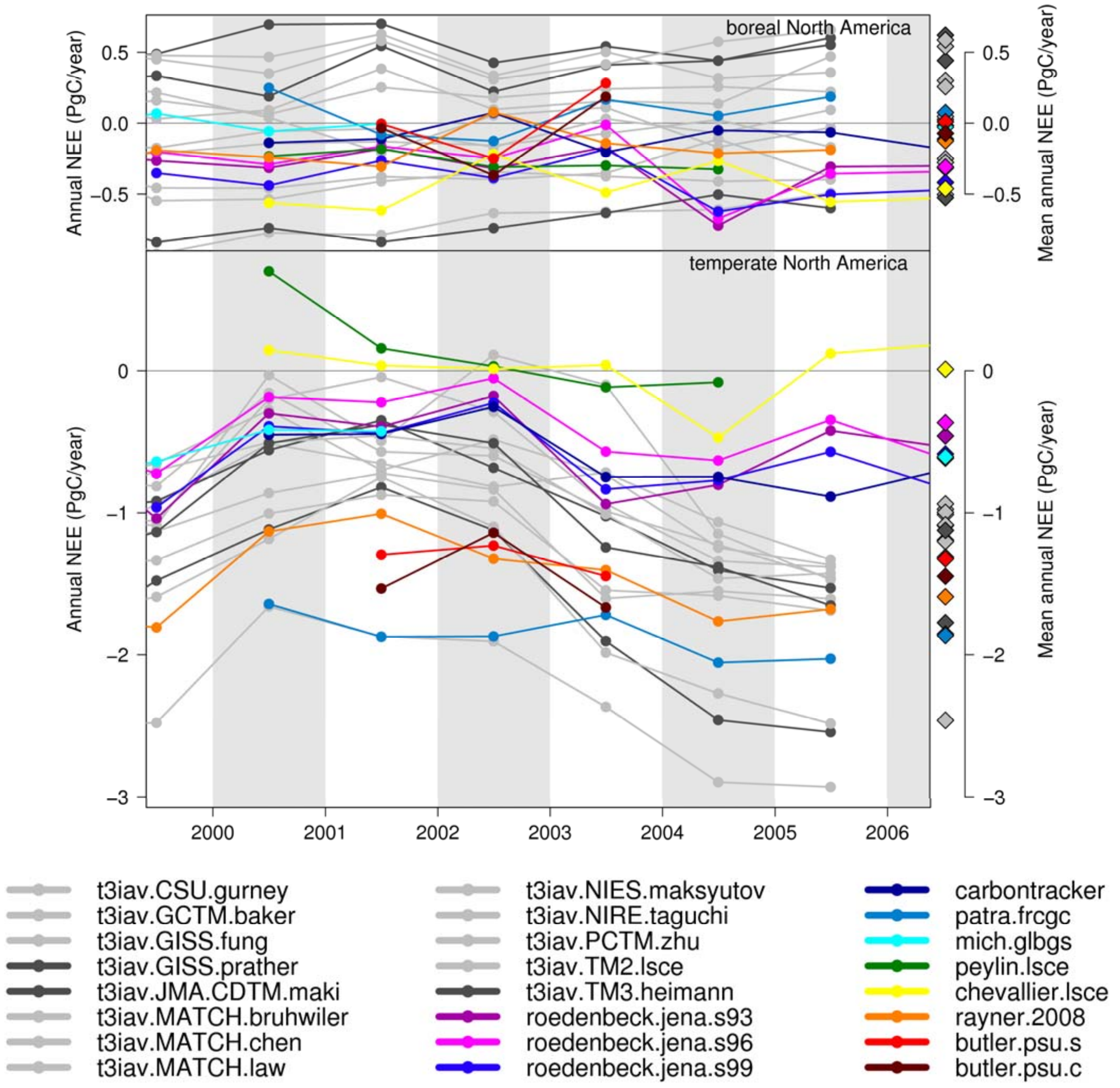
LOTS of models! (half full!)

“Forwards” models - annual NEE

Half ___ ?



“Inverse” models - annual NEE



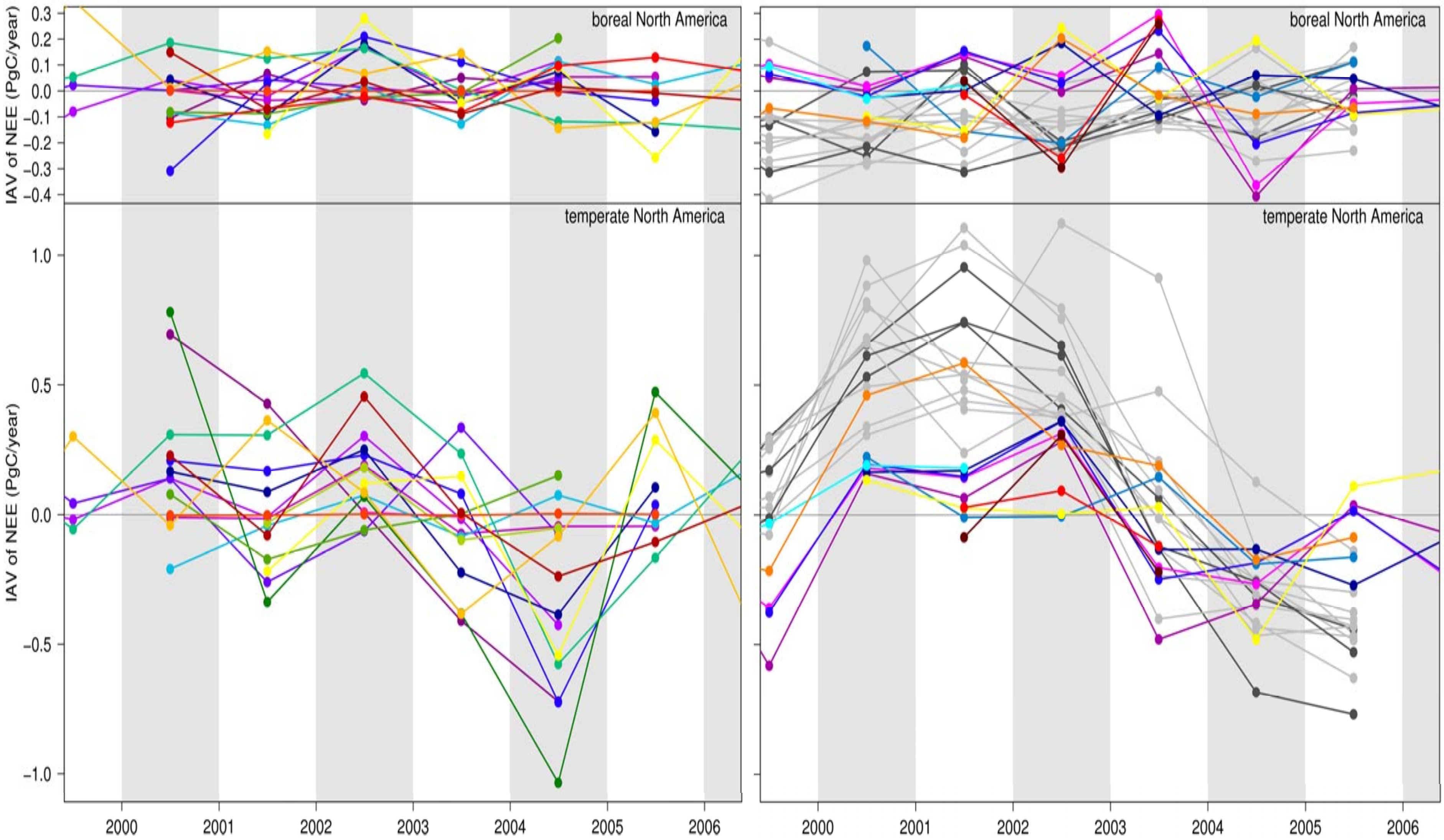
Annual NEE is highly variable across inversions.

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

0.5 PgC yr-1 uncertainty bound may be optimistic?

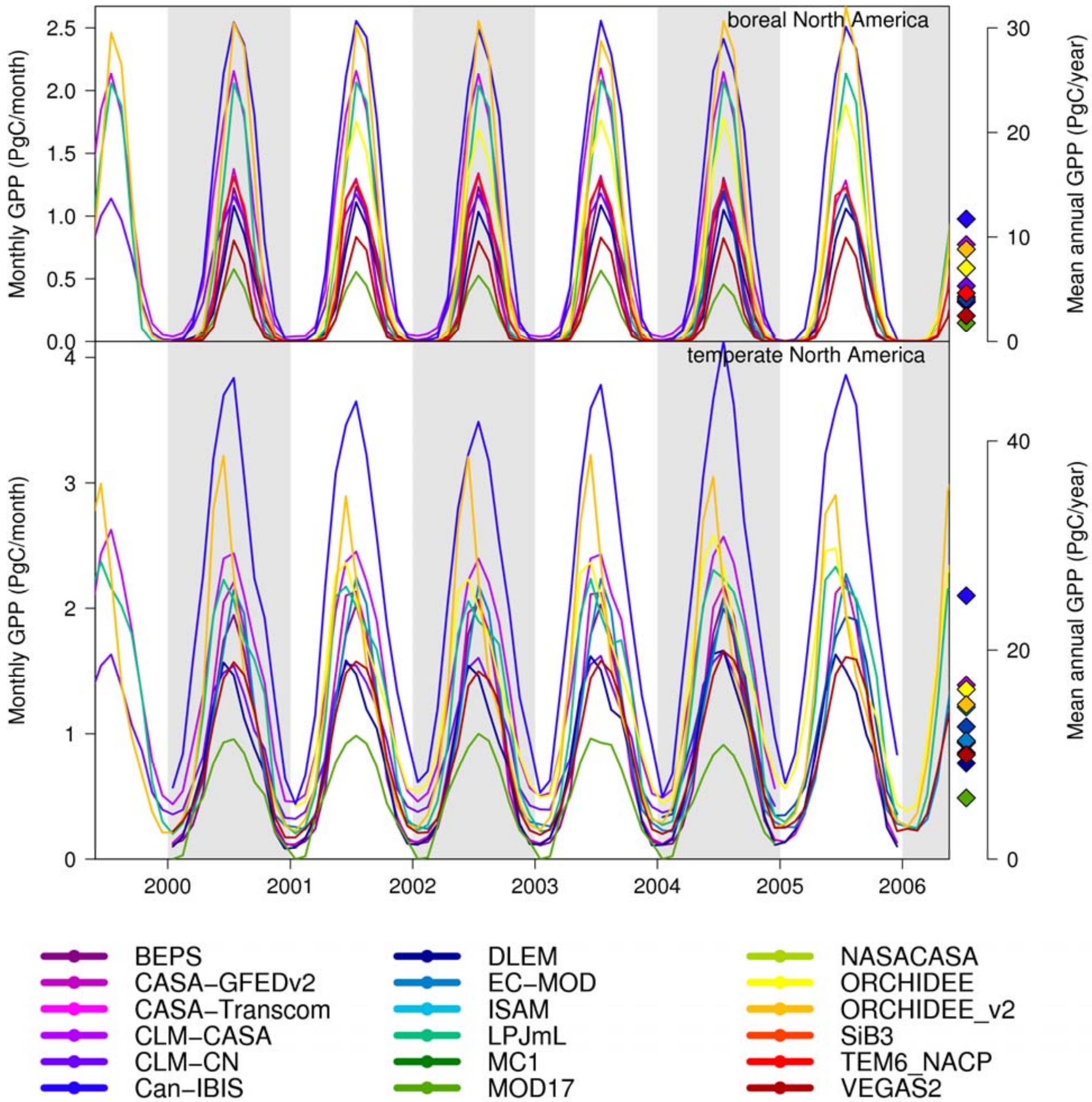
Evidence of coherence in the interannual variability.

“Forwards” models vs. Inverse models - interannual variability



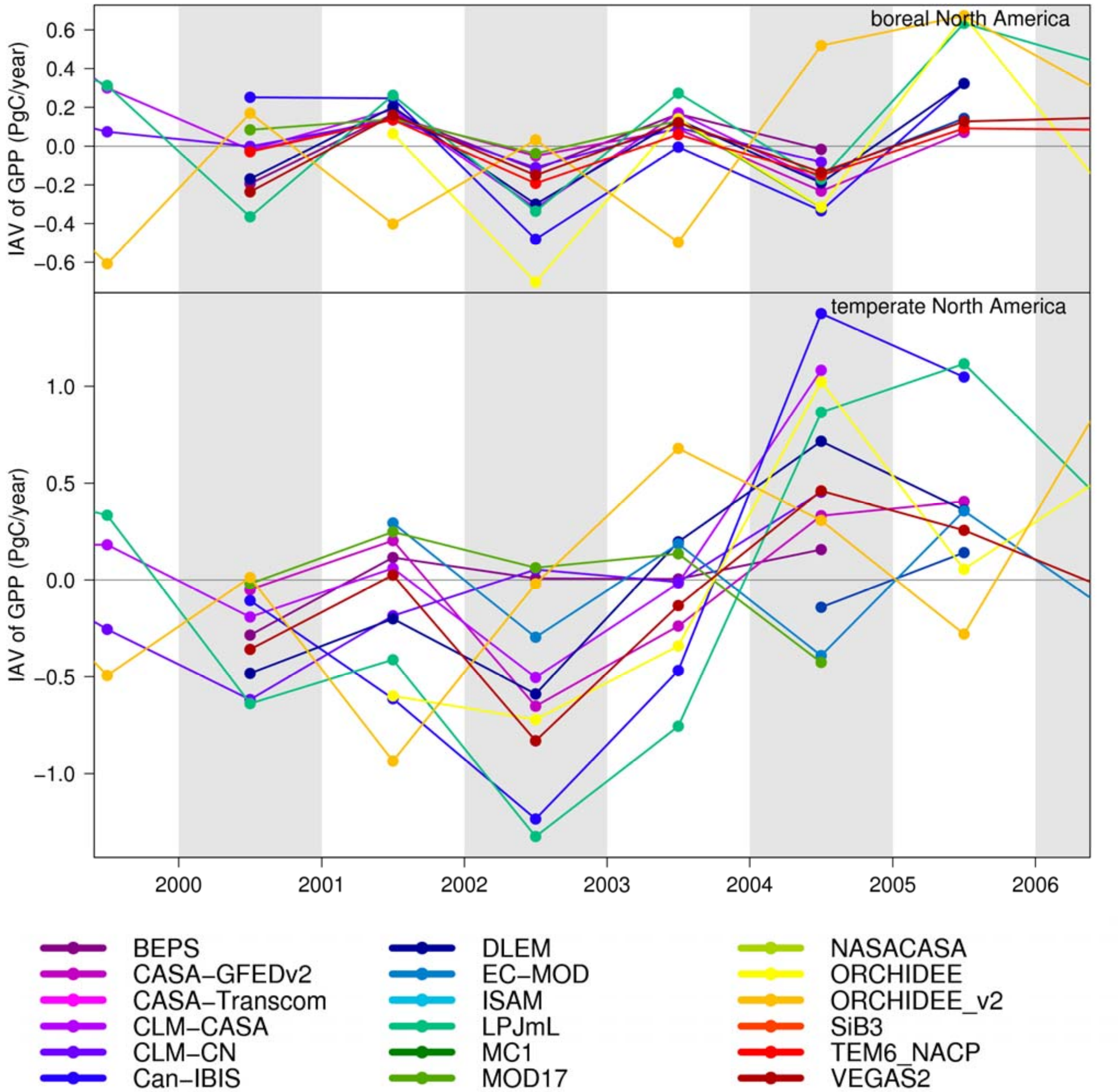
Encouraging coherence across models, and across forwards vs. inverse models. Half-full! (3/4 full?)

“Forwards” models - monthly GPP



Incredibly(?) large range of GPP estimates across forwards models.
Factor of 4.
(half empty?)

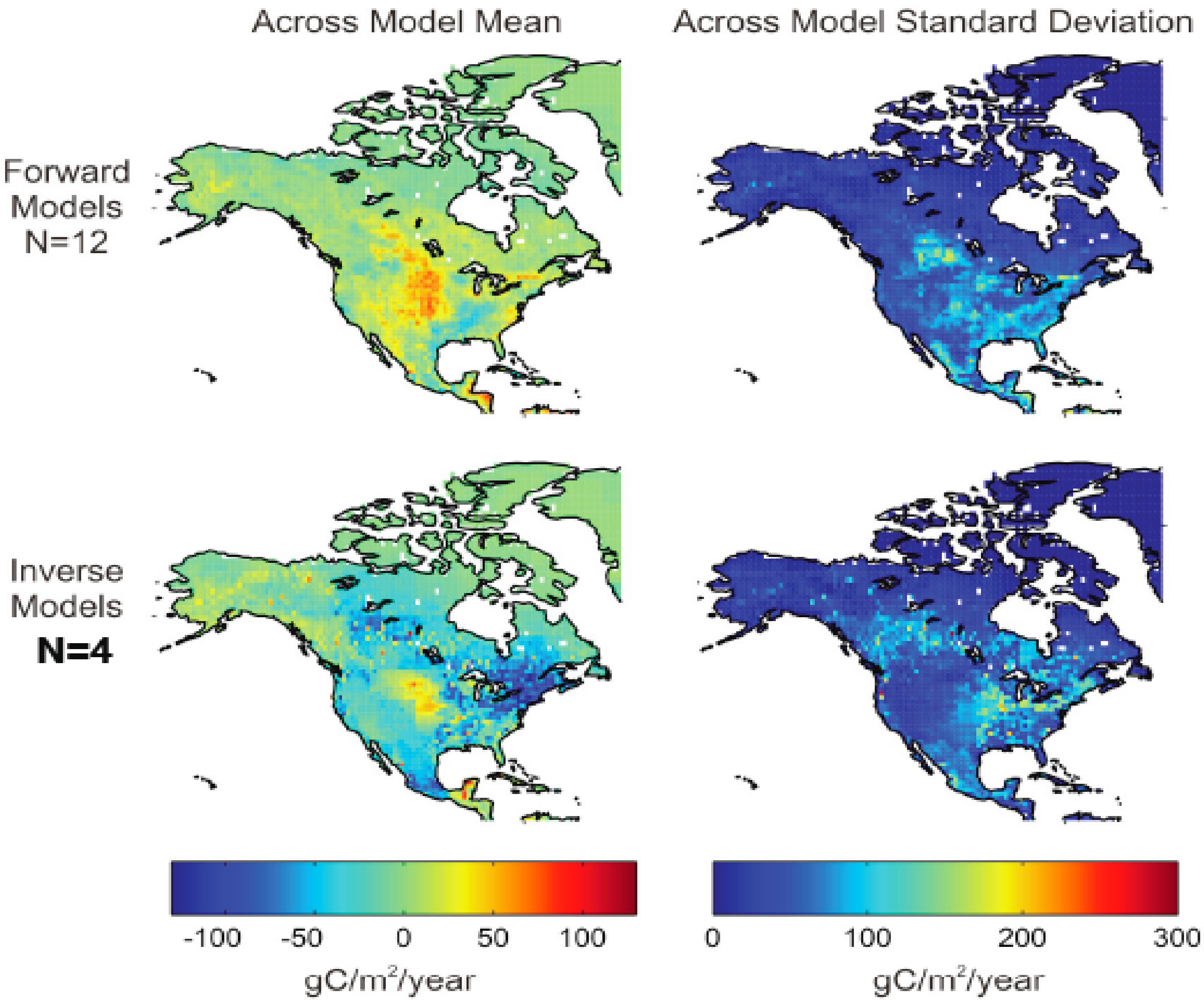
“Forwards” models - interannual variability in GPP



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

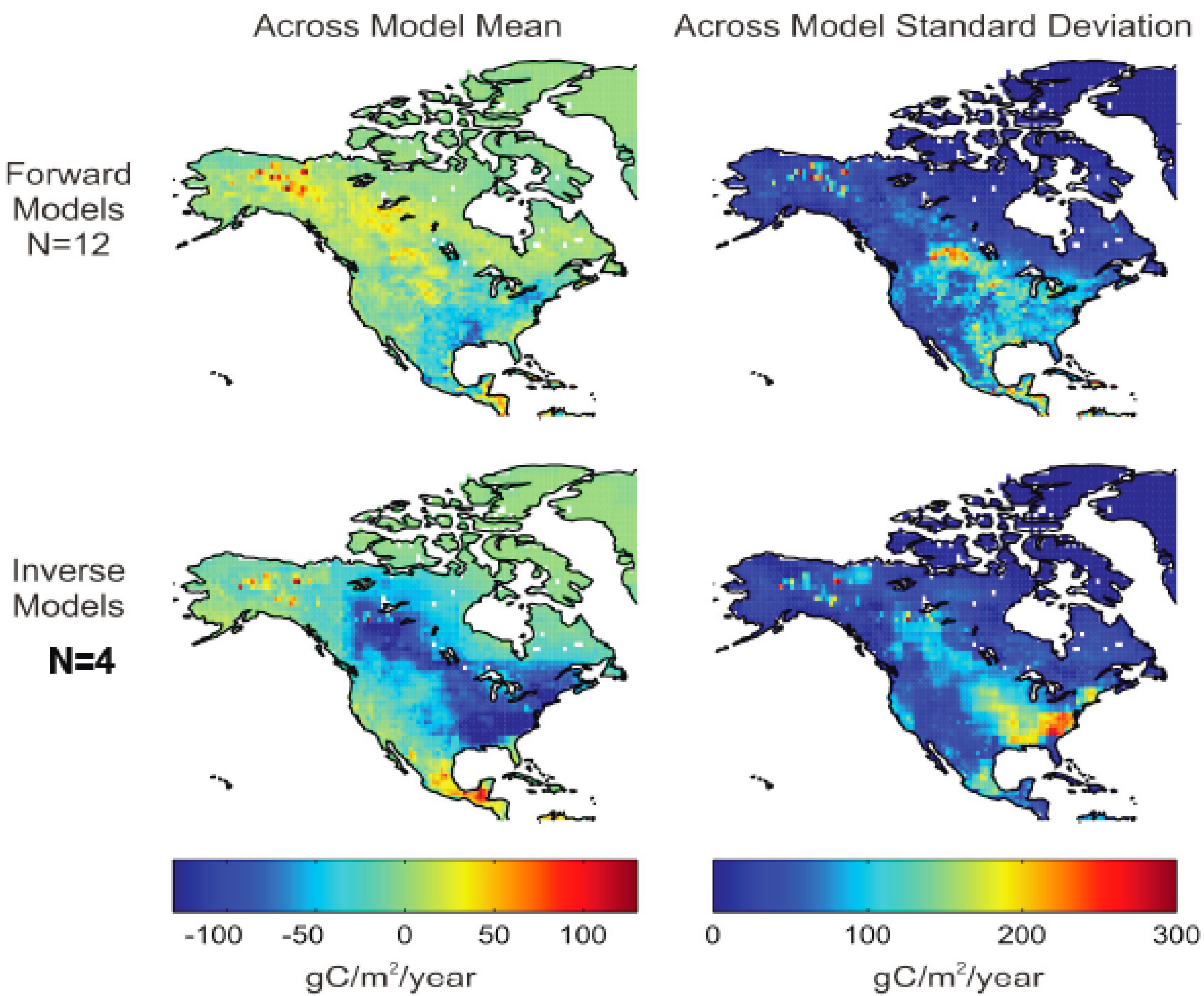


Drought year

Similarity across models and methods for central N. American drought response.

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:

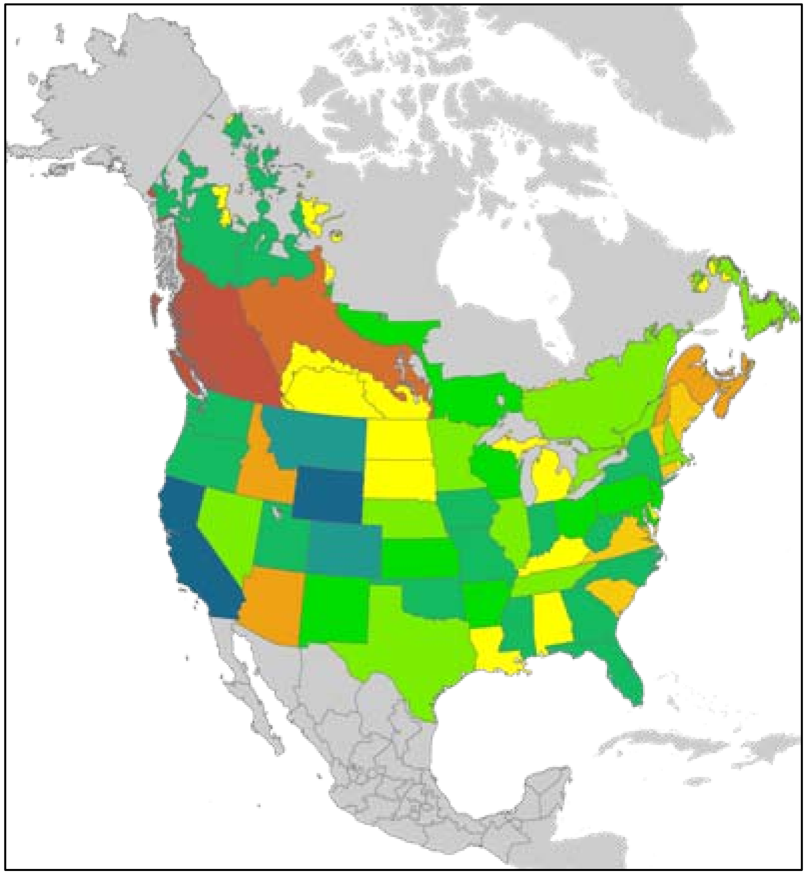
- biomass inventories
- flux towers

The NACP Regional Interim Synthesis "Fast-Track Analysis"

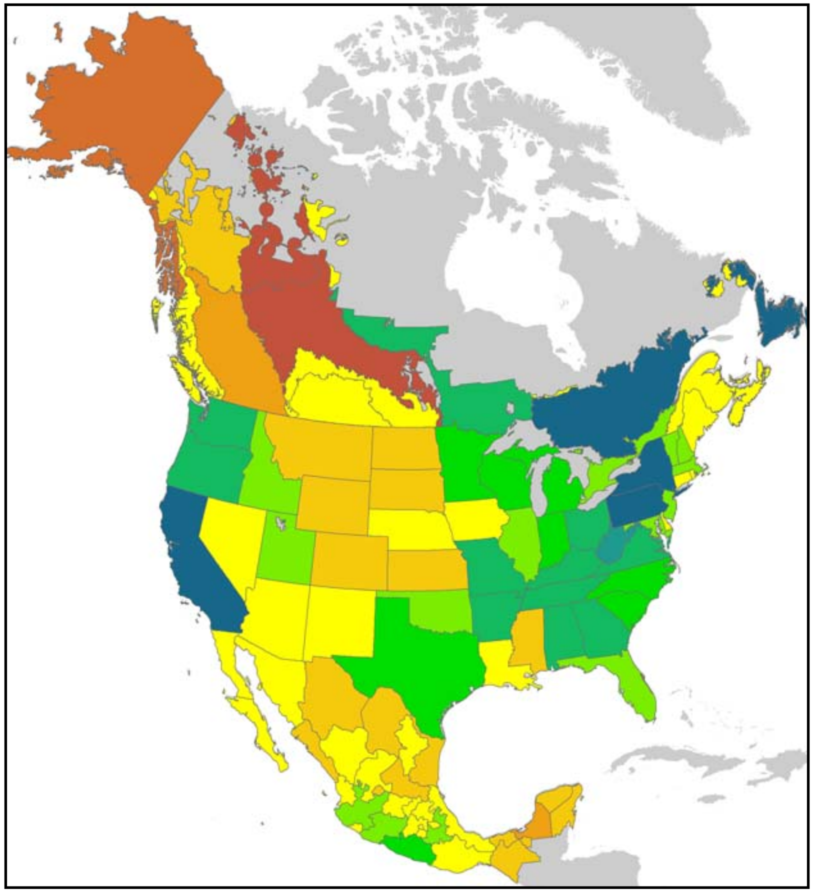
- examining the ability of forward and inverse models to identify sources and sinks of C for the North American continent by comparing model estimates with inventory-based estimates of forest C stocks and crop yields

NACP Model – Inventory Comparison

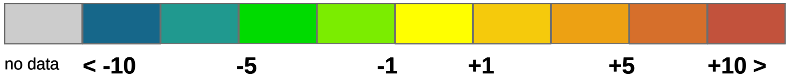
Change in Total Forest Sector C Stocks from Inventory-based Estimates



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



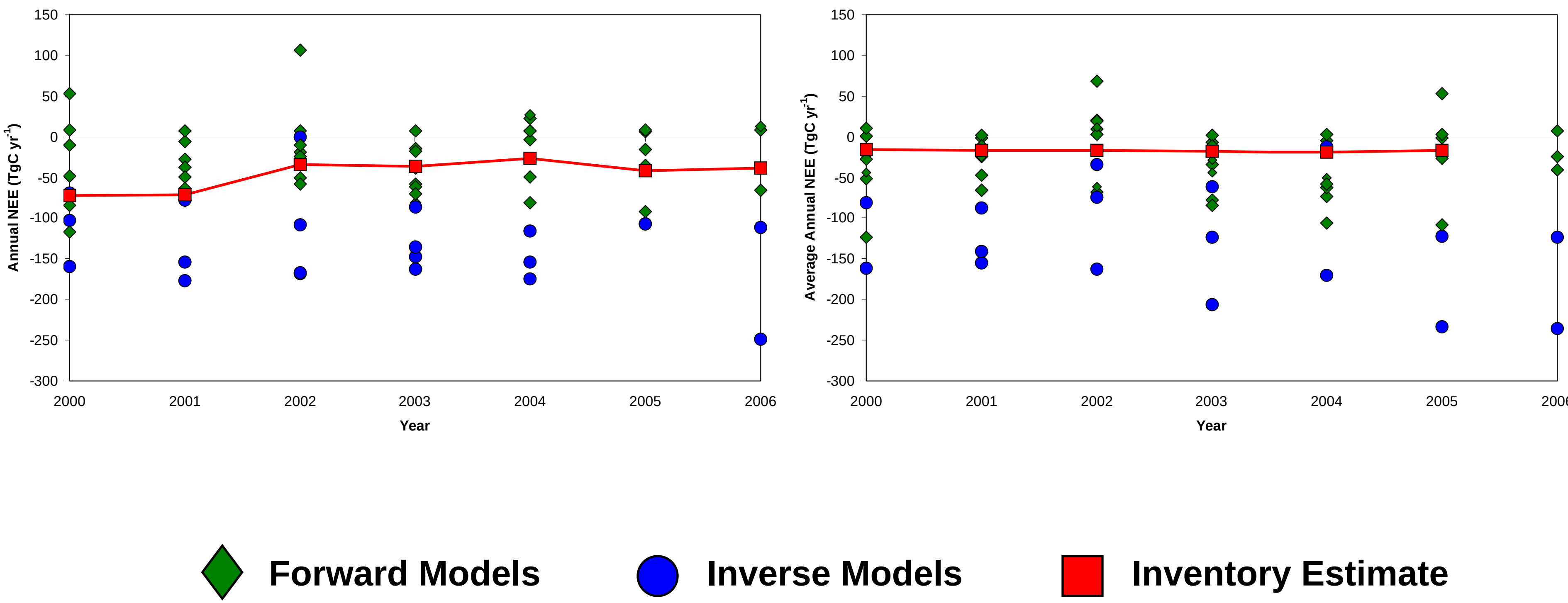
Avg. Annual Flux (TgC yr^{-1}), 2000 - 2006



*** negative values represent a land-based C sink**

NACP Model – Inventory Comparison

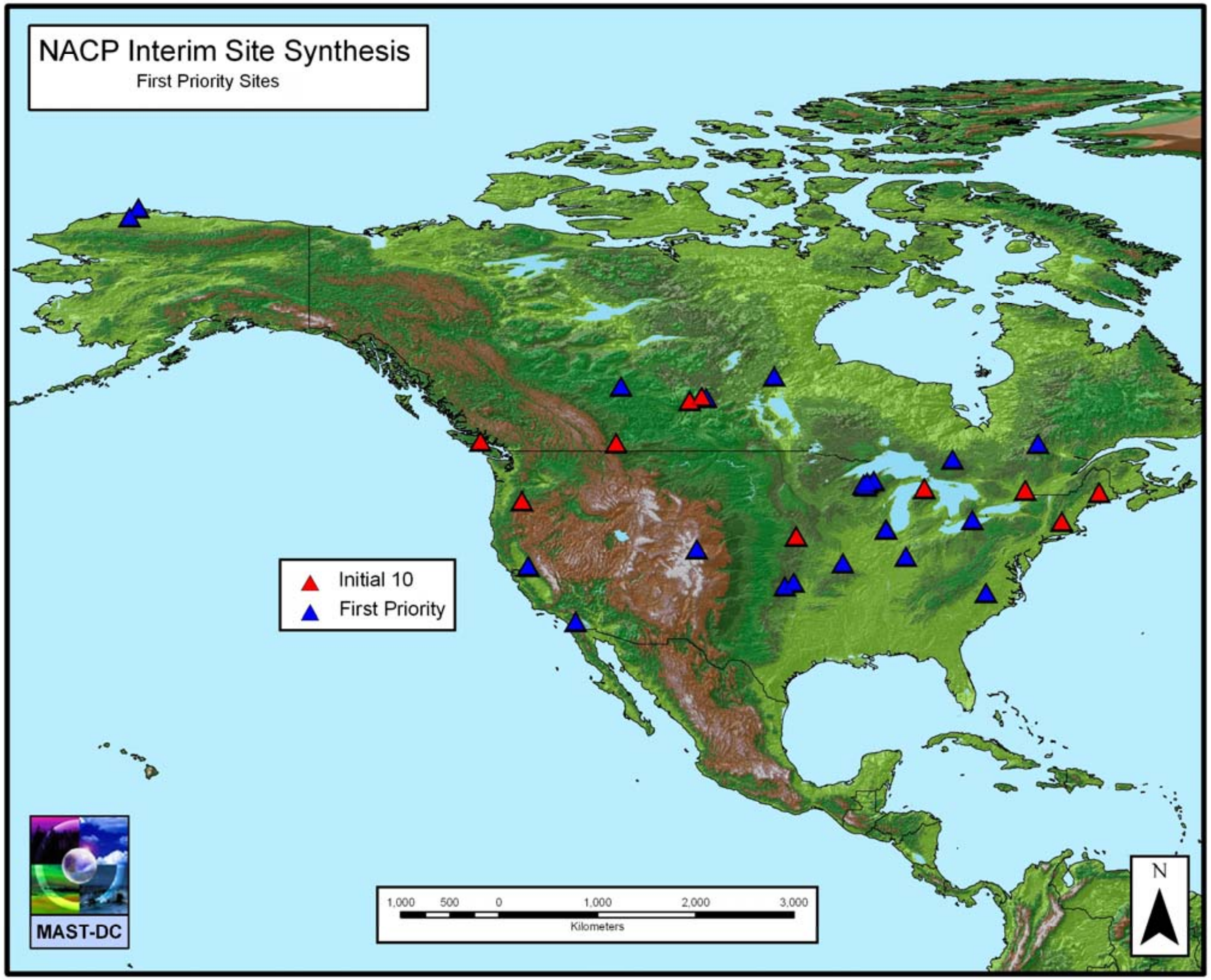
Forest Sector NEE, Canada | **Agricultural Sector NEE, U.S.**



Forwards models more similar in annual NEE to inventory estimates?

Site interim synthesis results

Flux Tower Sites



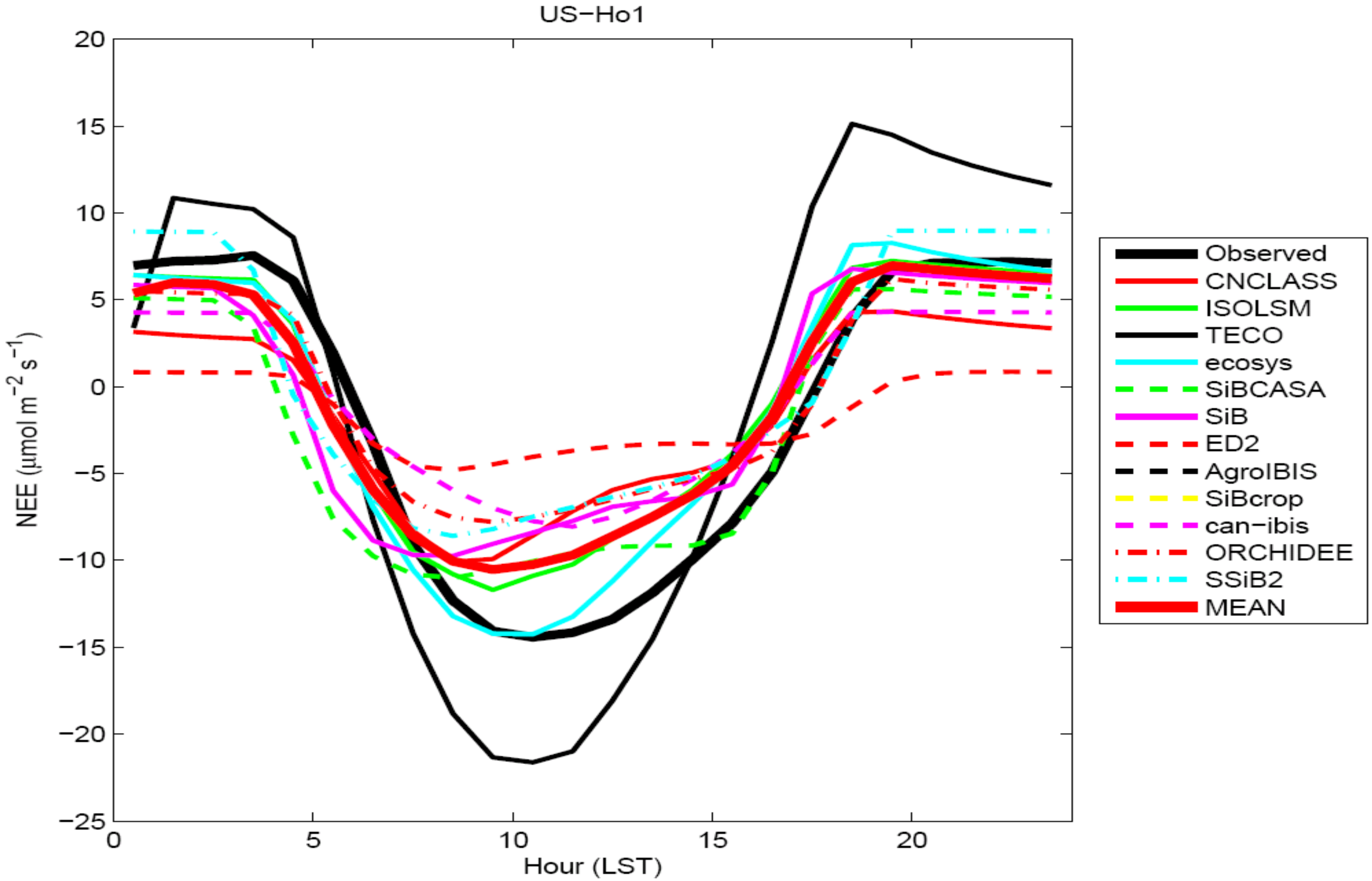
Participating Models

- BEPS
- CNCLASS
- ISOLSM
- TECO
- ecosys
- SiBCASA
- SiB
- DLEM
- ED2
- LOTEC_DA

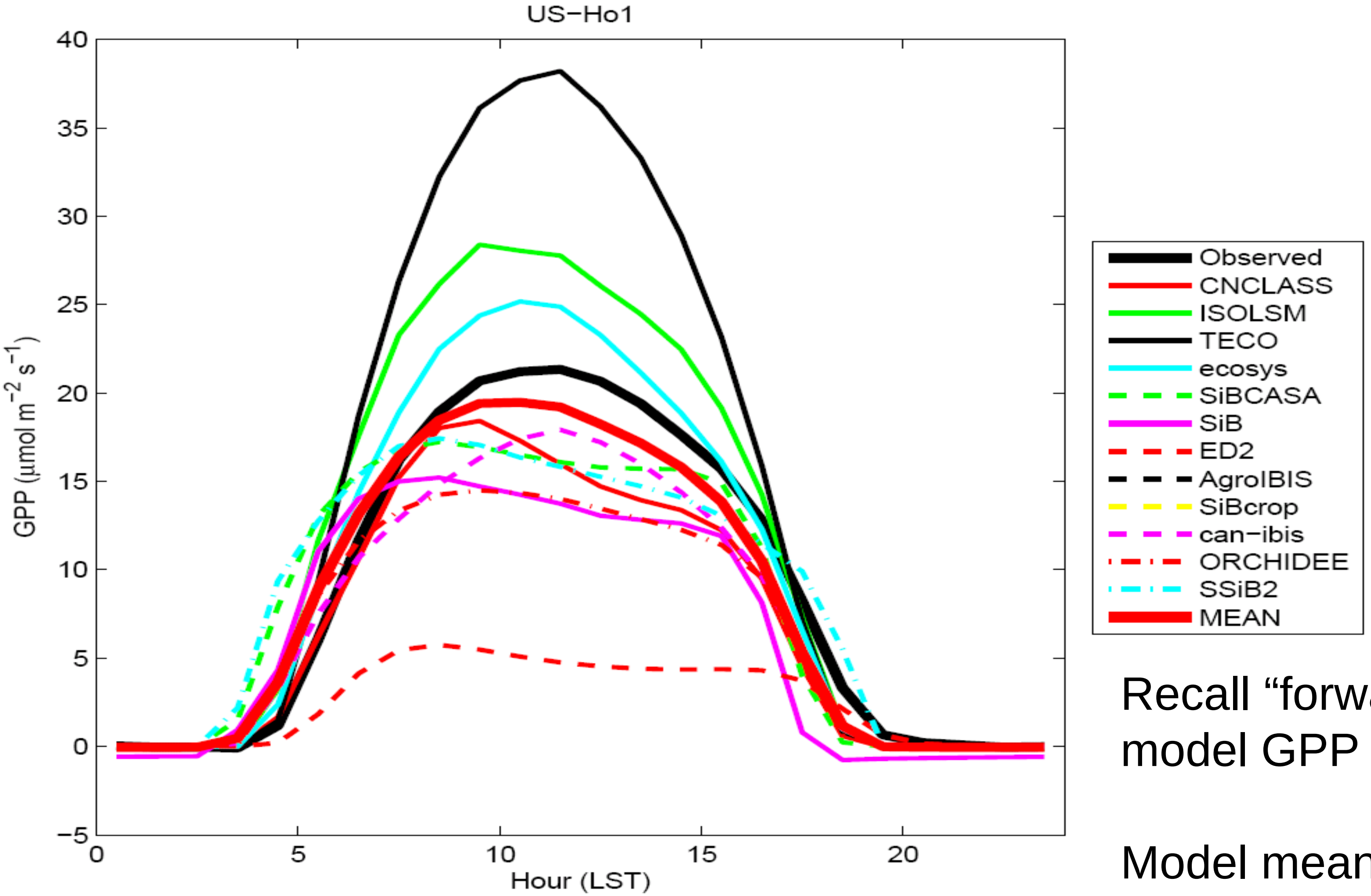
- DNDC
- SiBCrop
- can-ibis
- EDCM
- ORCHIDEE
- LPJ
- BIOME-BGC
- SSiB2
- TRIPLEX
- AgroIBIS

- 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 LOTEC_DA

NEE seasonal mean diurnal cycle (Howland forest example)



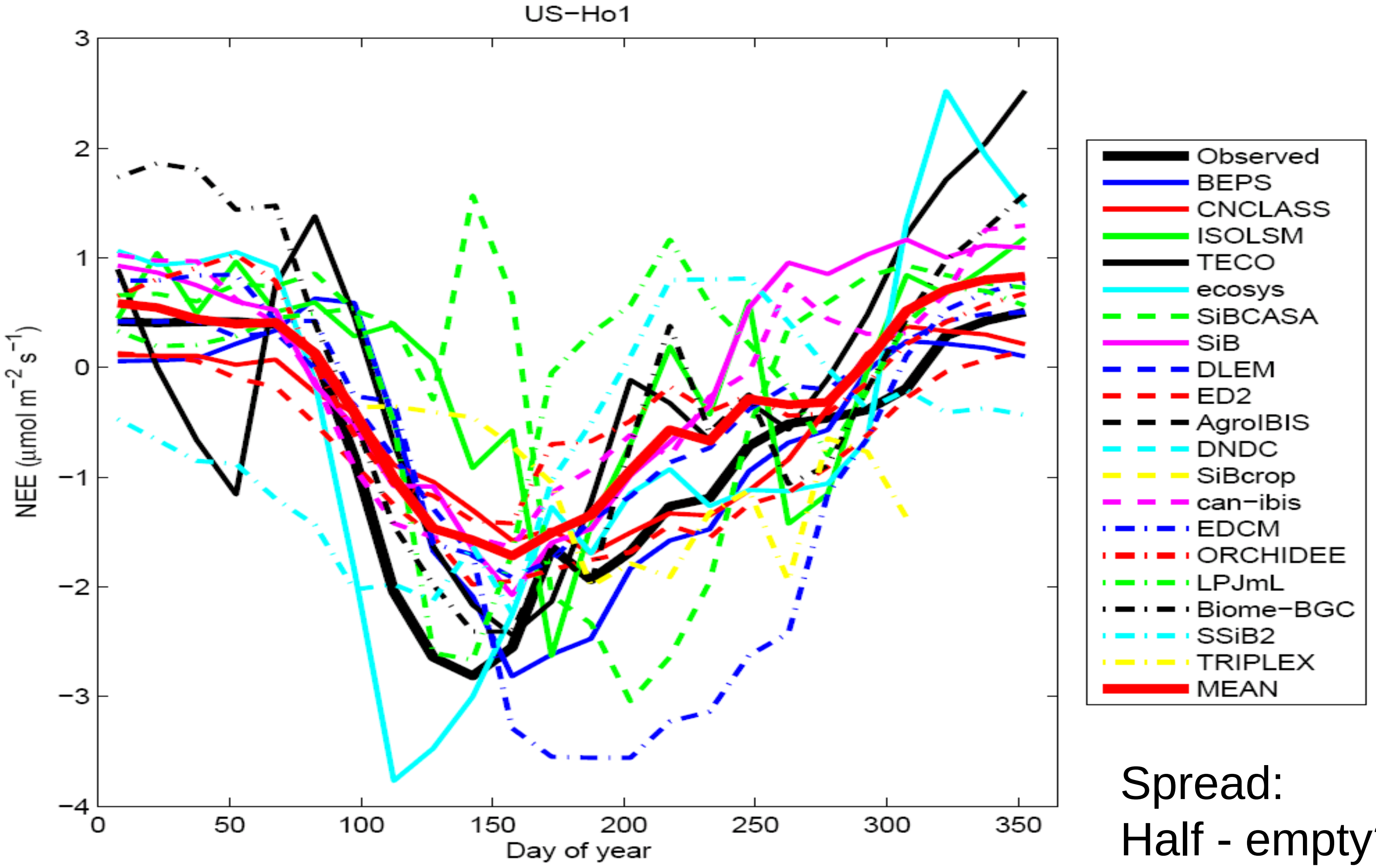
GPP seasonal mean diurnal cycle (Howland forest example)



Recall “forwards” model GPP results.

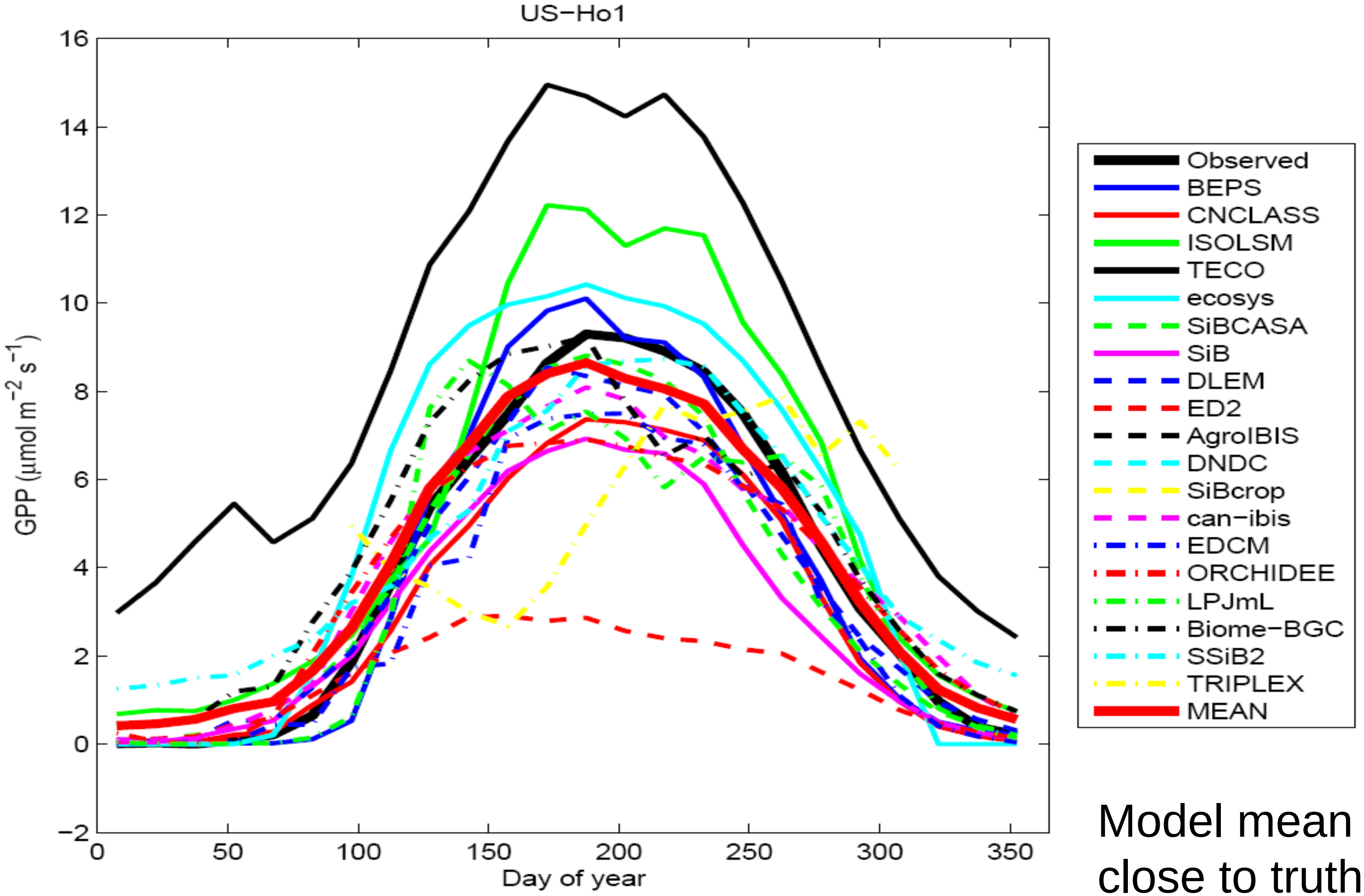
Model mean close to true GPP?

NEE multi-year mean seasonal cycle (Howland example)



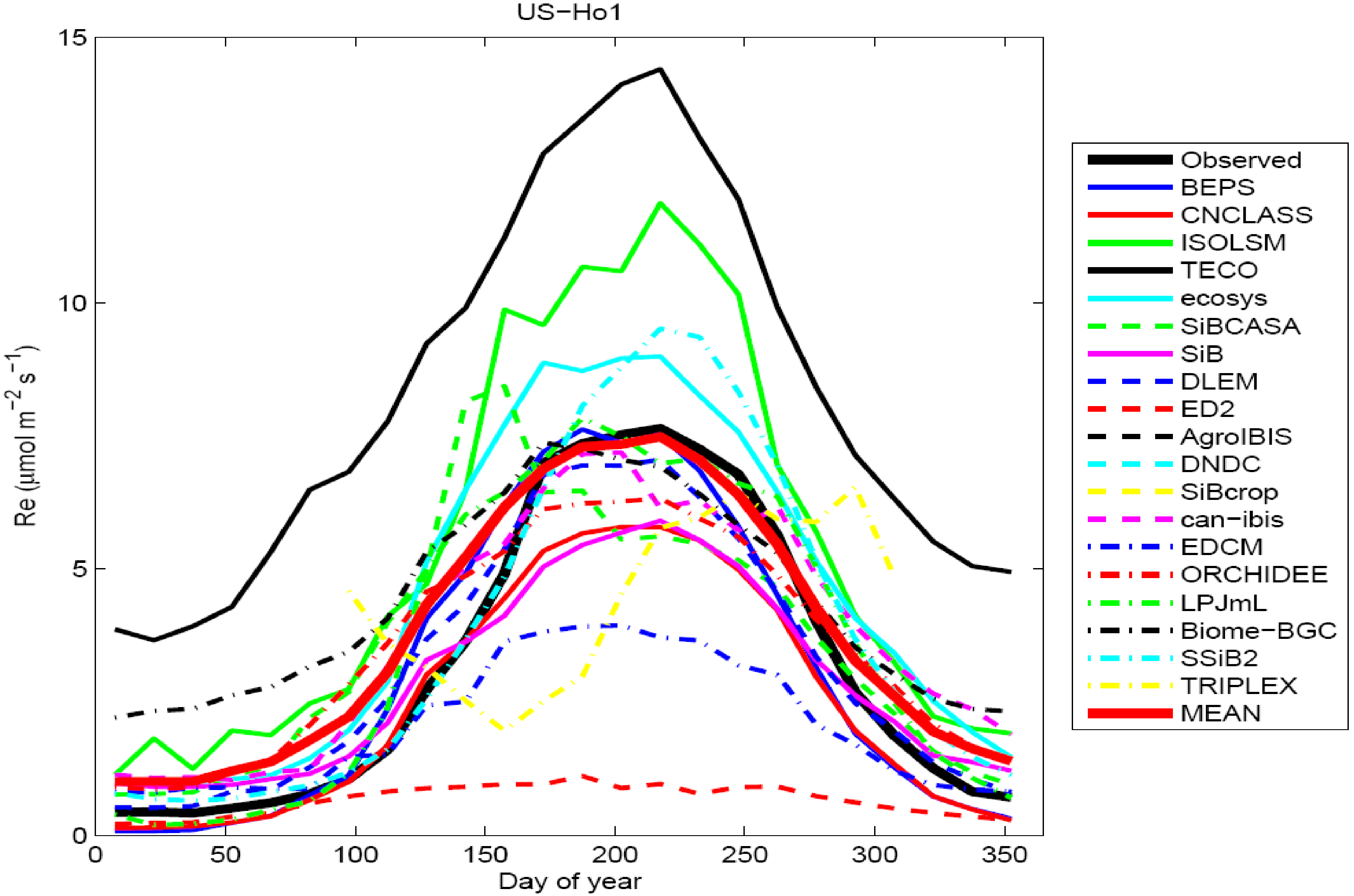
Spread:
Half - empty?
Comparison:
Half-full!

GPP multi-year mean seasonal cycle (Howland forest example)



Model mean close to truth?

Respiration multi-year mean seasonal cycle (Howland Forest example)



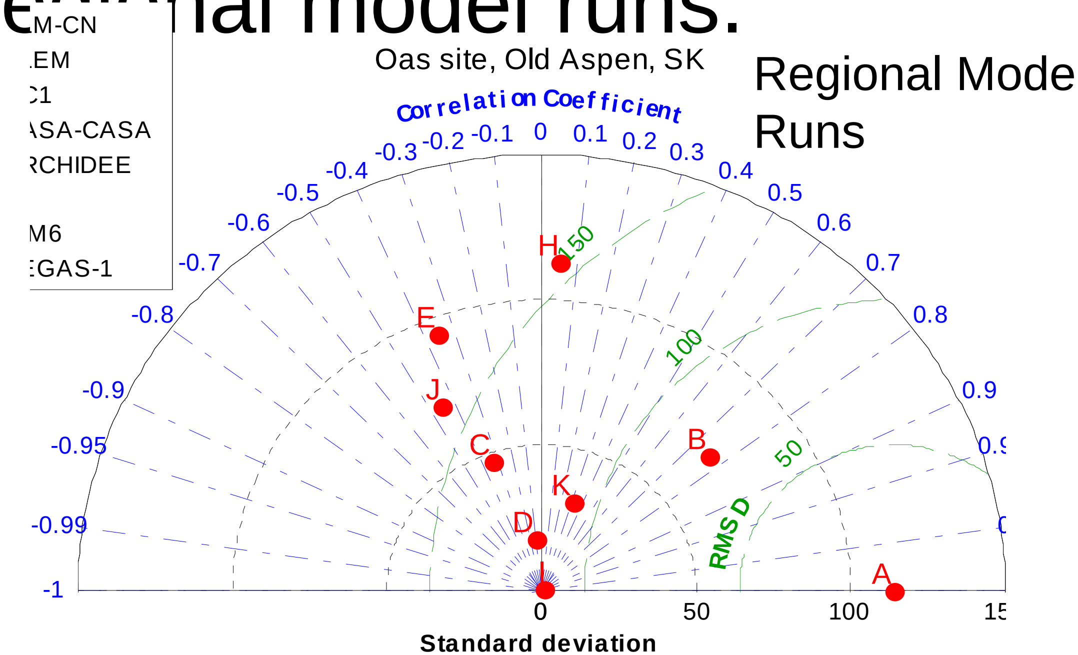
Inter-annual variability in annual NEE
Site and regional model runs.

Correlation coefficient:

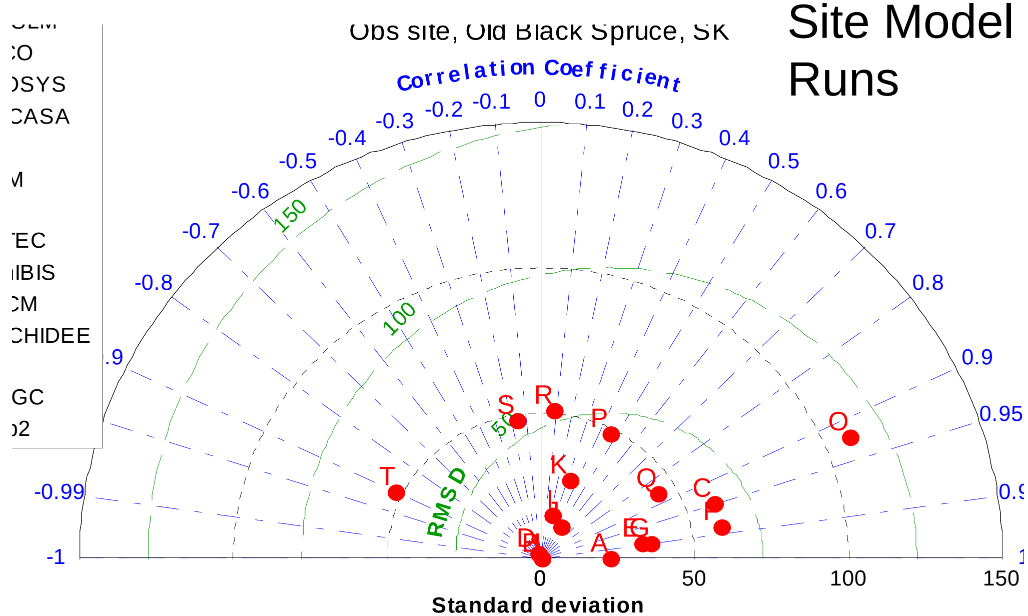
Regional model “extracts” show little correlation with flux tower observations.

Site level model runs show weak correlation with tower observations.

Regional Model Runs



Site Model Runs



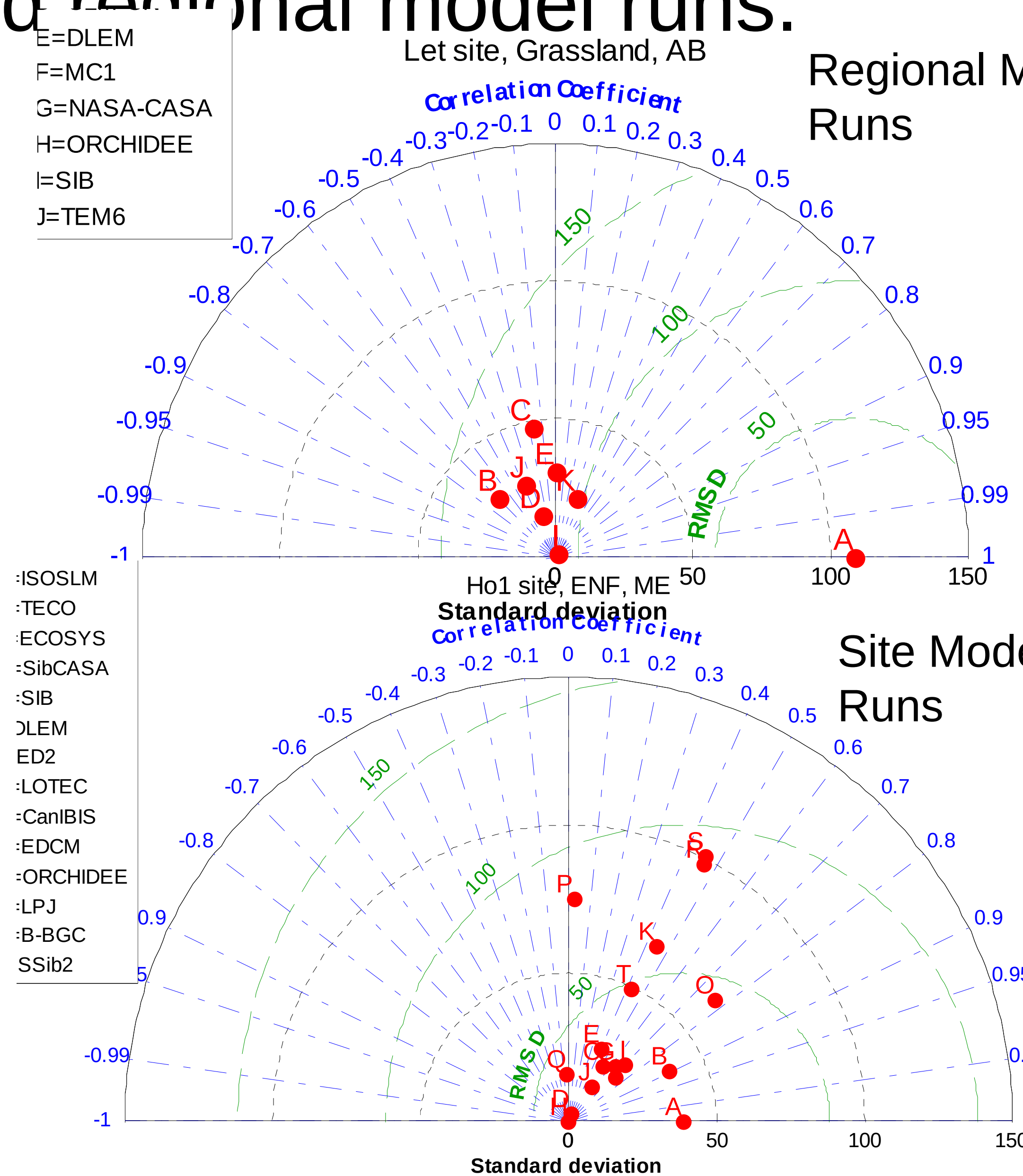
Inter-annual variability in annual NEE Site and regional model runs.

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?")

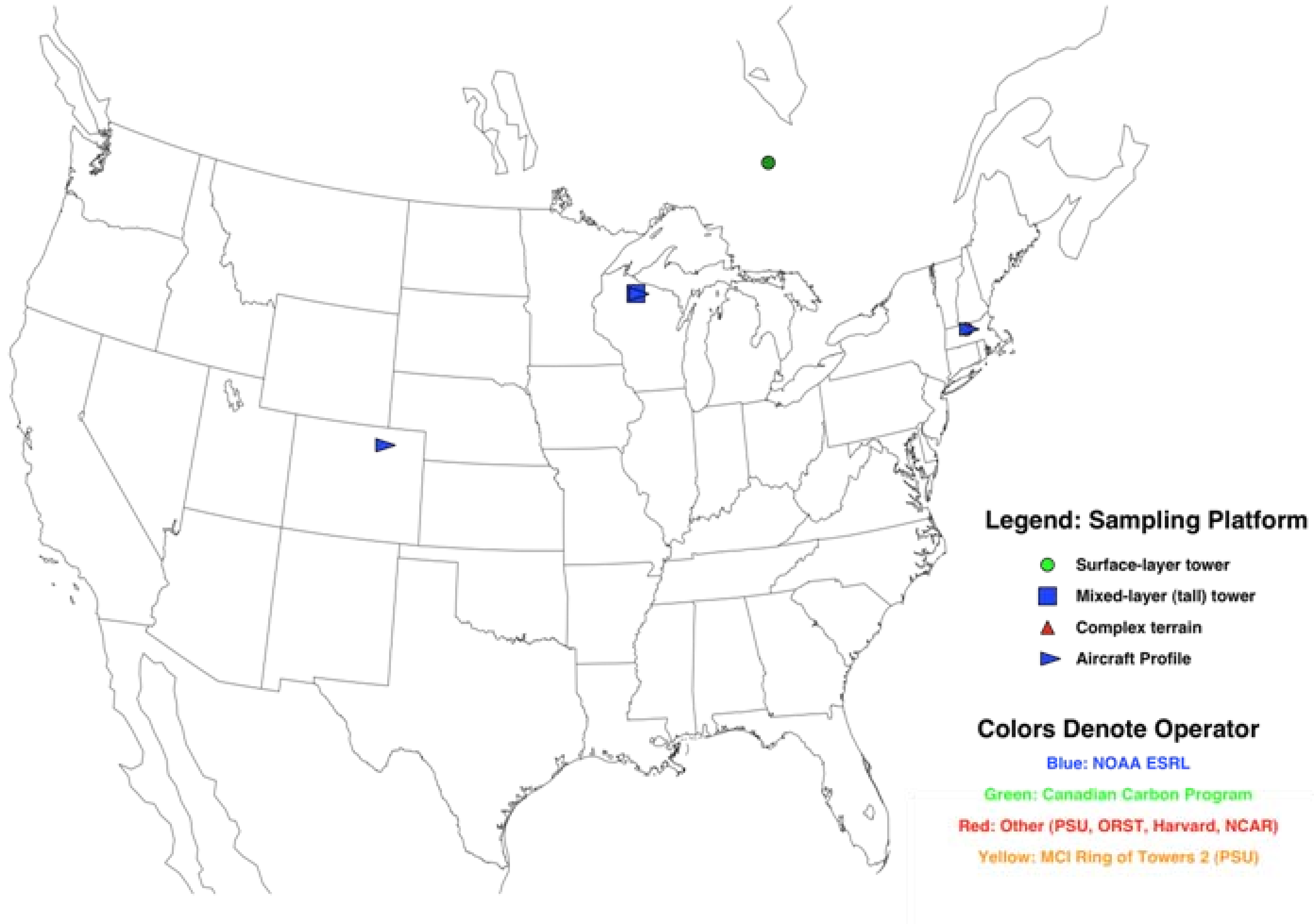


Regional Model Runs

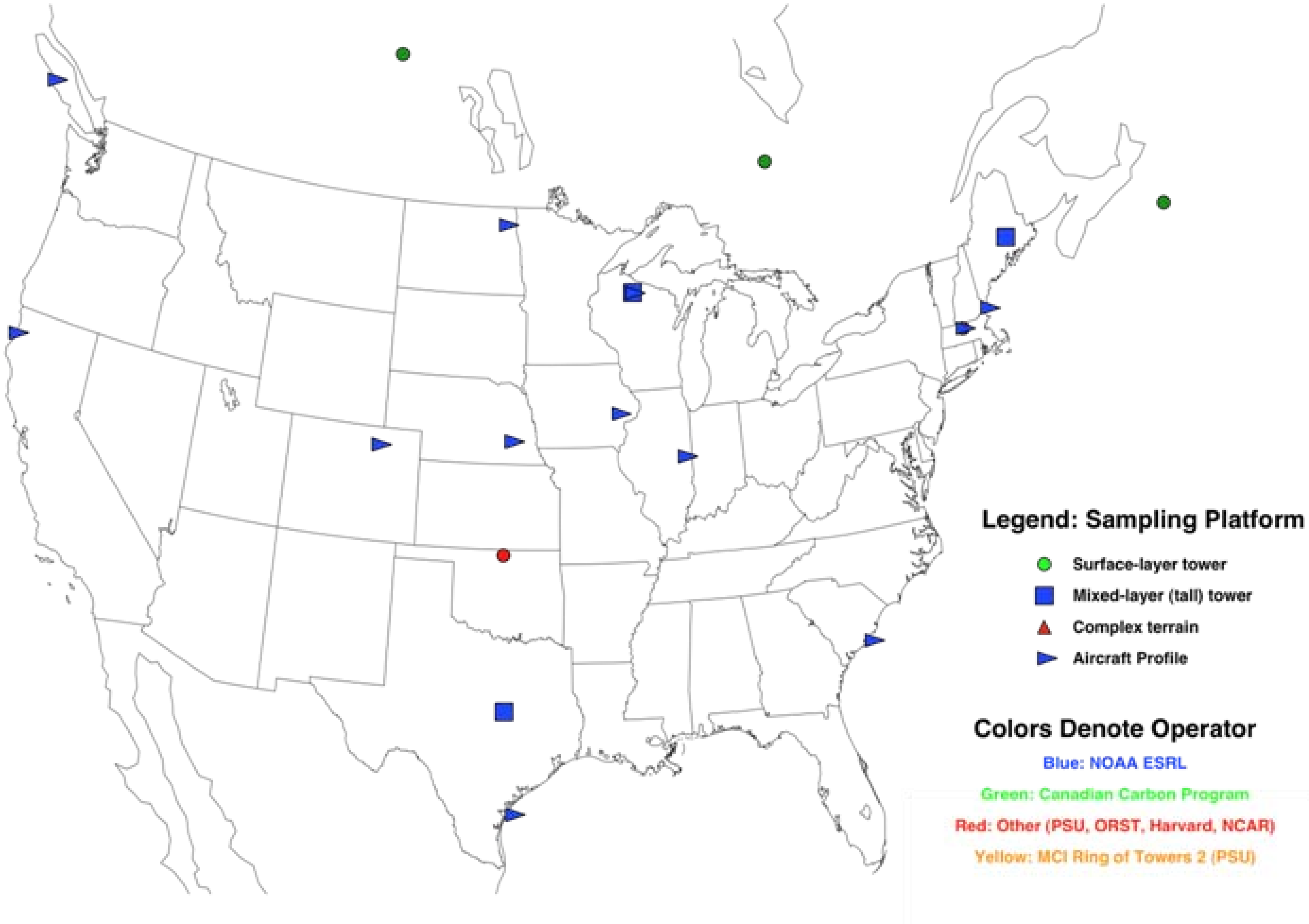
Site Model Runs

Imminent improvements in atmospheric inversions due to increased data density?

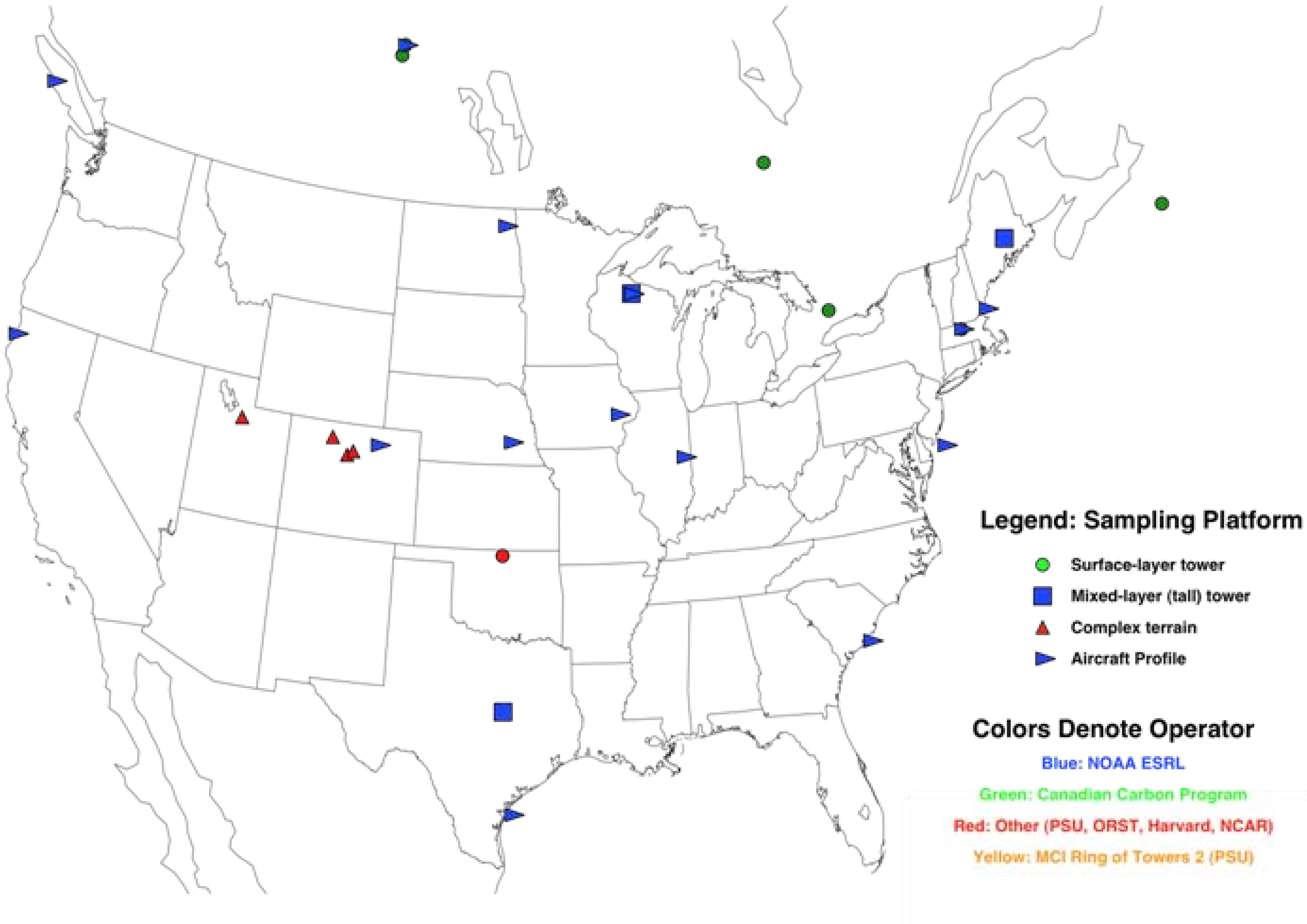
CO_2 Concentration Network: 2000



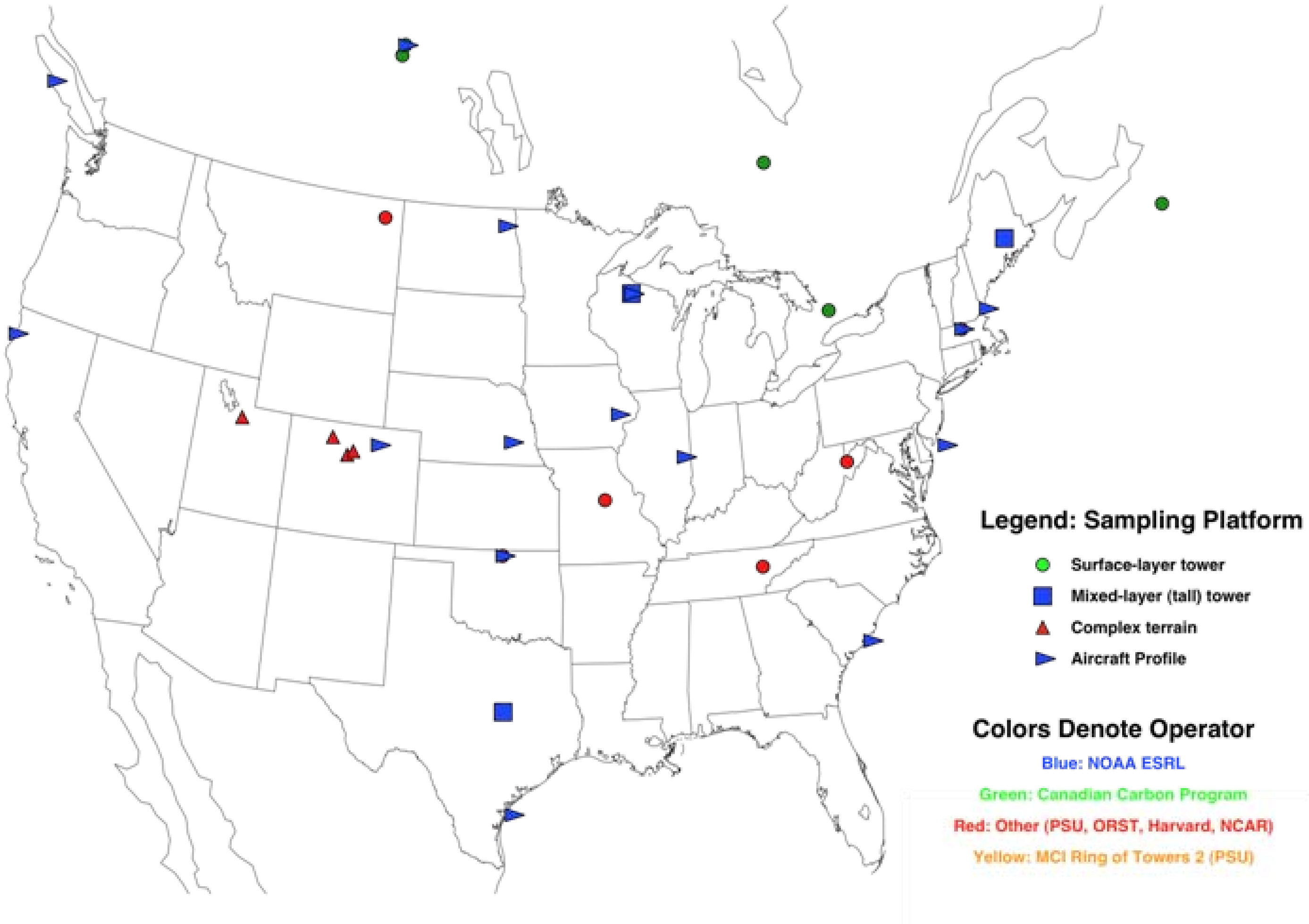
CO_2 Concentration Network: 2004



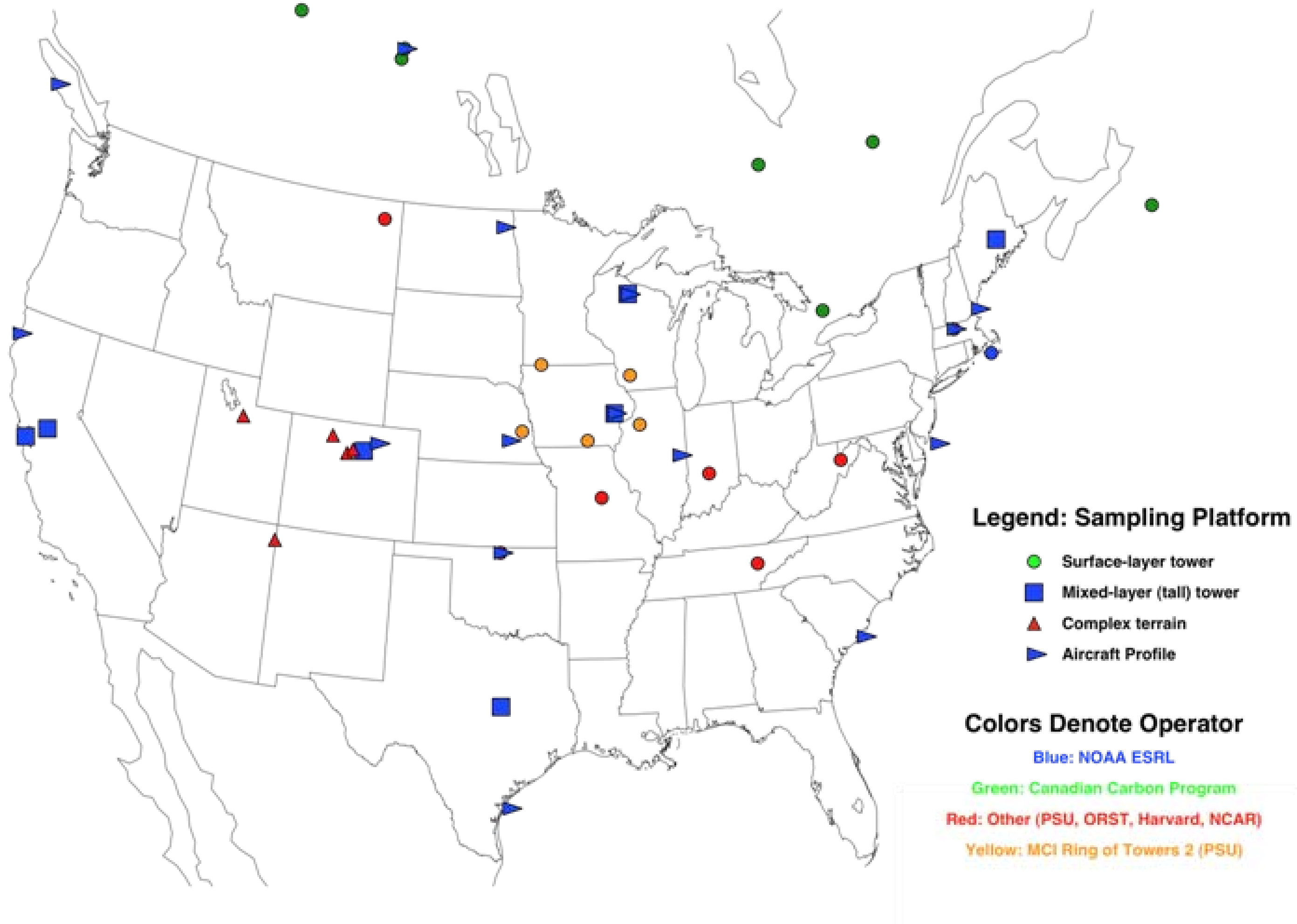
CO_2 Concentration Network: 2005



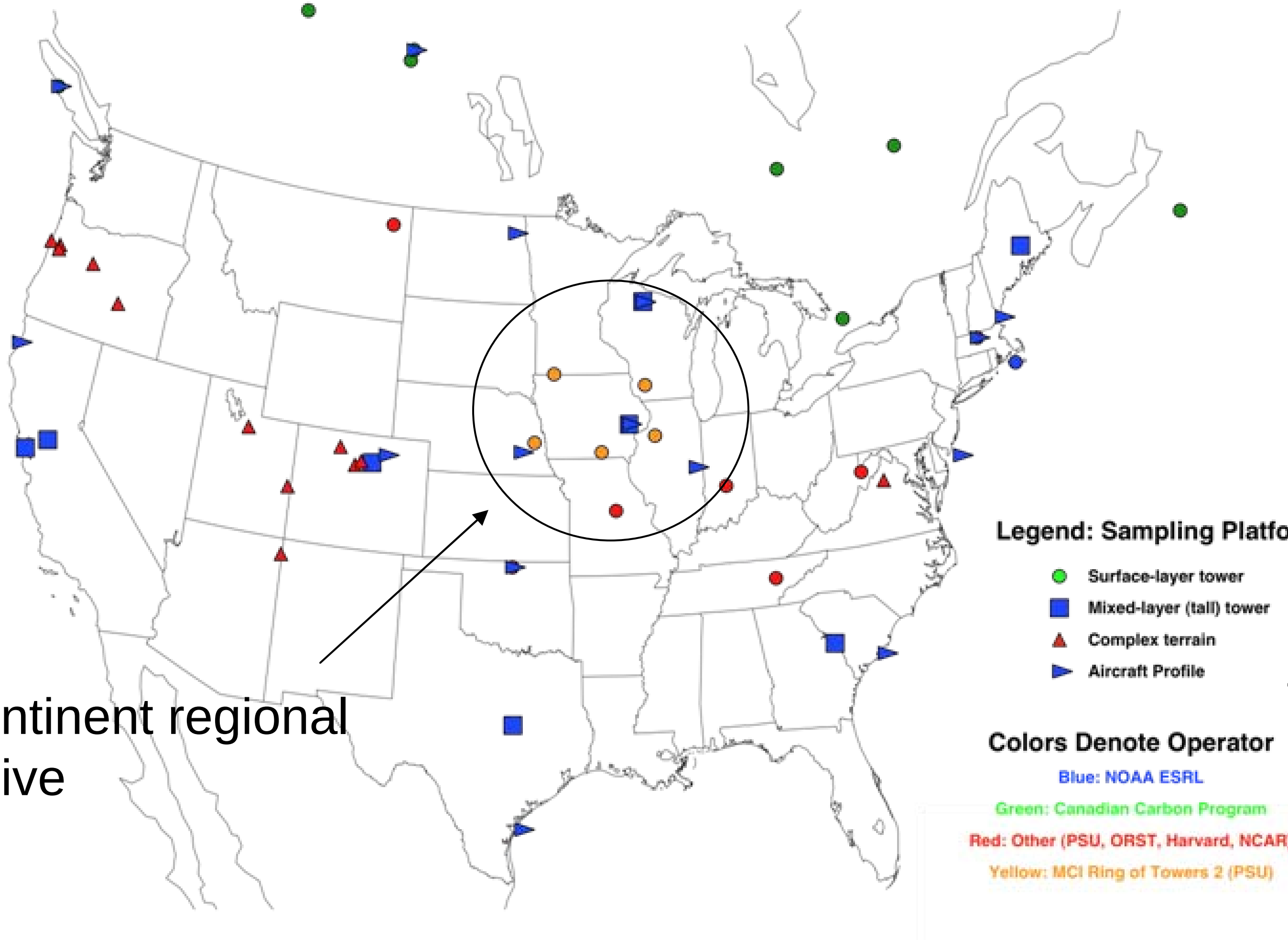
CO_2 Concentration Network: 2006



CO_2 Concentration Network: 2007



CO_2 Concentration Network: 2008



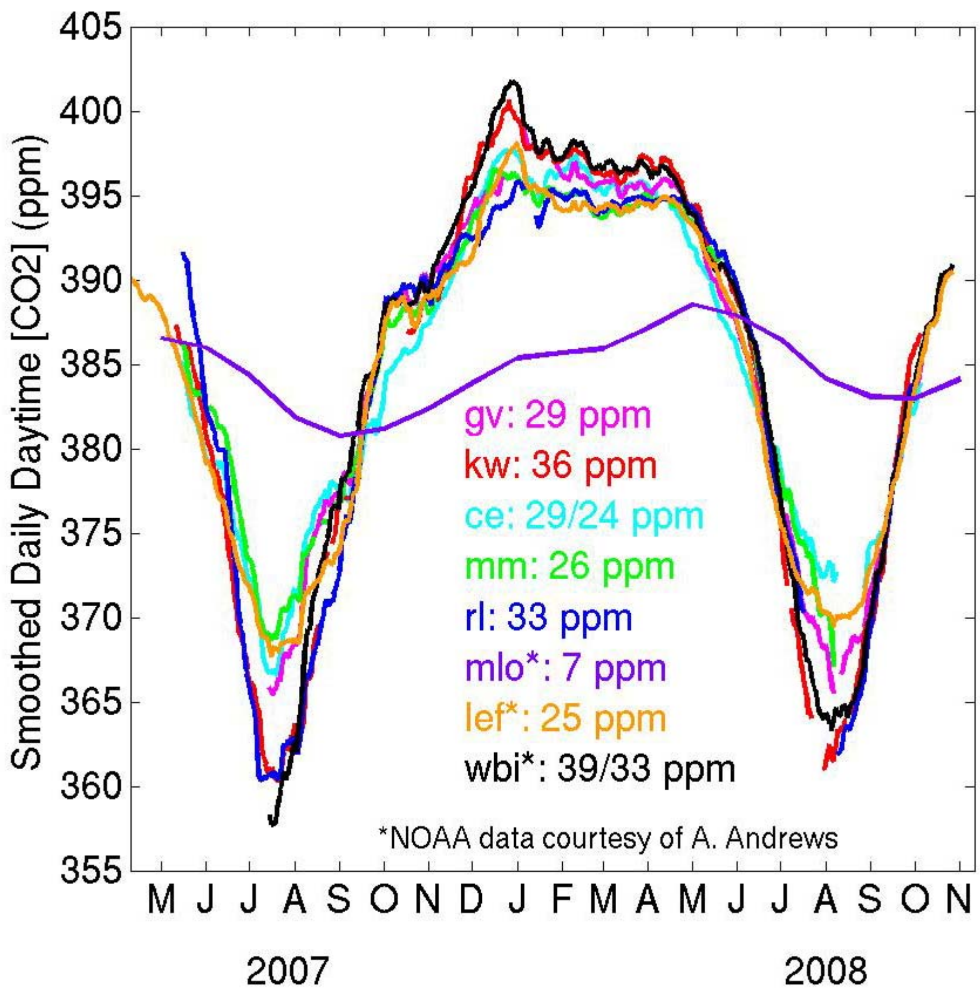
Midcontinent regional intensive

Half-full: Greatly improved data density.

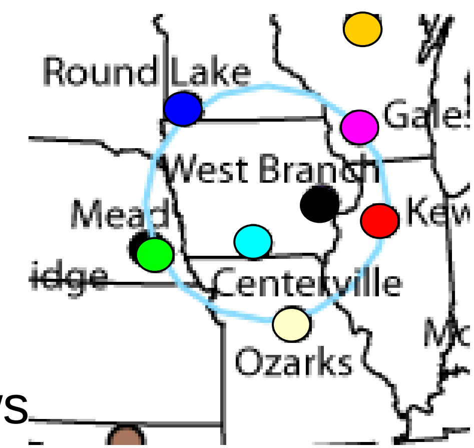
Half-empty: Partly due to a "coop" of short-term funding and multiple PIs. Not all a stable, centrally-supported network.

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

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 CO_2 data density over N. America likely to have a large impact on atmospheric inversions post 2005.

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