Regional Model-Data Comparison: An NACP Interim Synthesis Project

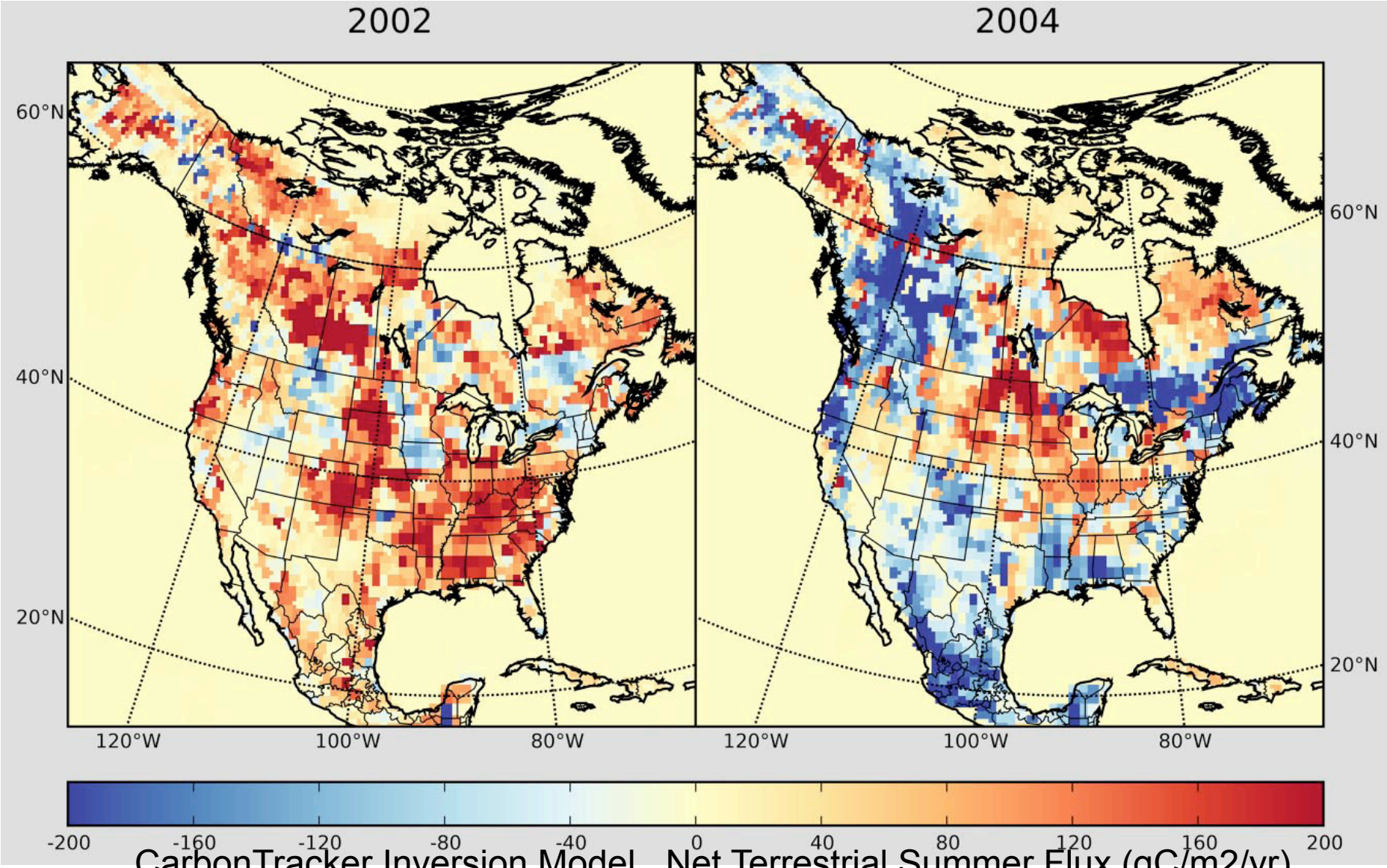
Coordinators: *Andy Jacobson, Mac Post, Debbie Huntzinger, Bob Cook*

Participants: *Dozens of modeling teams and data providers, Canada, USA, Mexico, Europe*

Regional MDC Questions with Focus on North America

- Interannual Variation
  - What is the spatial pattern and magnitude of interannual variation in carbon fluxes during 2000-2005?
  - What are the components of carbon fluxes and pools that contribute to this variation?
- 2002 Drought
  - Do model results and observations show consistent spatial patterns in response to the 2002 drought?
  - From measurements and ecosystem models, can we infer what processes were affected by the 2002 drought?
- Identification of Sources/Sinks
  - What are the magnitudes and spatial distribution of carbon sources and sinks, and their uncertainties during 2000-2005?

CarbonTracker Estimated C Source/Sink



CarbonTracker Inversion Model, Net Terrestrial Summer Flux (gC/m2/yr)

www.esrl.noaa.gov/gmd/ccgg/carbontracker/

NASA-CASA Estimated C Source/Sink

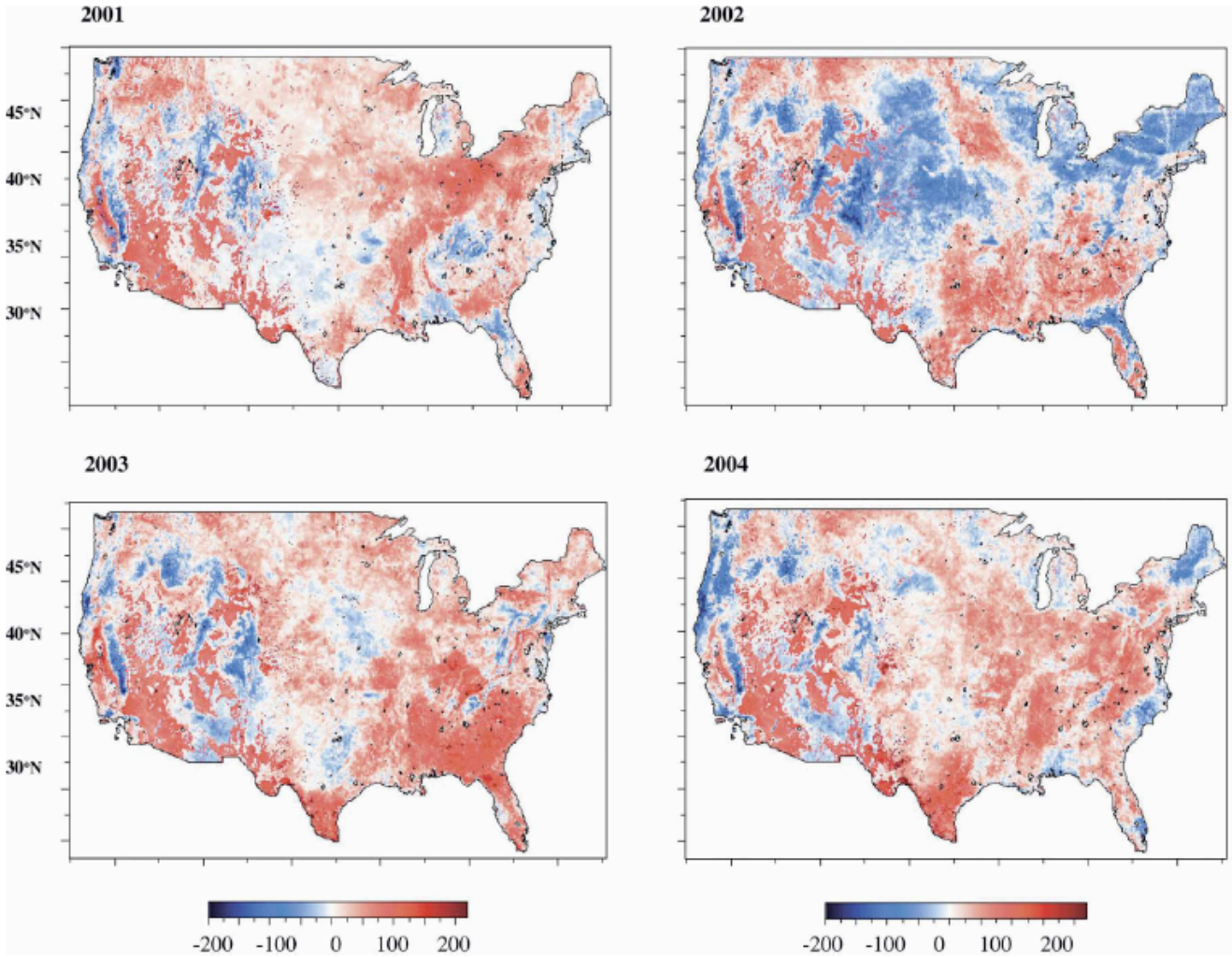
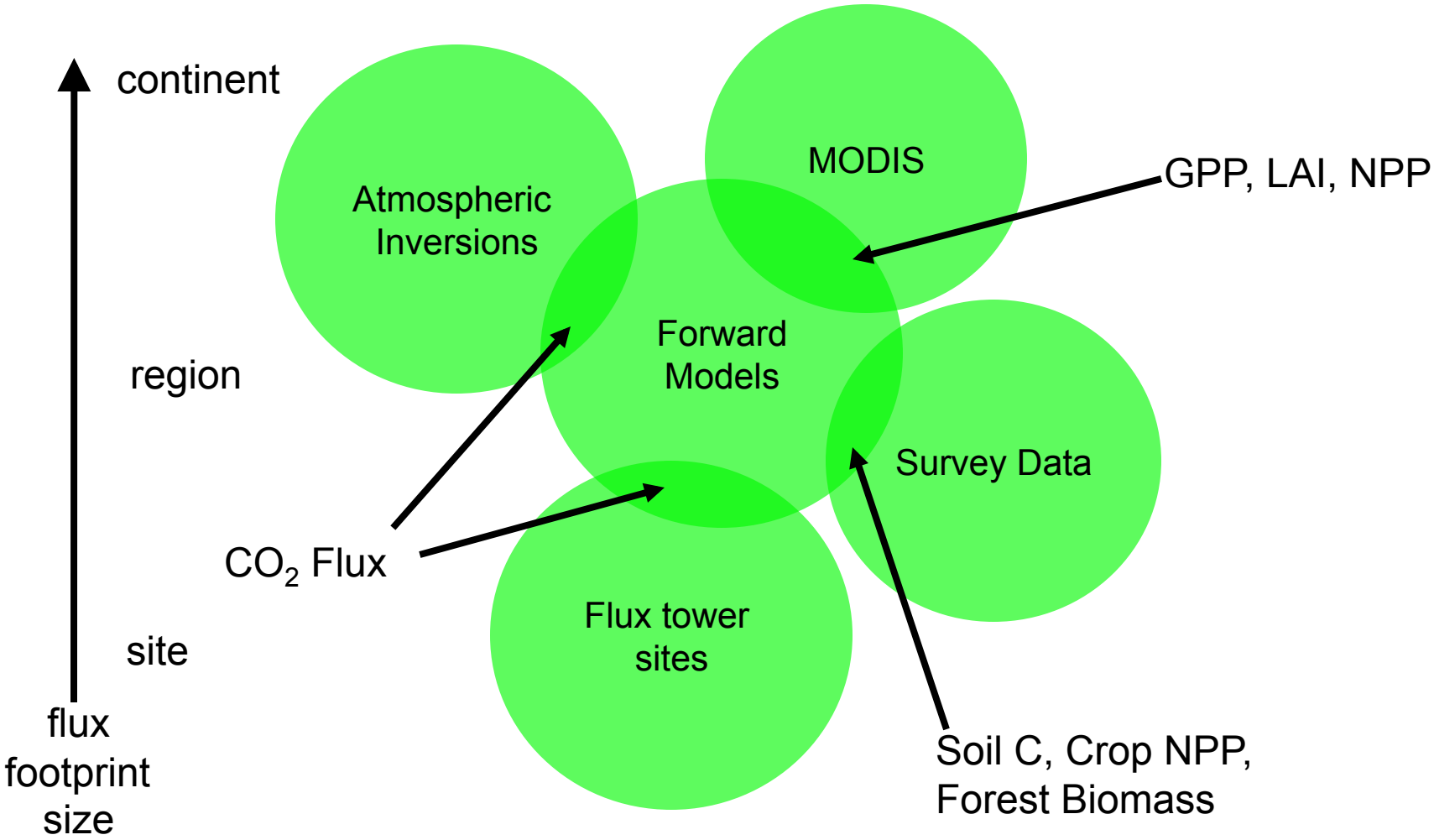


Figure 8. NEP maps for the coterminous United States from 2000 to 2004. Units are in Pg C per year, with red shading as annual C sinks and blue shading as annual C sources.

Use of Multiple Data Sources



Regional MDC Objectives

- Development of benchmark data sets and approaches for model-data evaluation.
- Evaluation of strengths and weaknesses of various model formulations, both inverse models and ecosystem models resulting from the comparison to data.
- Formal comparison of inverse and forward ecosystem model results for enhancing identification and diagnosis of temporal and spatial patterns of carbon fluxes.
- Understanding of mechanistic processes which lead to model differences

Synthesis of Interim NACP Results

Ecosystem Models

- Contribute in hand regional, continental results (including ones cut from global analyses)
- A range of temporal and spatial resolutions
- *No standardization of model runs!*

Inversion Models

- Contribute North America results in hand from TRANSCOM or from other relevant activities
- Spatial scales
  - TRANSCOM regions, and
  - 1º grids centered on half-degrees
- Temporal scale - monthly

Ecosystem (Forward) Models

Forward Models							
CLM-CASA	2000-2004	Monthly	Global	2.8° (T42)	netCDF	GPP, NPP, NEE, NEP, TLAI, landfrac, LEAFC, LITTERC, SOILC, WOODC, CWDC, FROOTC	Info
CLM-CN	2000-2004	Monthly	Global	2.8° (T42)	netCDF	GPP, NPP, NEE, NEP, TLAI, landfrac, LEAFC, LITTERC, SOILC, WOODC, CWDC, FROOTC	Info
ORCHIDEE	2001-2007	Monthly	N. America	0.3512° (T511)	netCDF	GPP, NPP, CO2FLUX, LAI, GROWTH_RESP, HET_RESP	Info
SIB	2000-2005	Monthly	N. America	1°	netCDF	NEE	
CASA Transcom	2002-2003	Monthly	N. America	1°	netCDF	NEE	
CASA GFed2	2000-2005	Monthly	N. America	1°	netCDF	NEE, GPP, R (Ra+Rh)	Info
NASA CASA	2001-2004	Monthly	Continental U.S.	8km	HDF	NPP, NEP	Info
MC1	2000-2007	Monthly	Continental U.S.	0.5°	netCDF	NPP, NEE, NBP, RespH, TotLivBiom, TSLC, BioCons	Info
TEM6	2000-2006	Monthly	N. America >45°N	0.5°	netCDF	GPP, NPP, NCE, NECB, RH, SOILC, VEGC	Info
ISO-LSM	2003-2004	Daily	ARM-CART	1km	netCDF	FCO2 (NEE)	
OSU-BGC	2000-2002	Daily	Oregon	1km	netCDF	GPP, NPP, NEP, auto_resp, hetero_resp, wmas	
DLEM	2000-2005	Monthly	N. America	32km	netCDF	GPP, NEE, NPP, Ra, Rh, TotLivBiom, TotSoilCarb	Info
VEGAS	2000-2007	Monthly	N. America	1°	netCDF	nee, npp, ra, rh, cleaf, csoil, evap	Info
EC-MOD	2000-2006	Monthly	N. America	1°	netCDF	nee (2005 only), gpp	
EC-LUE	2004-2005	Monthly	N. America	1°	netCDF	GPP	
MOD17	2000-2005	Monthly	N. America	1°	netCDF	GPP, Reco	
ISAM	2000-2007	Monthly	N. America	1°	netCDF	NPP, resp (Rh), NEE	

ftp://nacp.ornl.gov/synthesis/2008/firenze/continental/continental_data_model_inventory.html

Inversion Models

- **Results by Transcom Regions**
  - Transcom3 IAV inversion (D Baker),13 models
  - Rödenbeck Jena, 3 different networks
  - CarbonTracker
  - FRCGC Japan (Patra)
  - U Michigan geostat, 2 models
  - LSCE France (Peylin)
  - LSCE France (Chevallier)
  - LSCE France (Rayner)
  - Penn State (Butler), 2 models
- **Results by 1 degree**
  - U of Toronto
  - CarbonTracker
  - LSCE
  - Jena
  - U of Michigan
  - MLEF-PCTM – Colorado State University

Observations and Measurements

- Satellite based
  - In Hand:
    - MODIS GPP
    - MODIS NPP (annual)
    - MODIS LAI, FPAR, NDVI, EVI (gap filled, smoothed – from MODIS for NACP)
- Survey
  - In Hand:
    - NASS crop yield based annual NPP
    - Soil C (WISE-FC version 3.0), 30cm, 100cm
    - FIA based biomass
  - In Development:
    - Fast-track change in forest/agriculture C stocks for Canada, USA, Mexico
- Site based
  - Eddy flux NEE, estimated GPP, NPP

All of these are not strictly direct measurements and involve some level of model intervention

Conversion to Common Grid - both Data and Model

- Spatial Resolution: 1°x1°, centered at (x.5, y.5 for each grid cell)
- Domain: 50° to 170° W longitude, 10° to 84° N latitude
- Temporal Resolution: monthly (or annual)
- netCDF files, CF-1 convention
- ftp://nacp.ornl.gov/synthesis/2008/firenze/continental

Fast-Track Inventory-based data for evaluation of Forward Ecosystem Models

- Organization of Inventory-Based Information
- By 48/49 states in the U.S. (Alaska not available)
- By 18 reporting units in Canada
- By states in Mexico
- Aggregated estimates for 2000-2005

Agriculture Data by County

Sub-region	Cropland area	Soil C	Delta Soil C	NPP	RH	NEE	Harvest Removals	Fire Emissions	Area Burned
Canada	?	?	?	?		?	? (70 Tg)		?
U.S.	X	X	X	X		X	X (252 Tg)		
Mexico	X	X		?			X		X

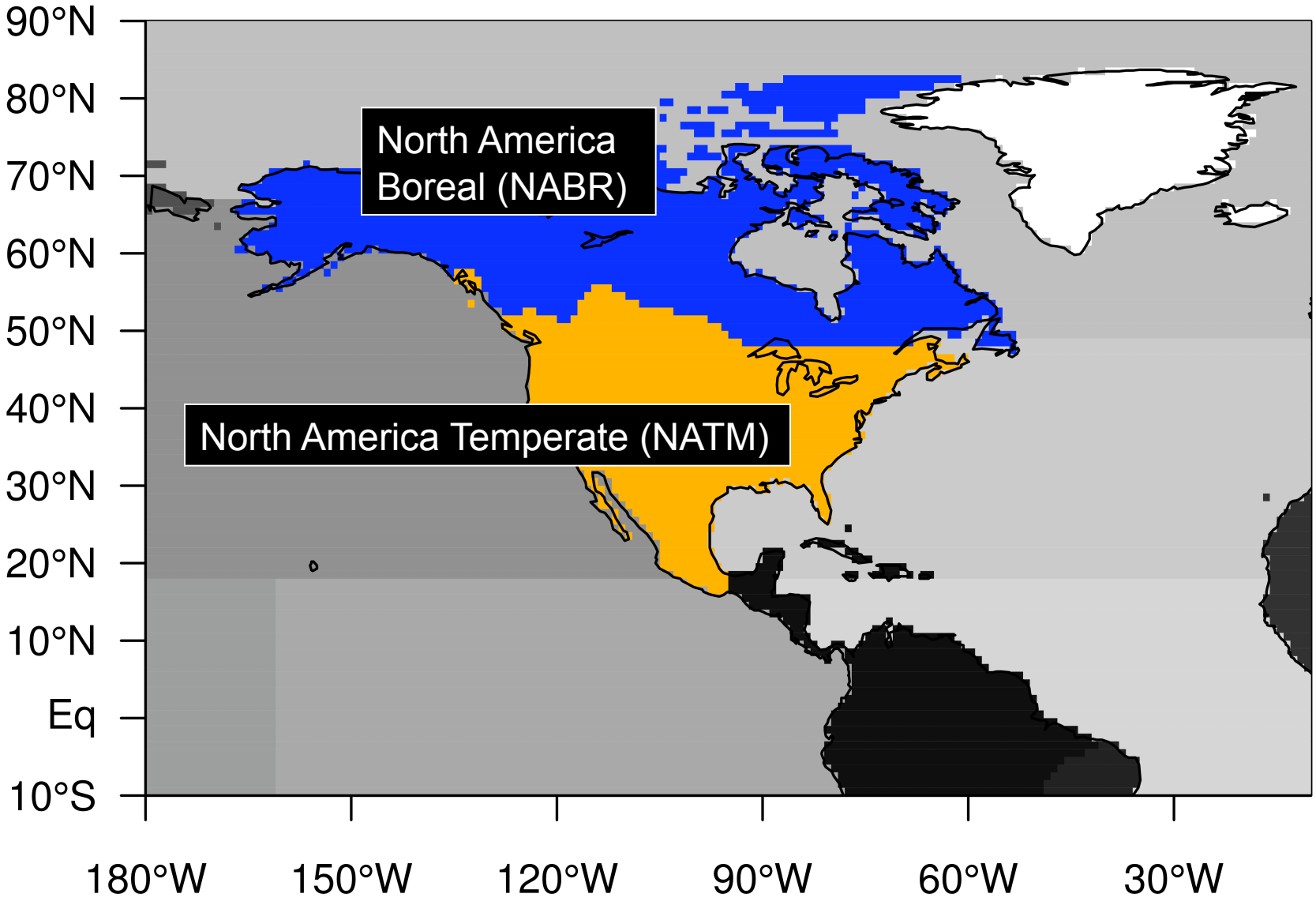
Forest Data by State

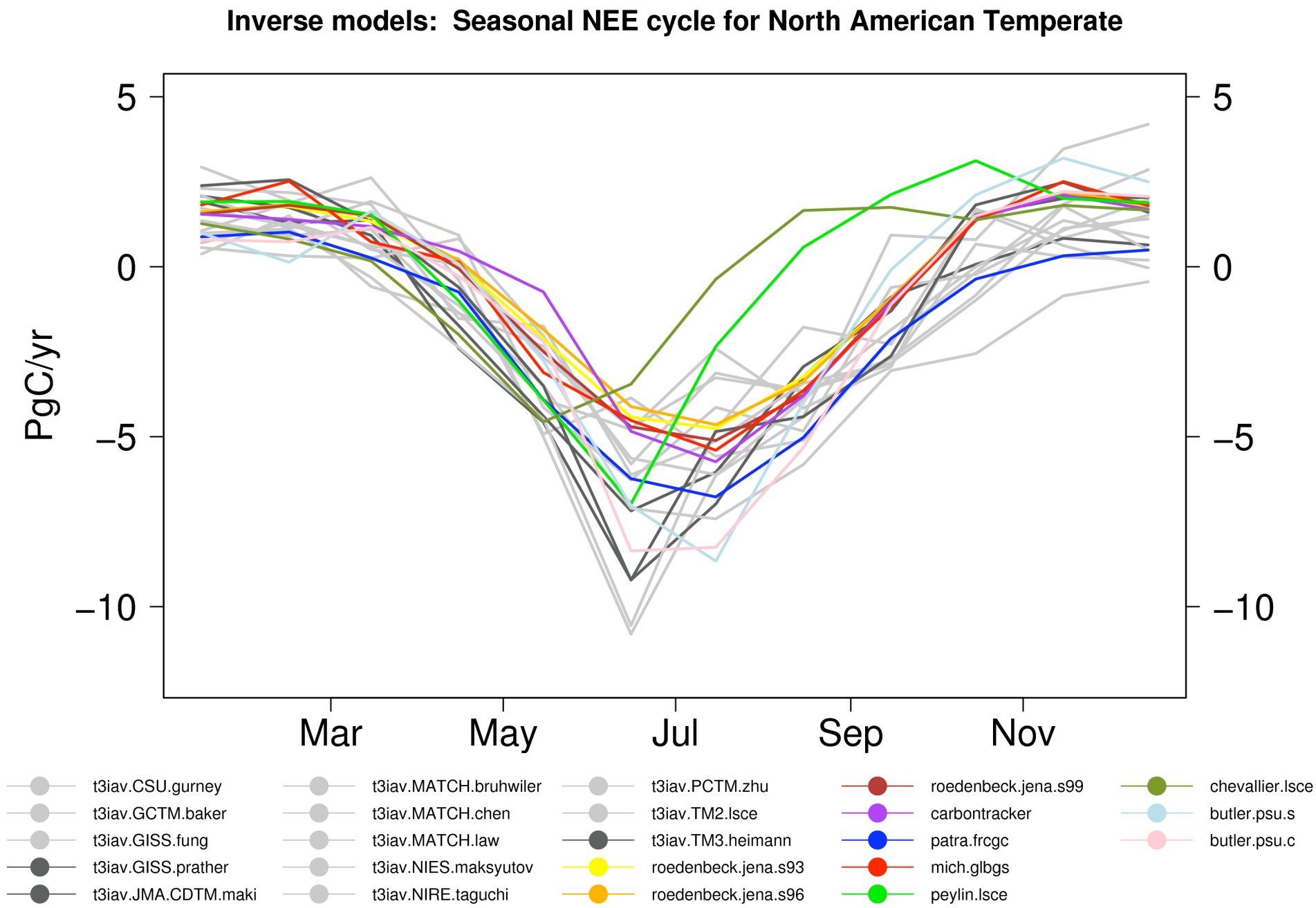
Sub-region	Forest area	Veg C	Delta Veg C	NPP	RH	NEE = - (NPP – RH – Fire Emissions)	Harvest Removals	Fire Emissions	Area Burned
Canada	X	X	X	X	X	X	X (45 Tg)	X	X
U.S.	X	X	X			X	X (140 Tg)	X	?
Mexico	X	X					X		?

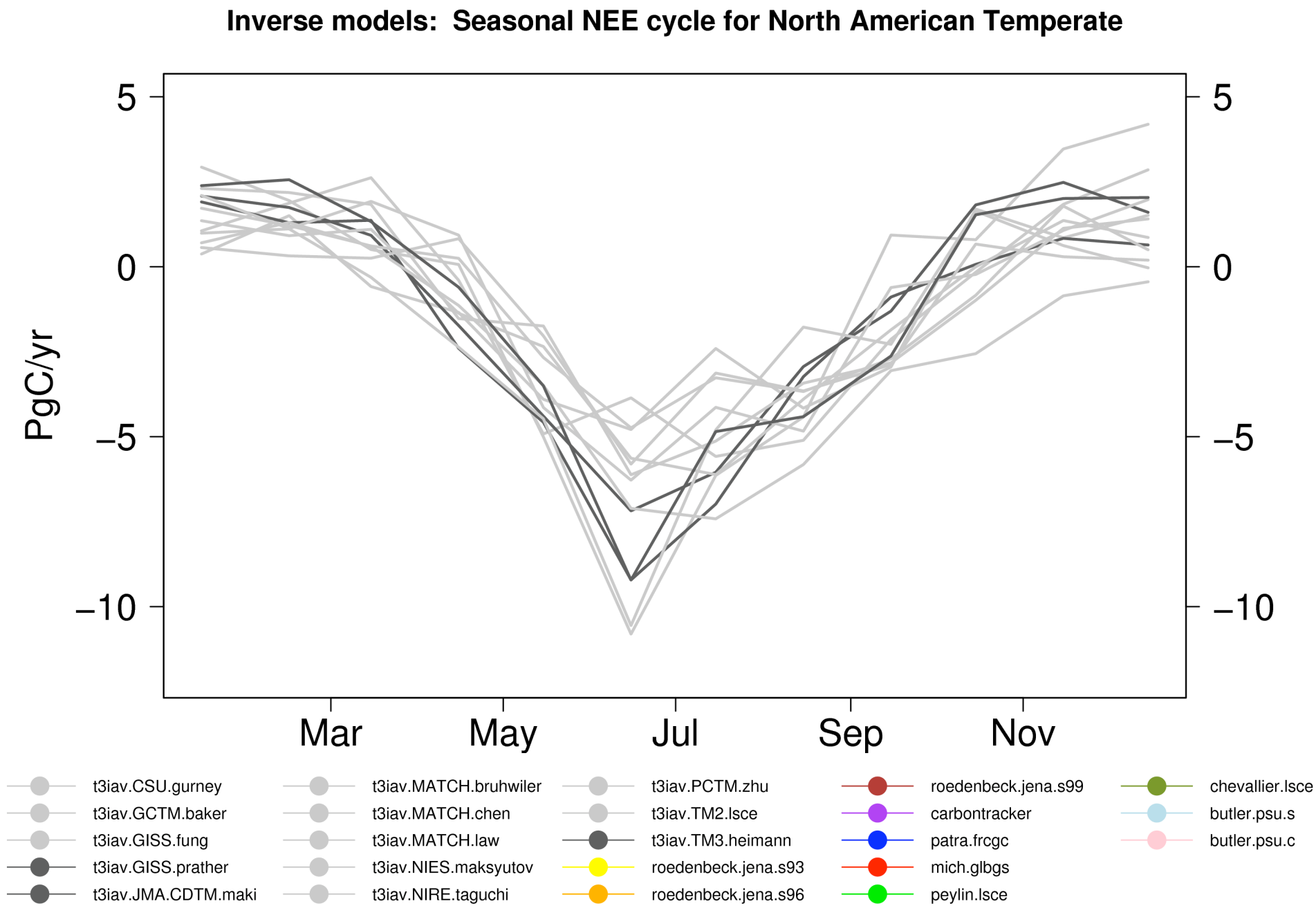
Inverse Models

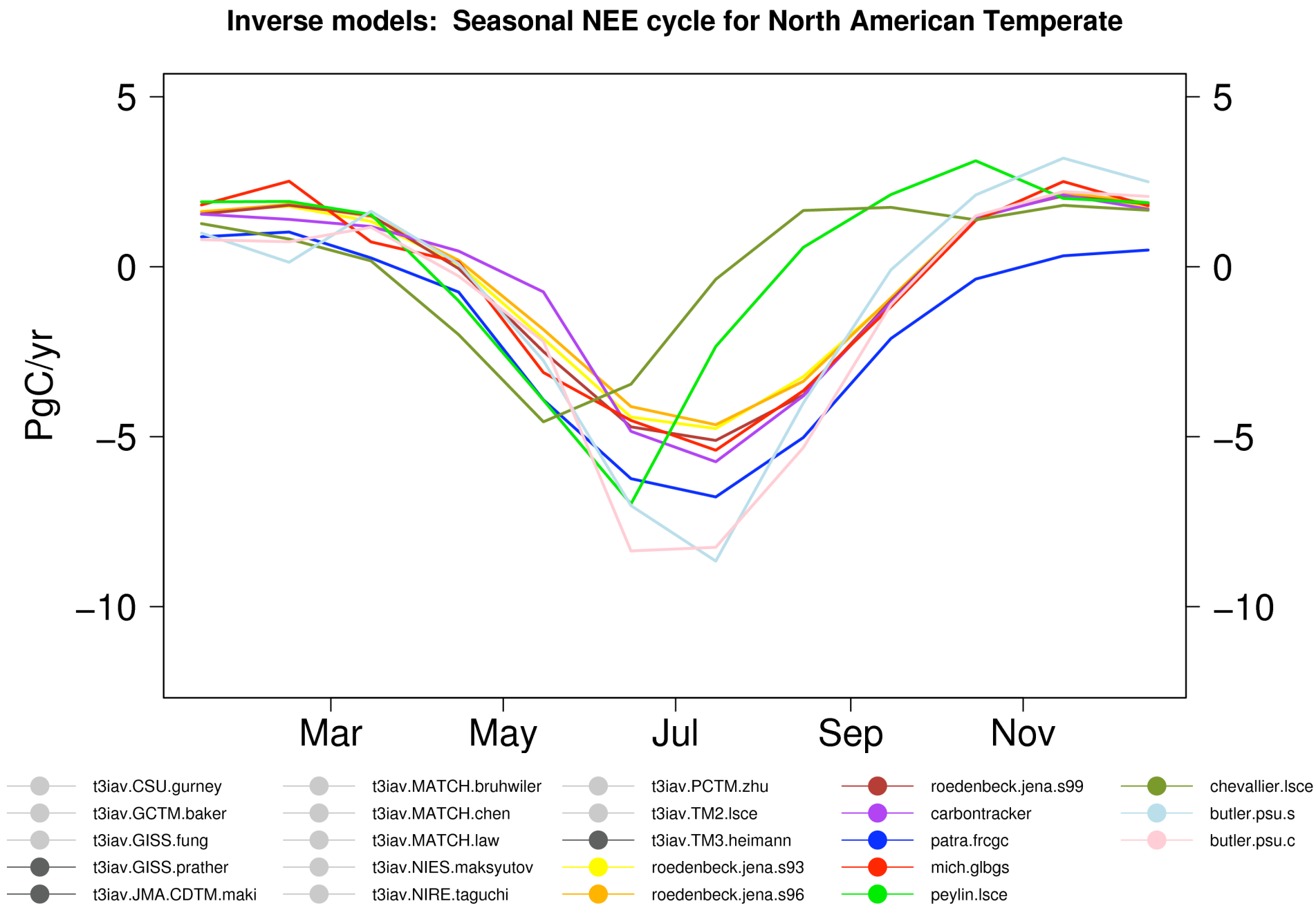
- Produce model predictions of atmospheric CO_2 mole fractions
- Compare with the observed atmospheric CO_2 mole fraction
- Difference between them is attributed to differences in estimated (first guess) and the actual sources and sinks
- Numerical techniques, reduce these differences and solve for a set of sources and sinks that most closely matches the observed CO_2 mole fraction

1° x 1° TransCom region map




Inverse models: Seasonal NEE cycle for North American Temperate
PgC/yr
5
0
−5
−10
Mar
May
Jul
Sep
Nov
t3iav.CSU.gurney
t3iav.GCTM.baker
t3iav.GISS.fung
t3iav.GISS.prather
t3iav.JMA.CDTM.maki
t3iav.MATCH.bruhwiler
t3iav.MATCH.chen
t3iav.MATCH.law
t3iav.NIES.maksyutov
t3iav.NIRE.taguchi
t3iav.PCTM.zhu
t3iav.TM2.lsce
t3iav.TM3.heimann
roedenbeck.jena.s93
roedenbeck.jena.s96
roedenbeck.jena.s99
carbontracker
patra.frcgc
mich.glbgs
peylin.lsce
chevallier.lsce
butler.psu.s
butler.psu.c


Inverse models: Seasonal NEE cycle for North American Temperate
PgC/yr
5
0
−5
−10
Mar
May
Jul
Sep
Nov
t3iav.CSU.gurney
t3iav.GCTM.baker
t3iav.GISS.fung
t3iav.GISS.prather
t3iav.JMA.CDTM.maki
t3iav.MATCH.bruhwiler
t3iav.MATCH.chen
t3iav.MATCH.law
t3iav.NIES.maksyutov
t3iav.NIRE.taguchi
t3iav.PCTM.zhu
t3iav.TM2.lsce
t3iav.TM3.heimann
roedenbeck.jena.s93
roedenbeck.jena.s96
roedenbeck.jena.s99
carbontracker
patra.frcgc
mich.glbgs
peylin.lsce
chevallier.lsce
butler.psu.s
butler.psu.c


Inverse models: Seasonal NEE cycle for North American Temperate
PgC/yr
5
0
−5
−10
Mar
May
Jul
Sep
Nov
t3iav.CSU.gurney
t3iav.GCTM.baker
t3iav.GISS.fung
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t3iav.NIES.maksyutov
t3iav.NIRE.taguchi
t3iav.PCTM.zhu
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roedenbeck.jena.s93
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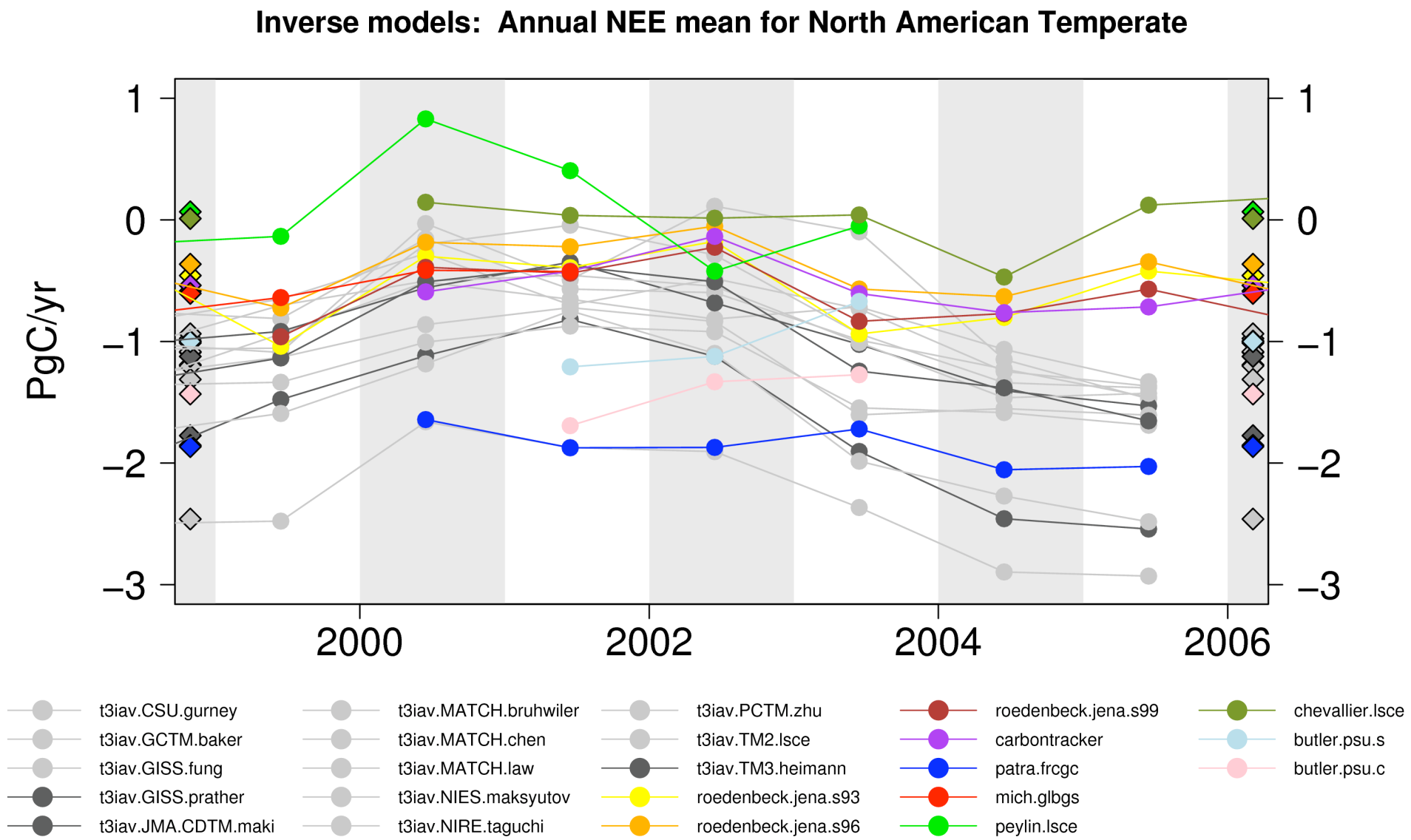
Inverse models: Annual NEE mean for North American Temperate
PgC/yr
1
0
−1
−2
−3
2000
2002
2004
2006
t3iav.CSU.gurney
t3iav.GCTM.baker
t3iav.GISS.fung
t3iav.GISS.prather
t3iav.JMA.CDTM.maki
t3iav.MATCH.bruhwiler
t3iav.MATCH.chen
t3iav.MATCH.law
t3iav.NIES.maksyutov
t3iav.NIRE.taguchi
t3iav.PCTM.zhu
t3iav.TM2.lsce
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roedenbeck.jena.s93
roedenbeck.jena.s96
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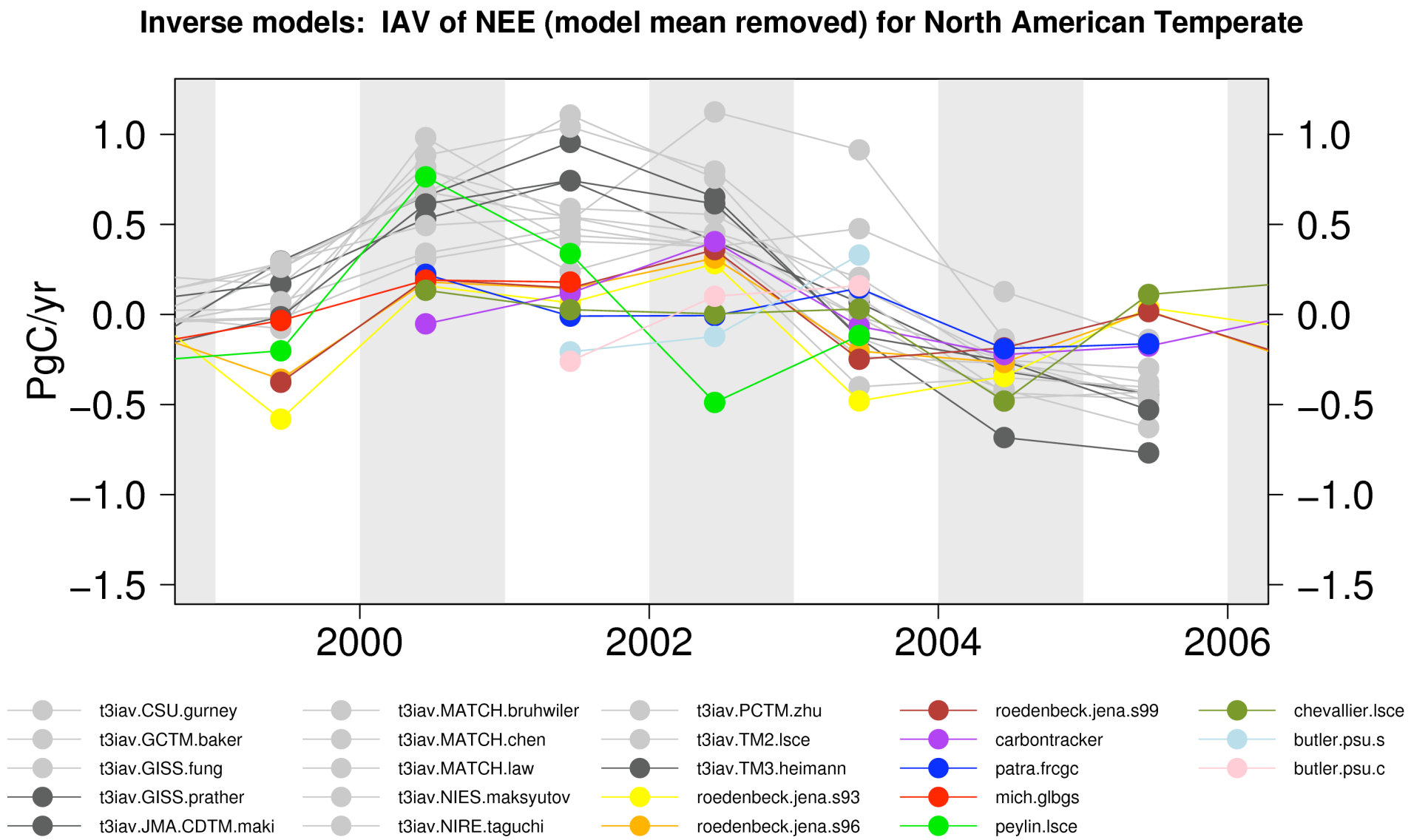
carbontracker
patra.frcgc
mich.glbgs
peylin.lsce
chevallier.lsce
butler.psu.s
butler.psu.c


Inverse models: IAV of NEE (model mean removed) for North American Temperate
PgC/yr
1.0
0.5
0.0
−0.5
−1.0
−1.5
2000
2002
2004
2006
t3iav.CSU.gurney
t3iav.GCTM.baker
t3iav.GISS.fung
t3iav.GISS.prather
t3iav.JMA.CDTM.maki
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butler.psu.s
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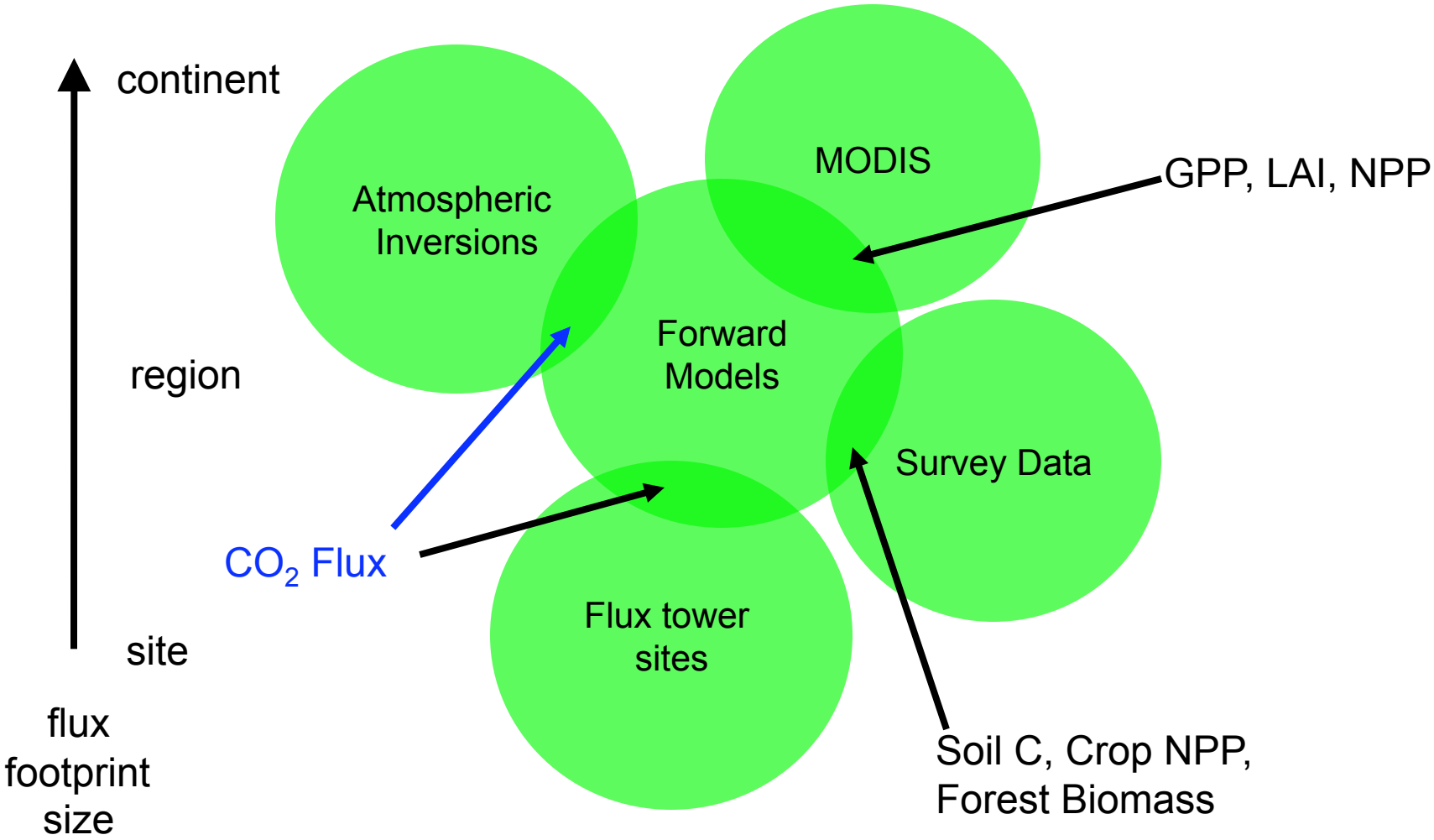
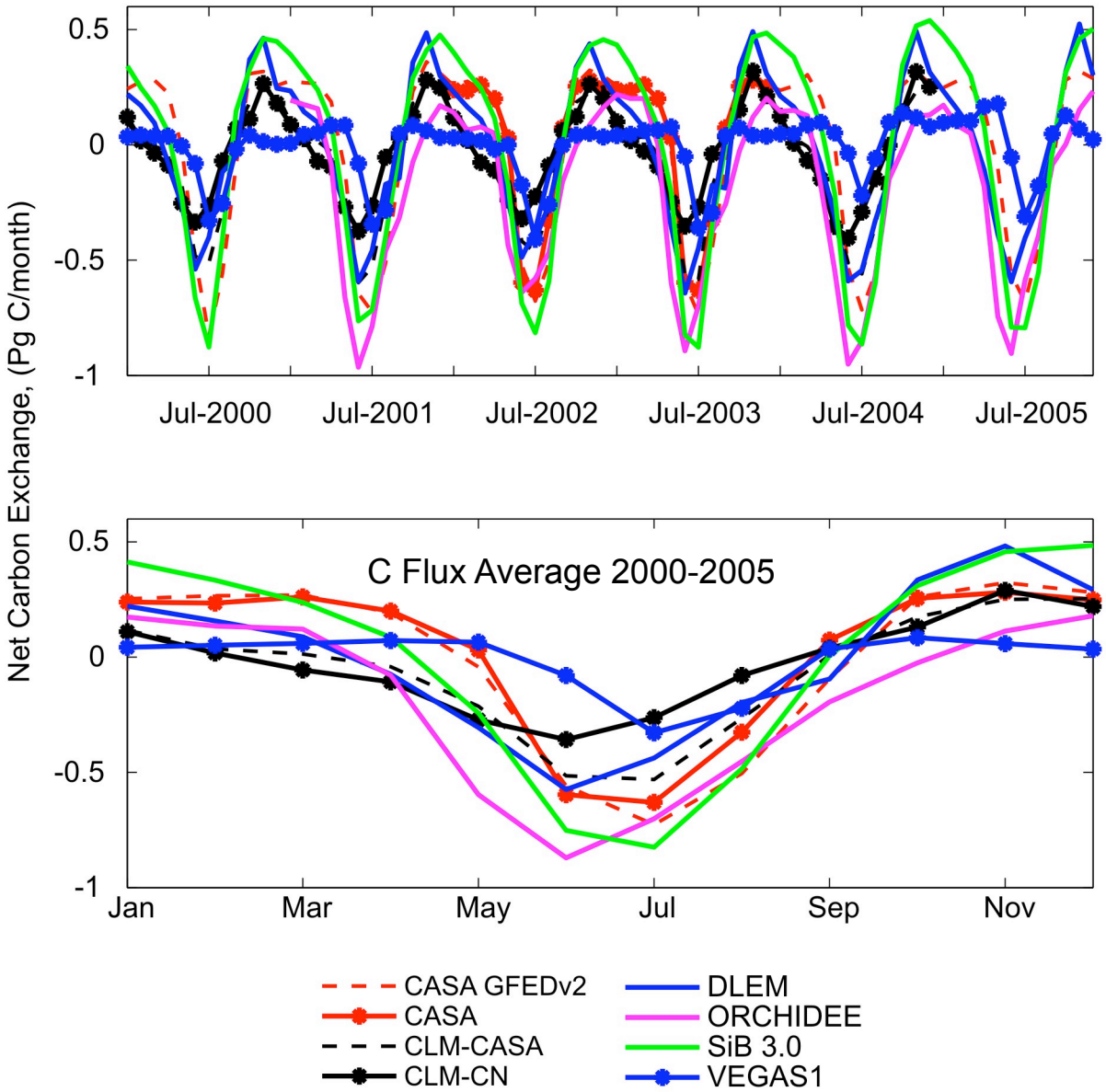
Use of Multiple Data Sources



North America: C Flux

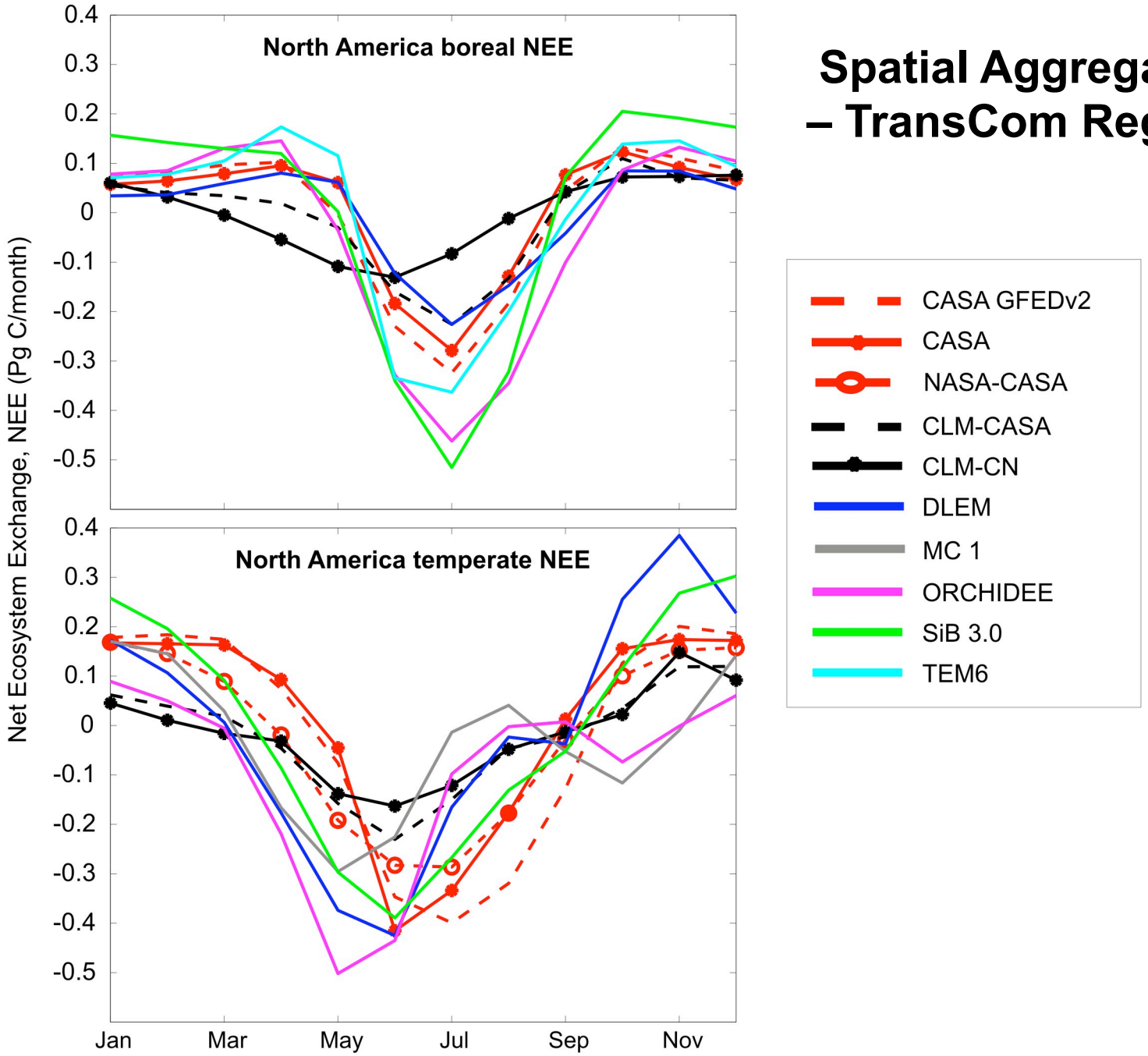


Convention:

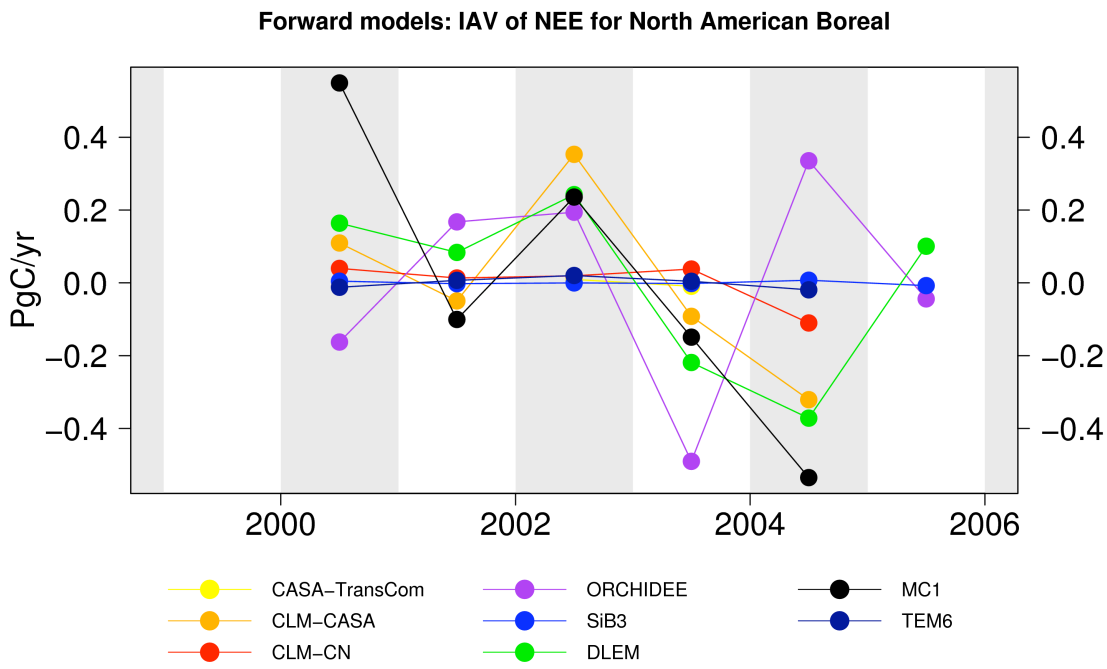
(-) sink

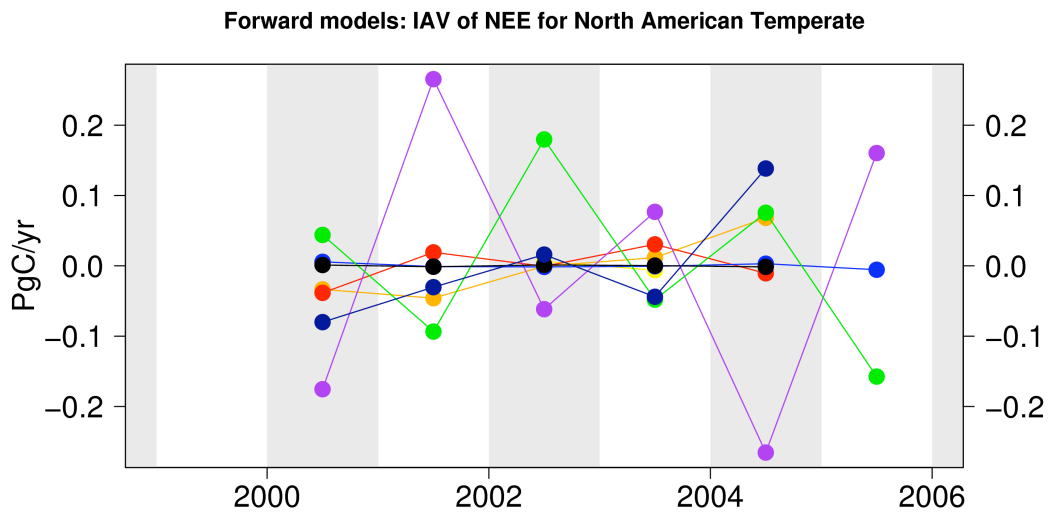
(+) source

Spatial Aggregation – TransCom Regions

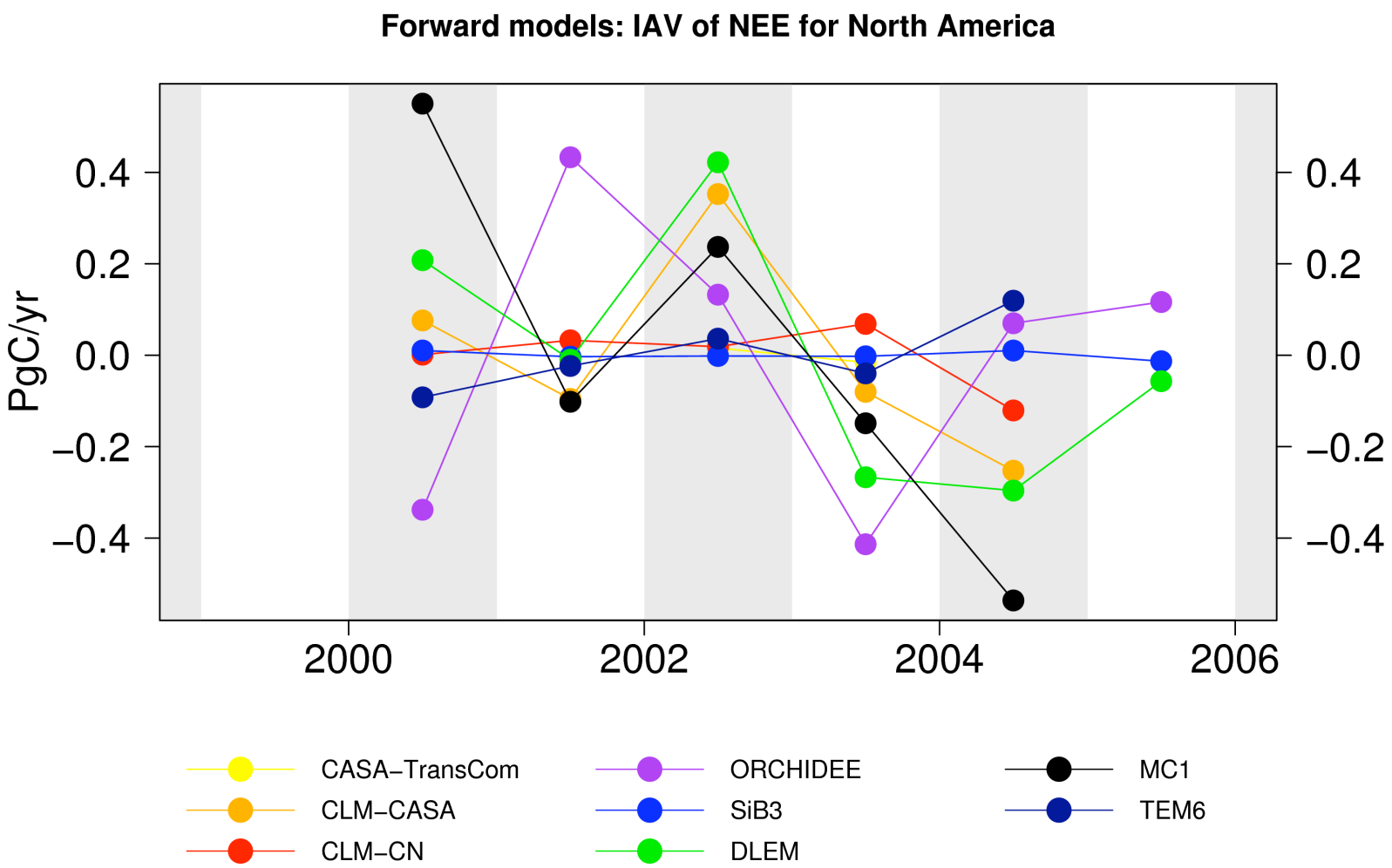


IAV of Carbon Exchange from Forward Models





IAV of Carbon Exchange from Forward Models



Summary of NEE (boreal and temperate) comparison between Inverse and Forward Models

Inversions	25th percentile	Central	75th percentile
Uptake	0.7	1.0	1.4
IAV peak-peak	0.8	1.2	1.6
IAV (sd)	0.26	0.34	0.44

Forward models	25th percentile	**Central**	75th percentile
Uptake	0.0	0.3-0.5	0.4
IAV peak-peak	0.2	0.5	0.8
IAV (sd)	0.06	0.18	0.29

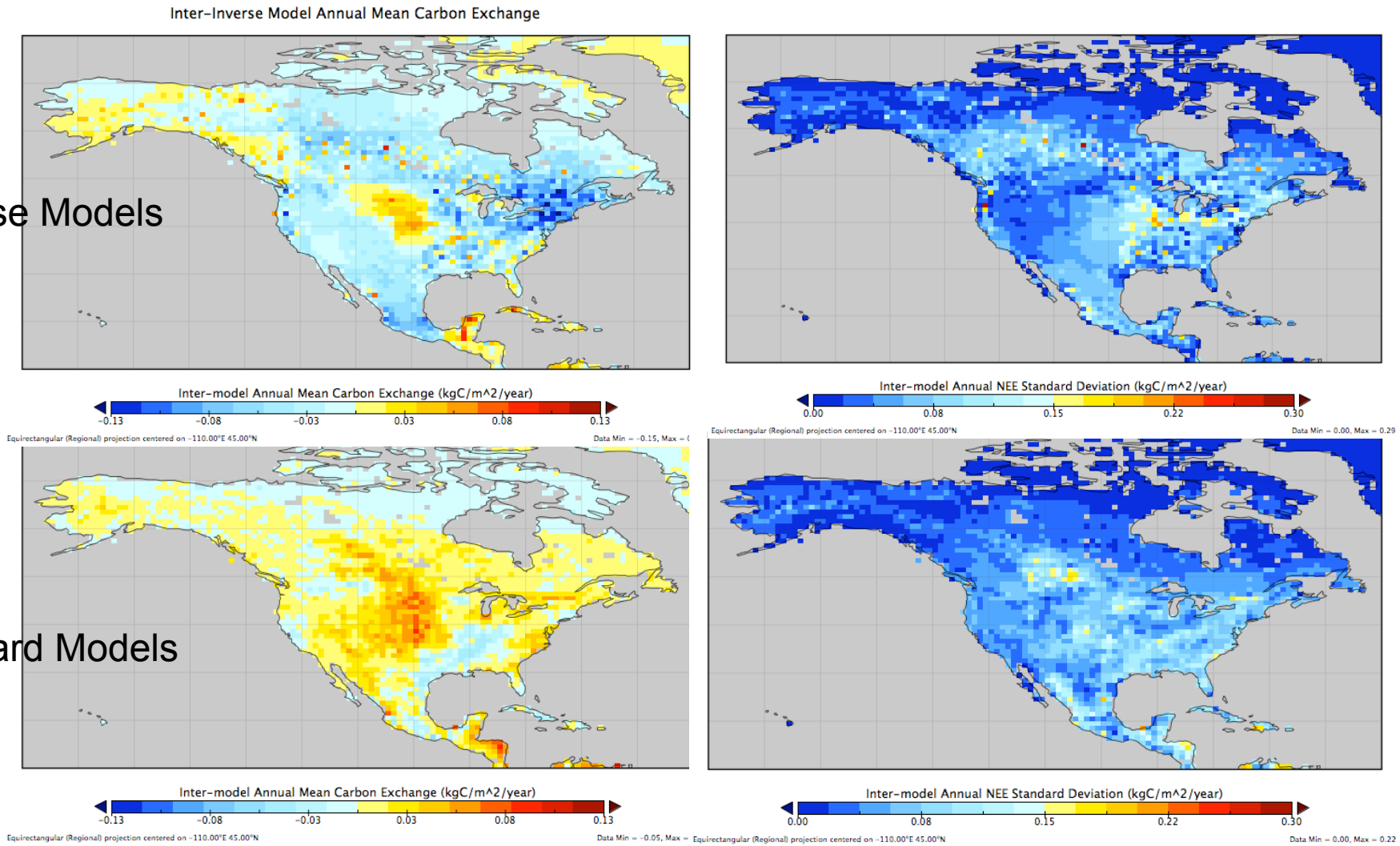
2002 Inter-Model Annual Carbon Flux

Mean Carbon Flux

Standard Deviation Carbon Flux

Inverse Models
N=6

Forward Models
N=12

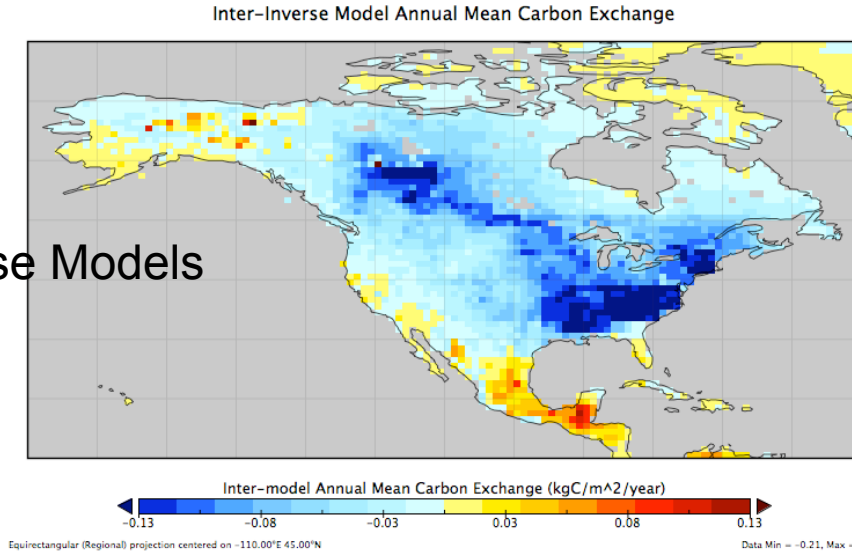


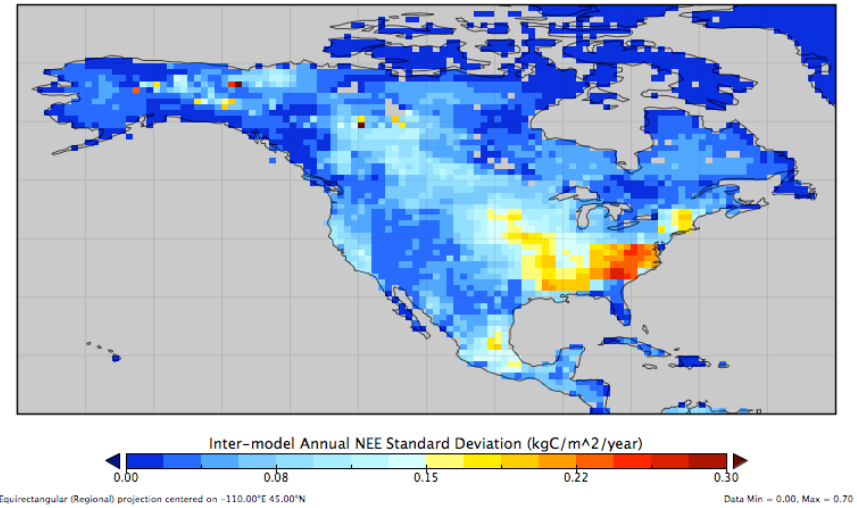
2004 Inter-Model Annual Carbon Flux

Mean Carbon Flux

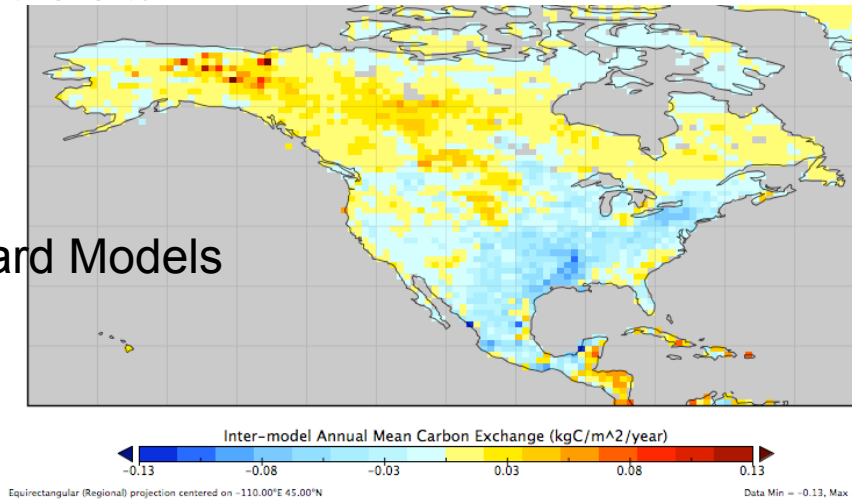
Standard Deviation Carbon Flux

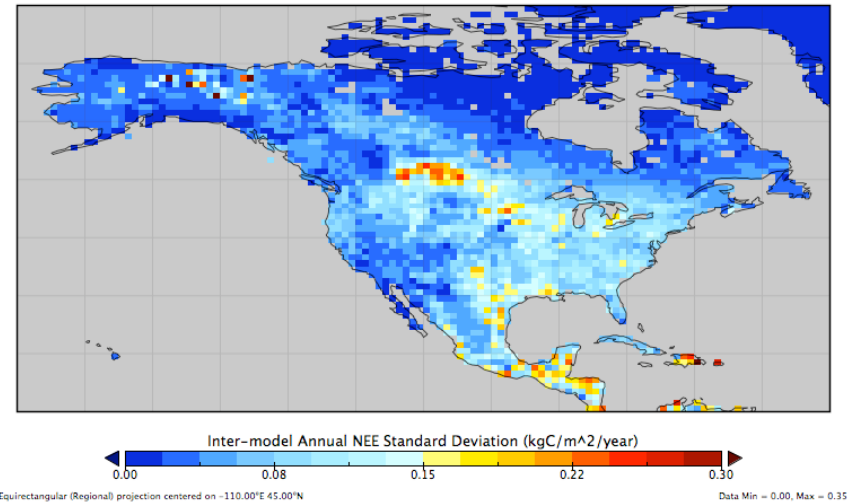
Inverse Models
N=6



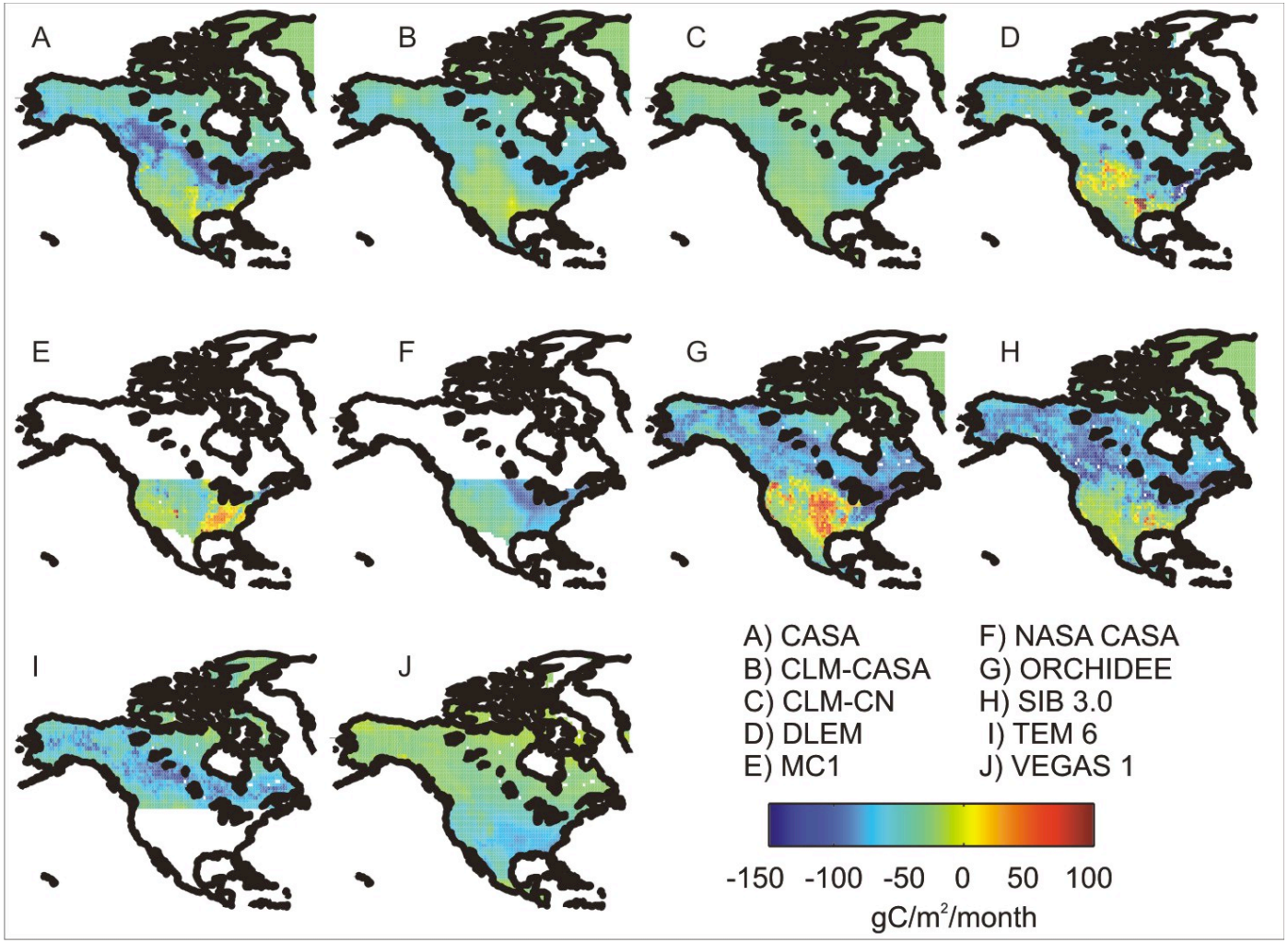


Forward Models
N=12





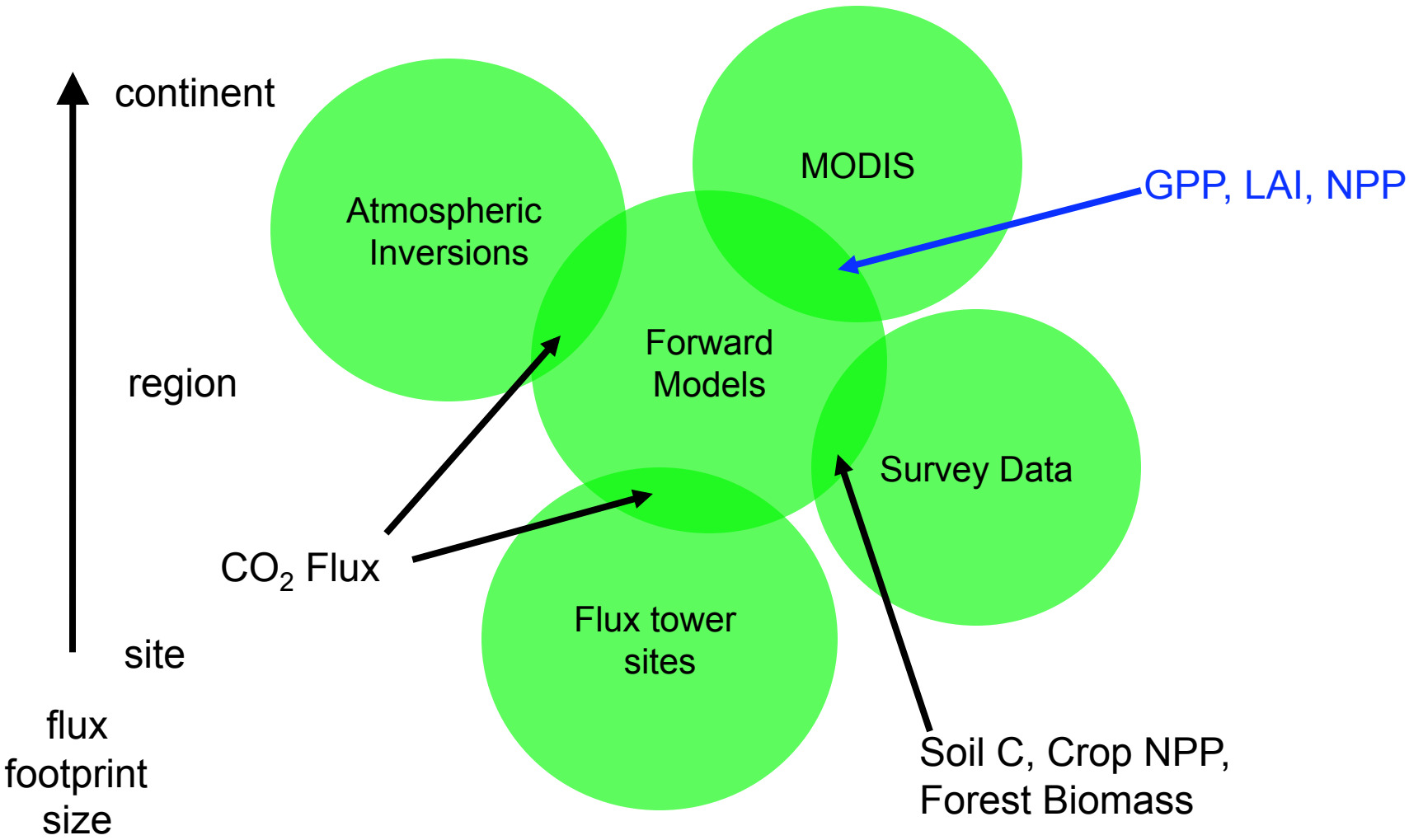
Forward Model Mean July C Flux



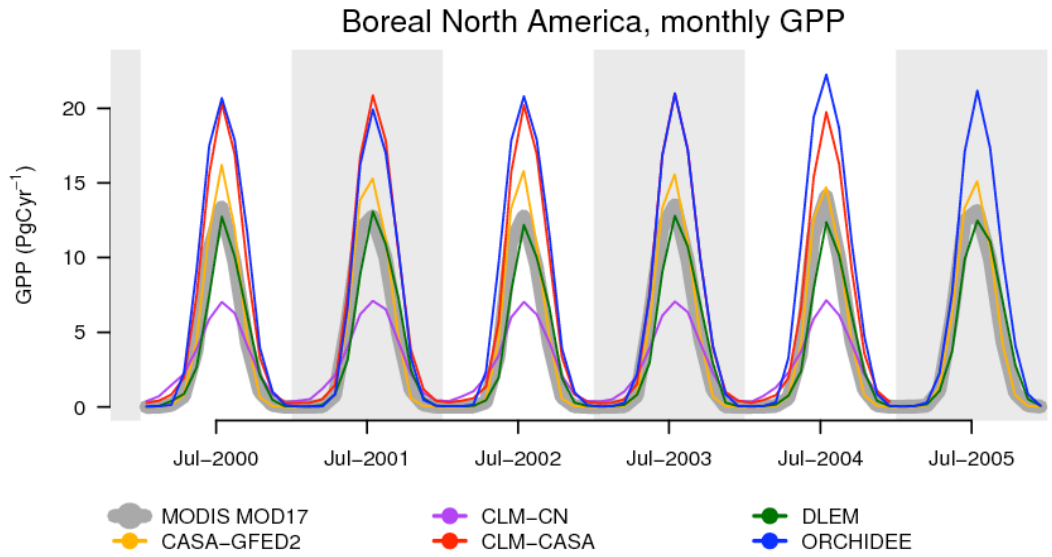
Forward or Ecosystem Models

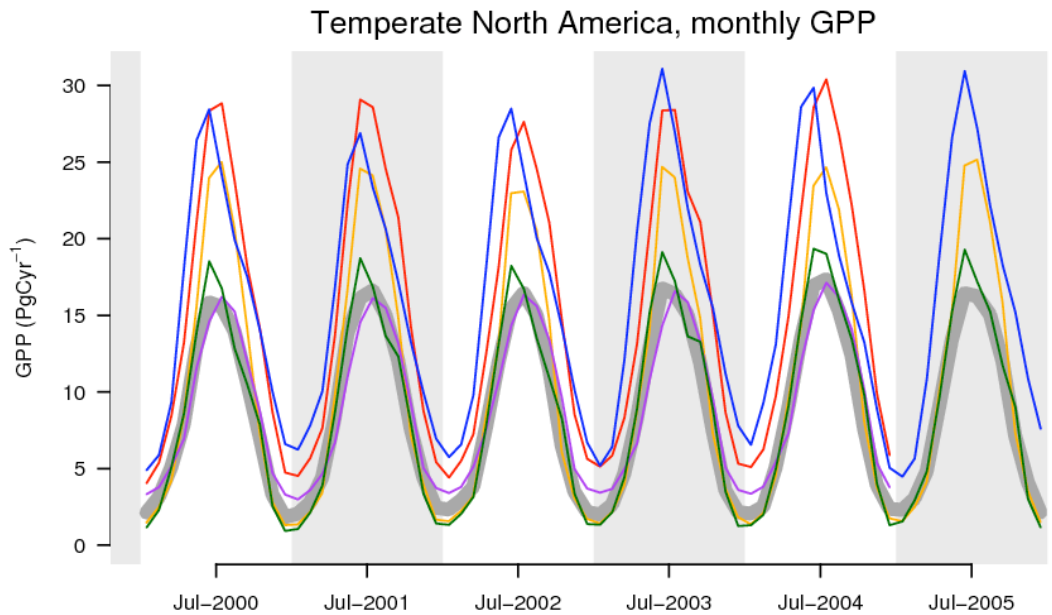
- Large diversity of model types constructed for different reasons
  - Statistical relationships with environmental factors
  - Biologically based process representations based on experimental analyses
  - Incorporate a subset of processes that contribute to total CO_2 flux – often disturbances that, for a single location, are episodic are left out (NEE vs. NECB).
- More ecosystem components are modeled and therefore allows comparison with wider range of observations
- Long-term carbon pools, steady-state issues, dependence on initial conditions introduce difficulties

Use of Multiple Data Sources

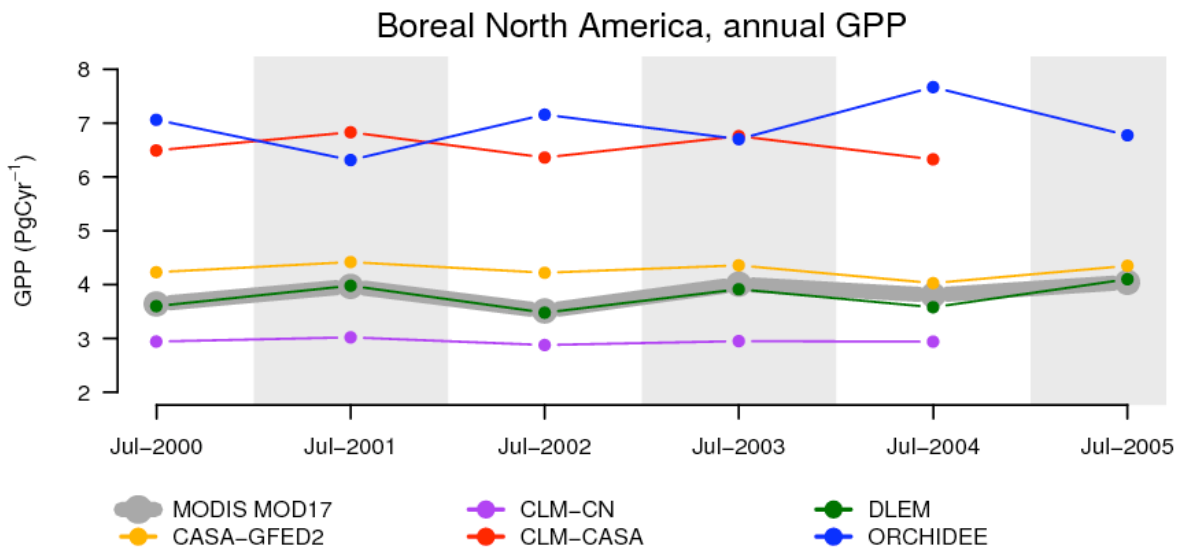


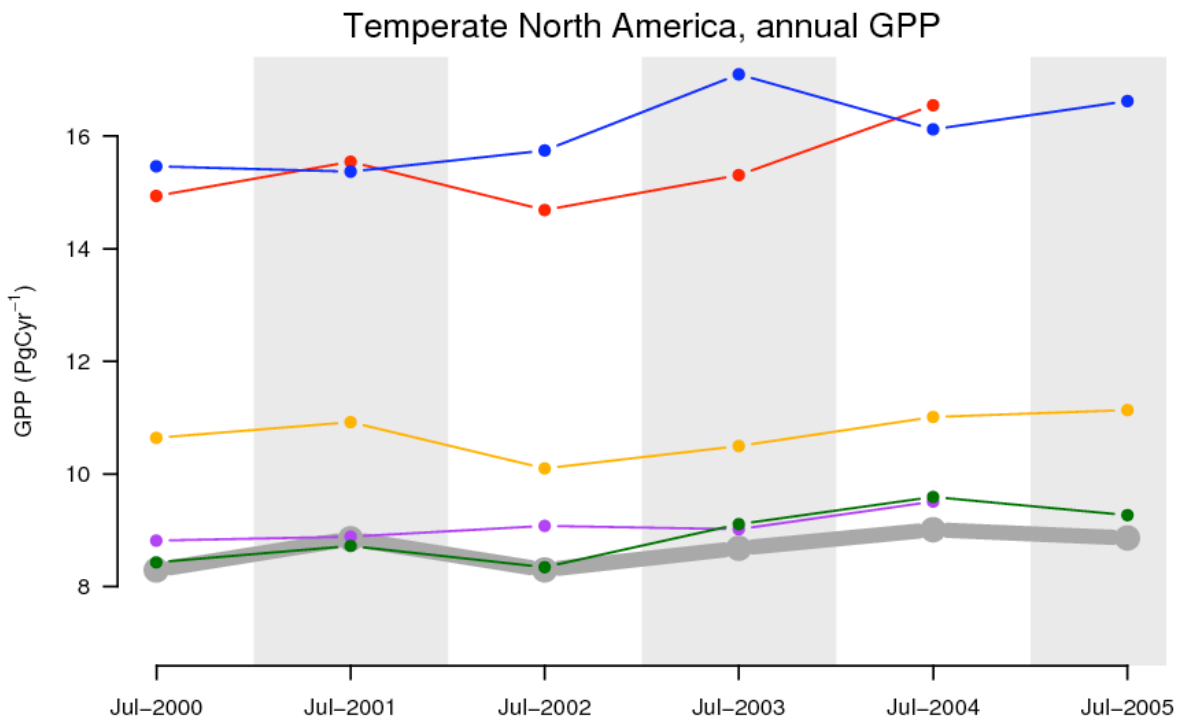
Spatial Aggregation Forward Models for TransCom Regions

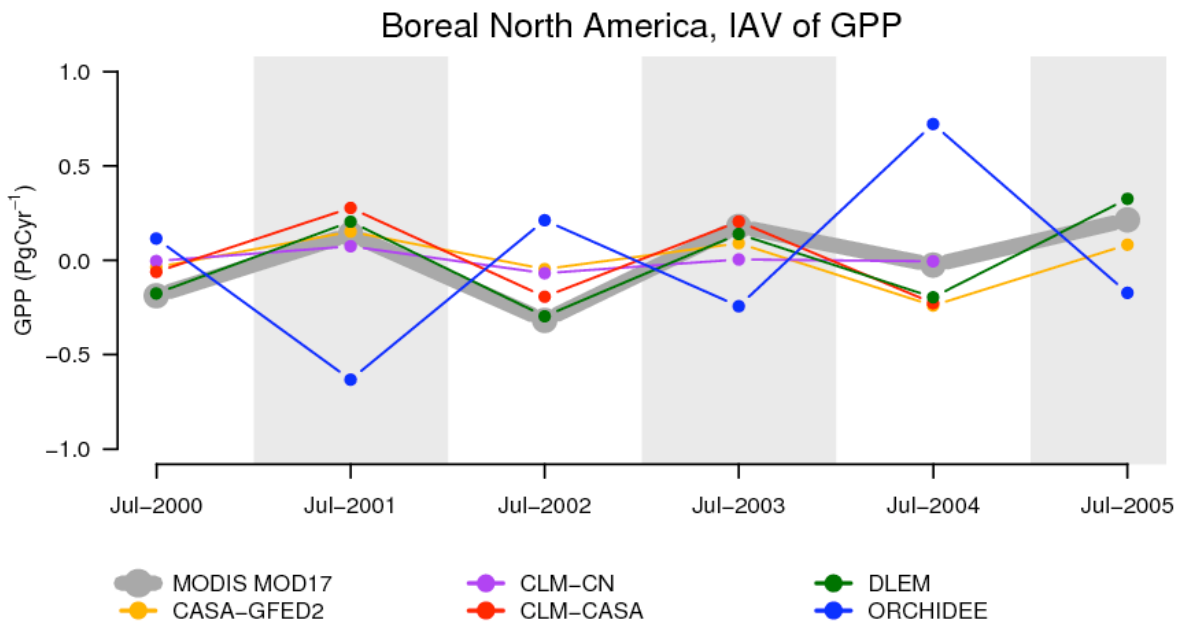


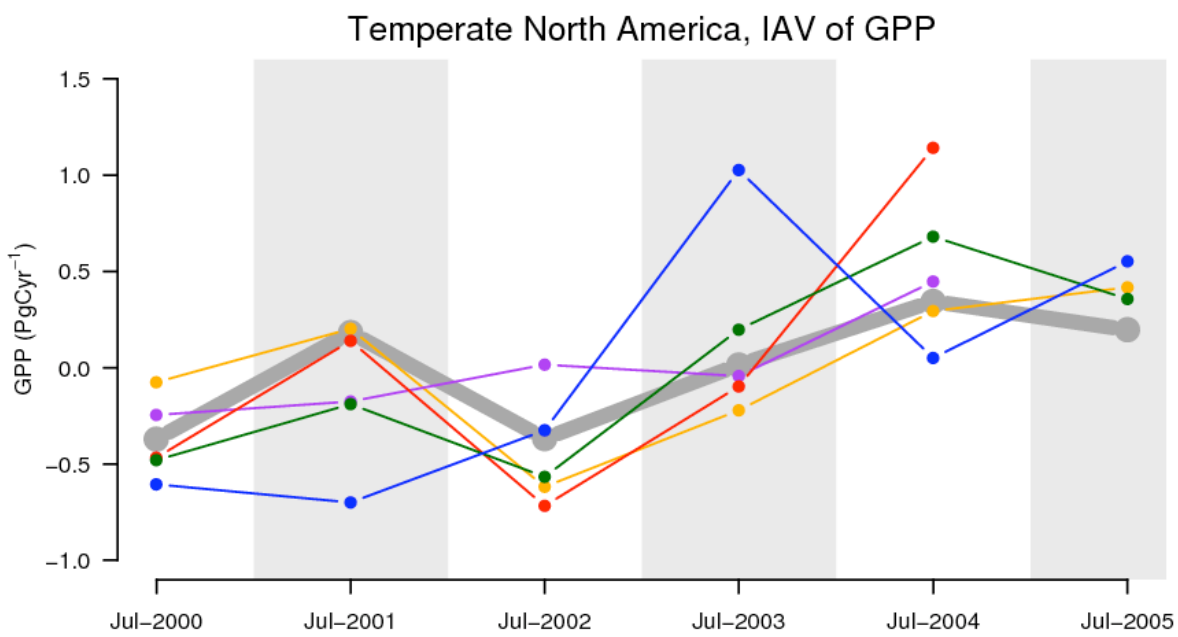


Prepared by Andy Jacobson, NOAA


Boreal North America, annual GPP
GPP (PgCyr^{-1})
8
7
6
5
4
3
2
Jul–2000
Jul–2001
Jul–2002
Jul–2003
Jul–2004
Jul–2005
MODIS MOD17
CASA–GFED2
CLM–CN
CLM–CASA
DLEM
ORCHIDEE


Temperate North America, annual GPP
GPP (PgCyr^{-1})
16
14
12
10
8
Jul–2000
Jul–2001
Jul–2002
Jul–2003
Jul–2004
Jul–2005

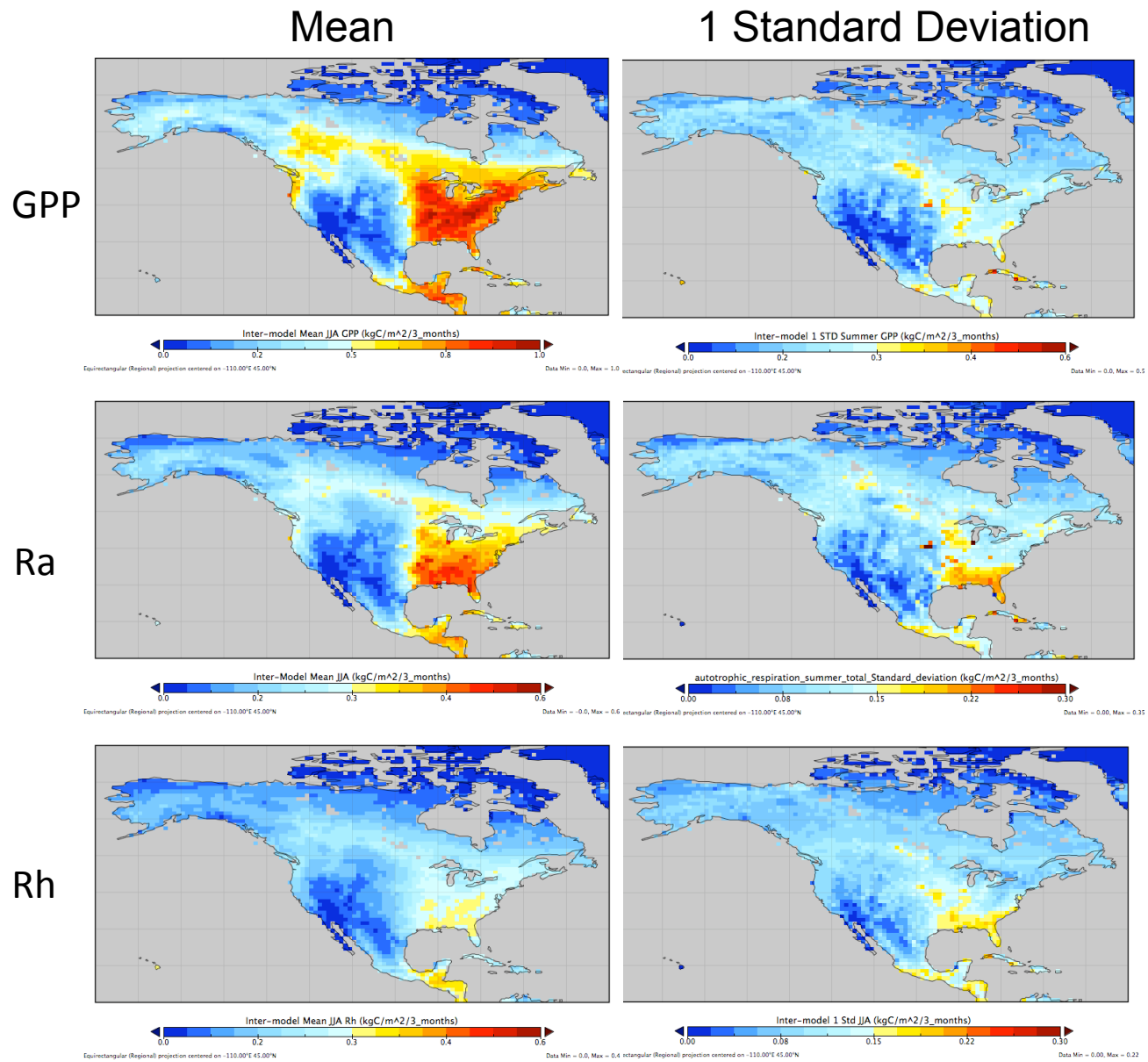

Boreal North America, IAV of GPP
GPP (PgCyr^{-1})
1.0
0.5
0.0
−0.5
−1.0
Jul−2000
Jul−2001
Jul−2002
Jul−2003
Jul−2004
Jul−2005
MODIS MOD17
CASA−GFED2
CLM−CN
CLM−CASA
DLEM
ORCHIDEE


Temperate North America, IAV of GPP
GPP (PgCyr^{-1})
1.5
1.0
0.5
0.0
−0.5
−1.0
Jul−2000
Jul−2001
Jul−2002
Jul−2003
Jul−2004
Jul−2005

Inter-Model Variation in NEE Components – JJA (summer) 2002

Models included:

- CLM-CASA
- CLM-CN
- ORCHIDEE
- VEGAS1
- EC-LUE
- MC1
- TEM6
- CASA-GFed2
- NASA-CASA
- DLEM



Inter-Model Variation in NEE Components – JJA (summer) 2004

Models included:

- CLM-CASA
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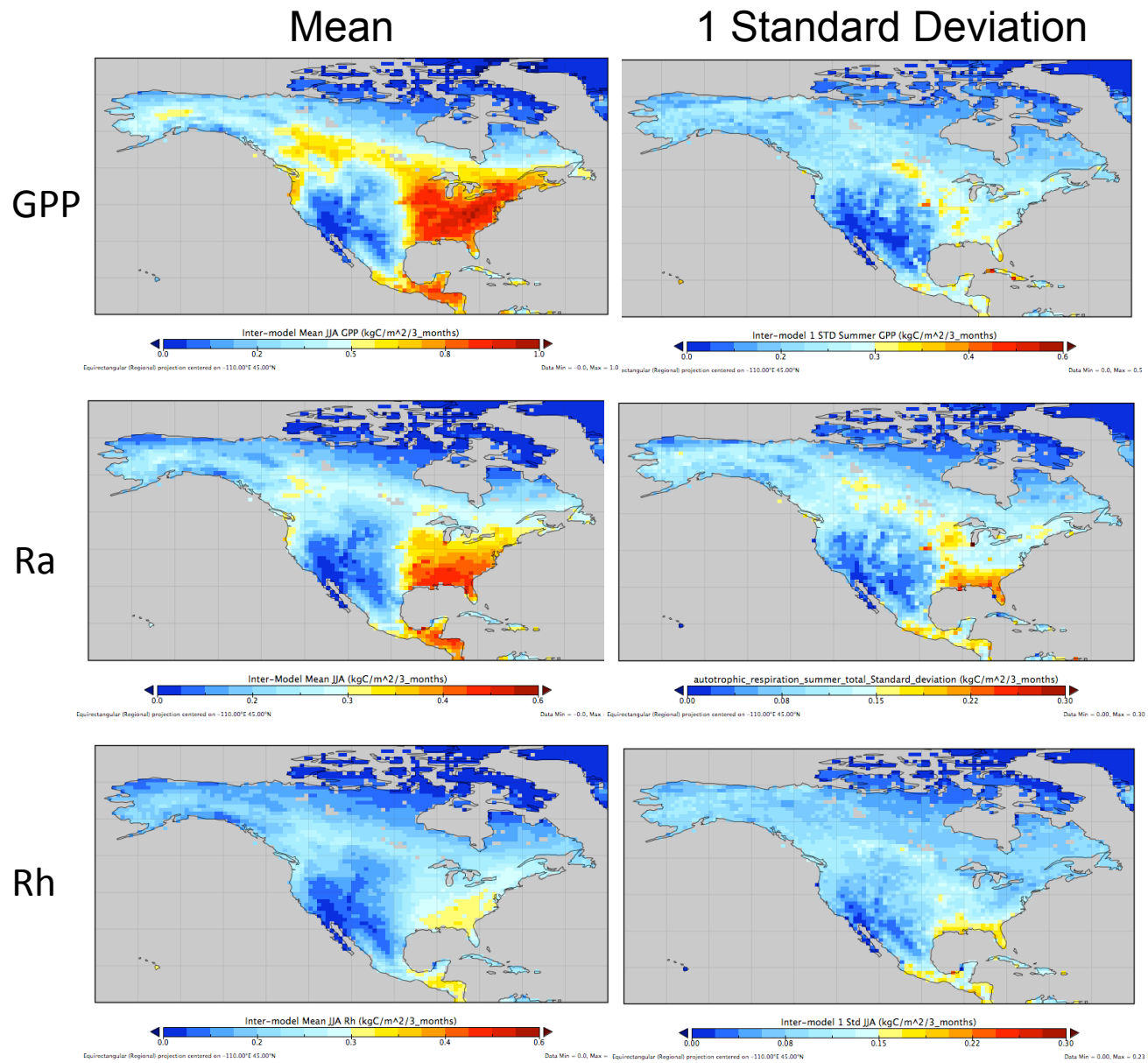
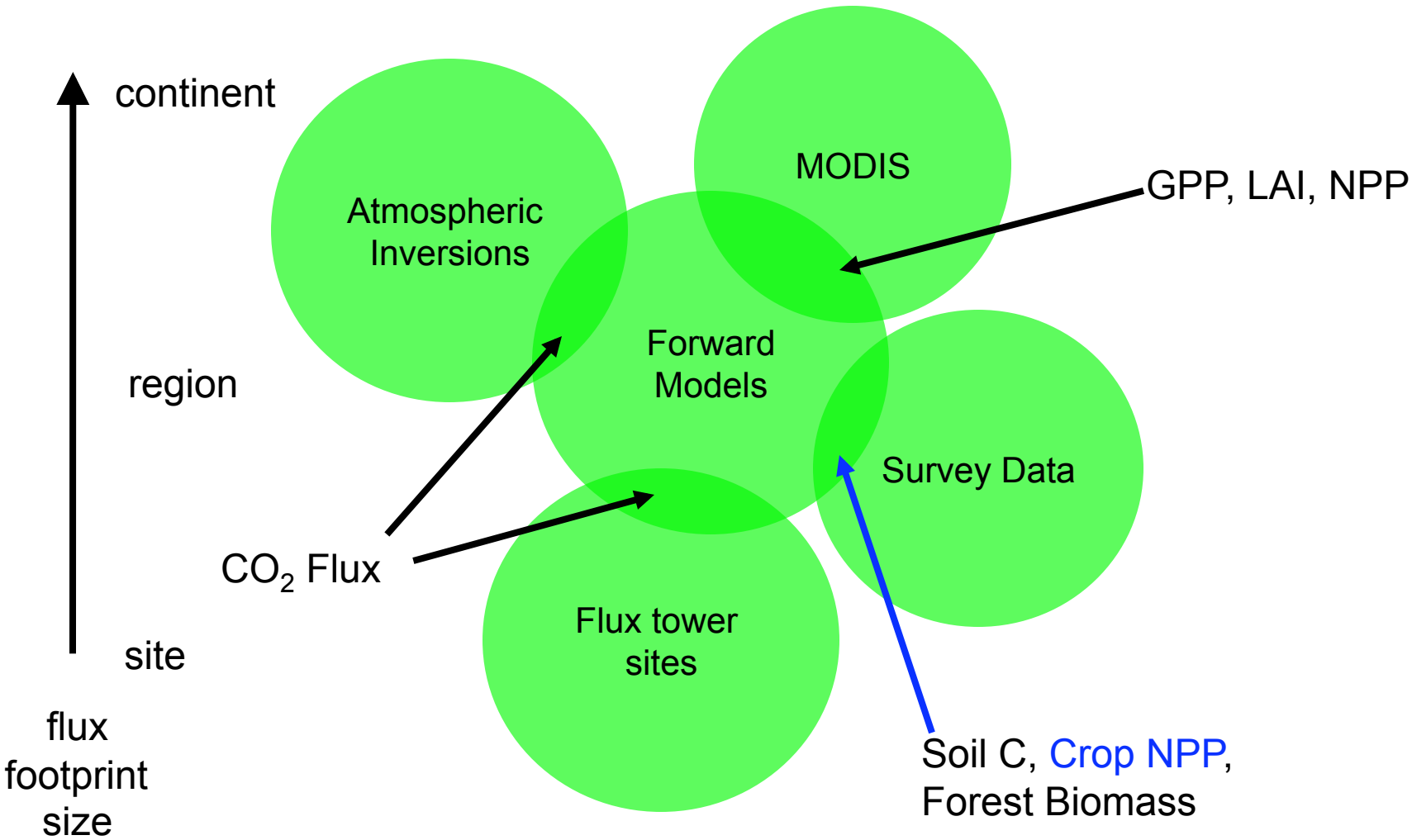
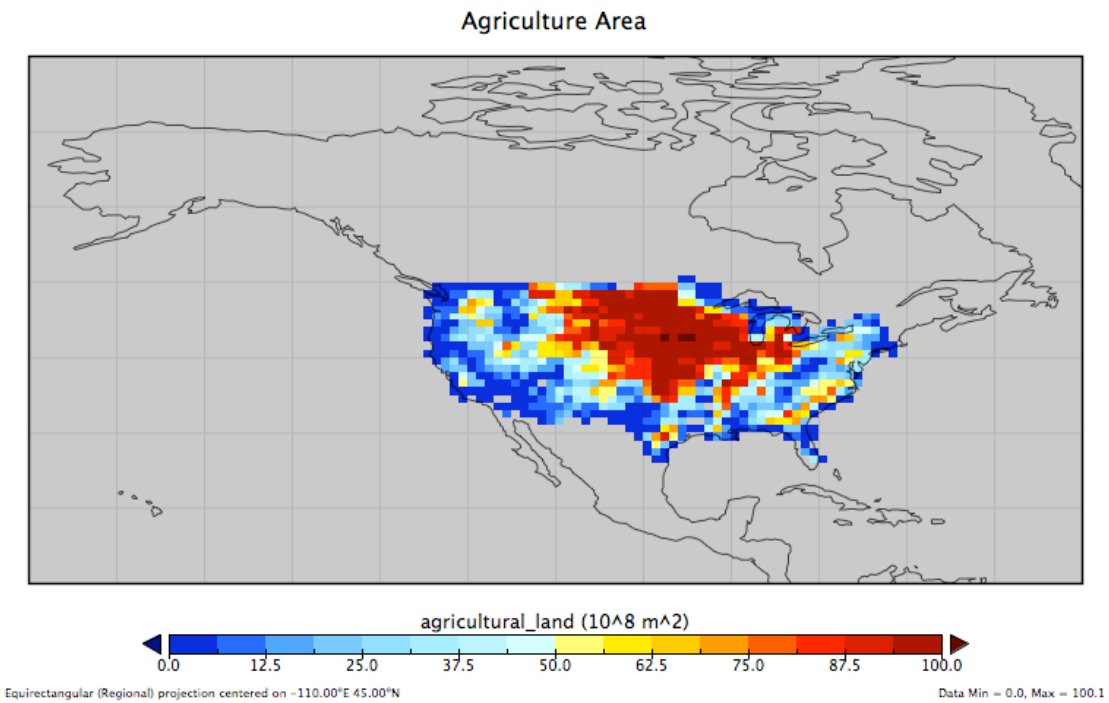


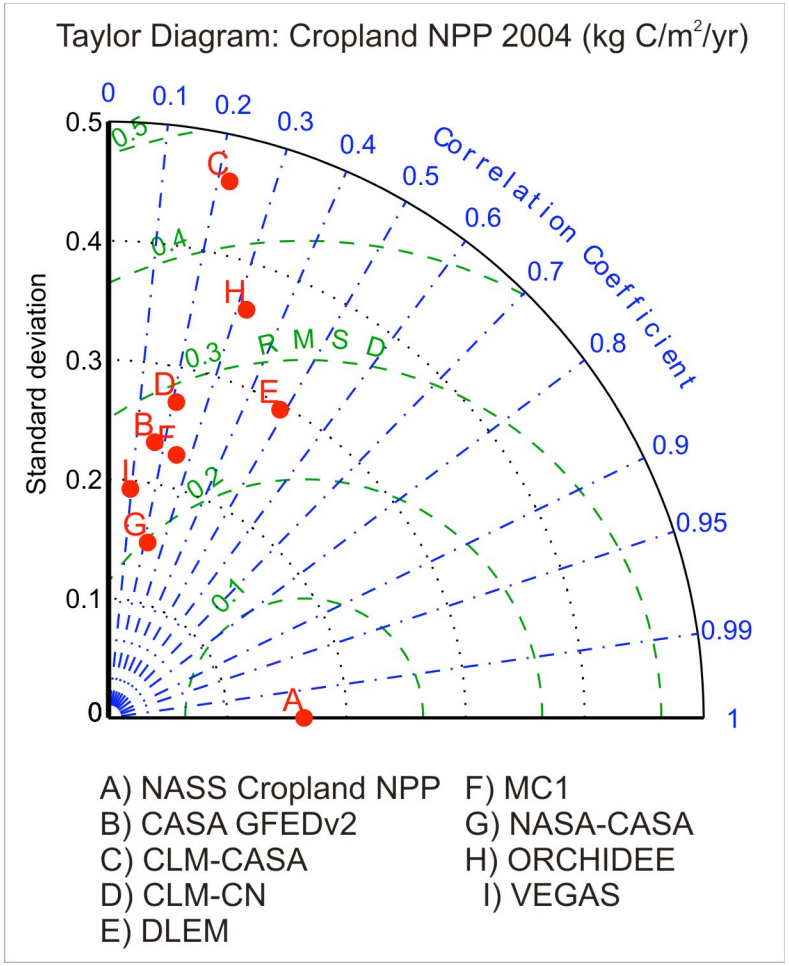
Use of Multiple Data Sources



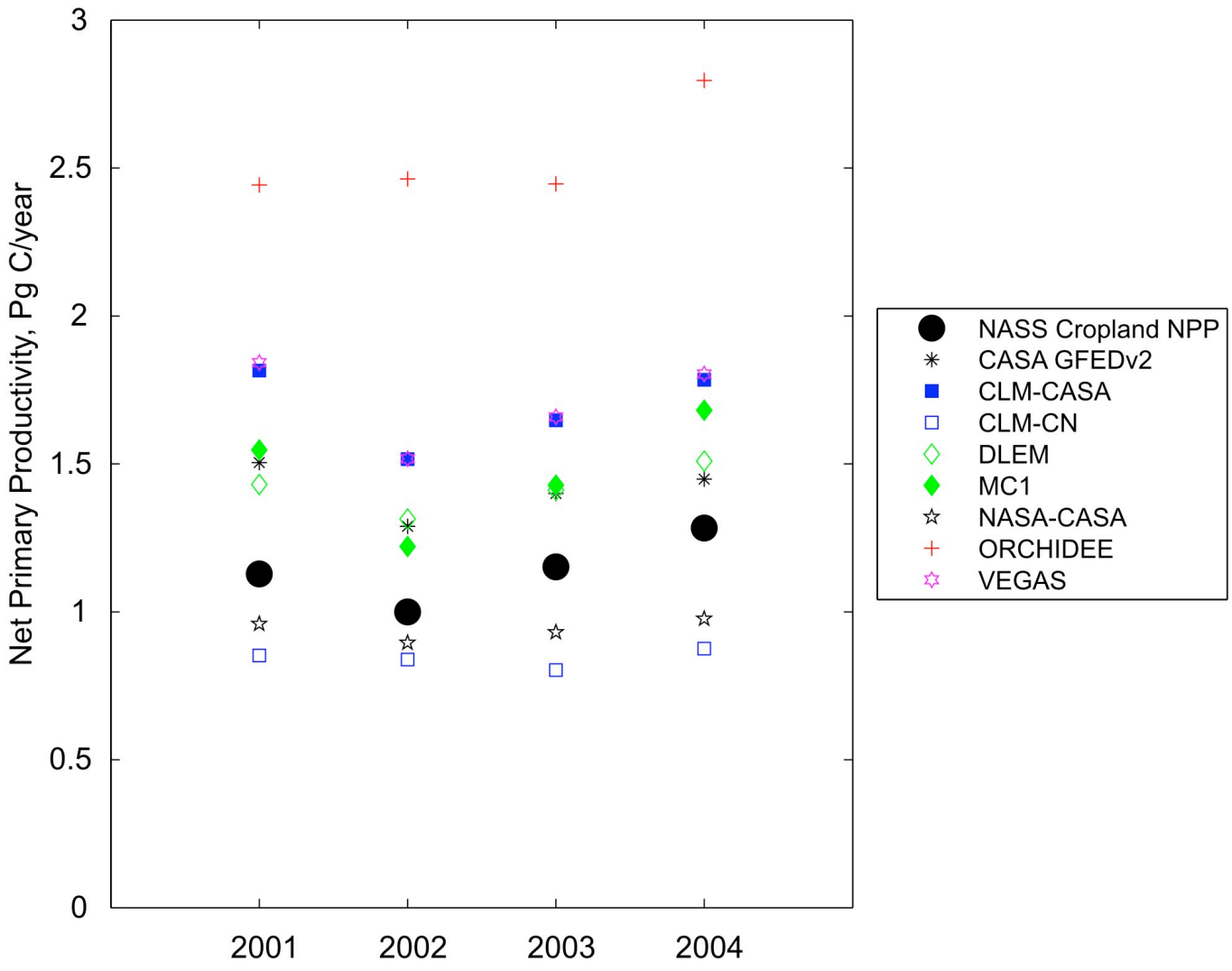
Agricultural NPP

- Select 1 degree cells that are 50% managed agriculture
- Compare model NPP in same 1 degree cells





Agricultural NPP



Forward Model Summary and Observations

- Forward models are very different and do not agree on timing or spatial distribution of C sources/sinks
- Examination of NEE components shows GPP is largest component of discrepancies
- Need additional analyses
  - Site data and information about model performance with site NEE
  - Examine managed forest NPP, esp. Southeast US
  - Need to clarify additional components of NECB in addition to components of NEE

Proceeding from Here

Need Additional Model Variables:

- GPP, NPP, NEE, Ra, Rh, LAI (FPAR, NDVI, EVI), Soil C, Biomass at monthly or annual times

Need Additional Model Experiments:

- Especially various disturbance effects – fire, biomass harvest, insect outbreaks
- CO_2 forcing, N deposition, management

Need ideas:

- Additional regional/continental observation based datasets
- Creative methods for model-data comparison

Reporting of Current Findings

Tasks

- Gather additional forward model metadata
  - What components of NECB are included
  - How processes are represented
  - Details on boundary and forcing conditions
- Develop Manuscripts
  1. Fast-track Forest and Agriculture inventory – Model comparison
  2. Temporal Analysis – mostly completed, need to complement with and “expert” update of the SOCCR estimates on an annual time step (Jacobson, McGuire, Post, others). This could involve interaction with Site Synthesis results for non-managed ecosystems (Tundra, wetlands, grasslands, stc.)
  3. Spatial Analysis (Huntzinger, Post)
  4. Extreme event analysis (Zeng)

After the Interim Synthesis: The Well Planned Regional Synthesis

- Conduct a formal regional scale data-model comparison
- Development of benchmarks for model evaluation ala C-LAMP
- Development of inventory change estimates and uncertainties in those estimates that are spatially and temporally resolved – Soil C, Forest, Agriculture
- Evaluation of inversion sensitivity to terrestrial biosphere model priors and other inversion uncertainties
- Evaluation of sensitivity of flask station CO_2 concentration estimates to terrestrial biosphere model and fossil fuel fluxes
- Model-data synthesis activities should NOT be delayed until after all data collection. They should begin now!