United States Carbon Cycle Science Program
An Interagency Partnership

The State of North American Carbon Science: A State of Transition

North American Carbon Program
2nd NACP All-Investigators Meeting
San Diego, California
February 17-20, 2009

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[1]Penn State University
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This talk is a

…straw-person.

- You will update the science via the upcoming posters and talks.
- You will provide feedback on the proposed needs, challenges and opportunities via the upcoming breakout sessions.

Please treat this talk as such in the coming days.

Outline

- **Review: What is the NACP?**
  - **NACP Goals, Questions and Deliverables**
- **State of the science**
  - **Prelude to the coming talks**
- **Needs, opportunities and challenges**
  - **A state of transition**

Conclusions

- We are nearing "success" at regional and continental diagnoses of the CO_2 budget.
- Essential elements of our continental observation and analysis system are endangered.
- We need to engage whole-heartedly in research that is integrated with decision support. This will require:
  - Increased emphasis on prediction, model-data syntheses and model comparisons.
  - Increased emphasis on uncertainty assessment, network design, and data/metadata management.
  - Increased focus on human emissions of carbon and study of the mechanisms governing these emissions.
- We need to articulate which decisions we are supporting.

Review: What is the NACP?

Documents, groups, acronyms

- CCSP - (U.S.) Climate Change Science Plan
- U.S. Carbon Cycle Science Plan - Sarmiento and Wofsy, 1999
- CCIWG - Carbon Cycle Interagency Working Group
- CCSSG - Carbon Cycle Science Steering Group
- NACP Plan, Harriss, Wofsy et al., 2002.
- NACP SSG
- NACP Science Implementation Strategy (SIS) - Denning et al., 2005
- NACP Midcontinent Intensive (MCI) Science Plan - Ogle et al., 2006
- JNACP - Joint NACP - collaboration with Mexican and Canadian research efforts
- CCSWG - Carbon Cycle Science Working Group

(Yellow - currently being updated)

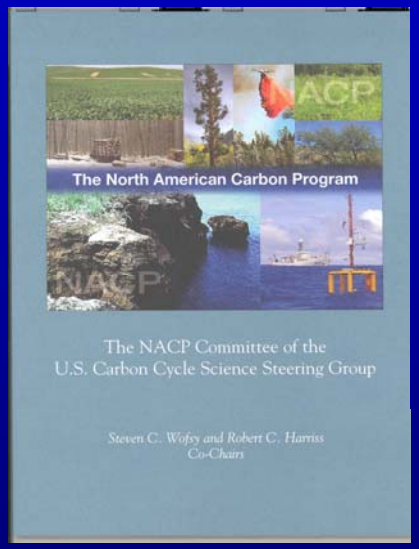
http://www.nacarbon.org
http://www.carboncyclescience.gov

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.

NACP Goals

1. Develop quantitative scientific knowledge, robust observations, and models to determine the emissions and uptake of CO_2, CH_4, and CO, the changes in carbon stocks, and the factors regulating these processes for North America and adjacent ocean basins.
2. Develop the scientific basis to implement full carbon accounting on regional and continental scales.
3. Support long-term quantitative measurements of sources and sinks of atmospheric CO_2 and CH_4, and develop forecasts for future trends.



NACP Plan, 2002

Five-Year Deliverables from *NACP Plan*

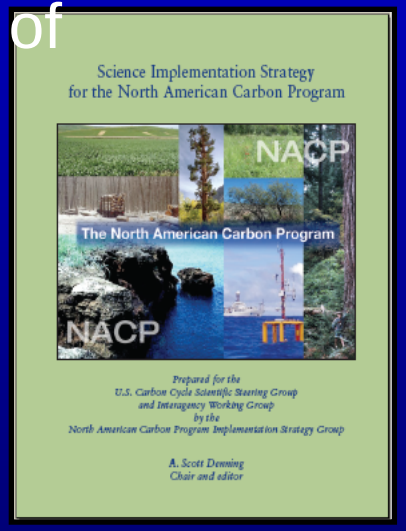
- Measurements of sources and sinks for CO_2, CH_4, and CO for North America and adjacent ocean basins at scales from continental to local, with seasonal resolution.
- Attribution of sources and sinks to contributing mechanisms.
- Documentation of North America's contribution to the Northern Hemisphere carbon budget.
- Optimized sampling networks (both ground-based and remote) to determine past, current, and future sources and sinks.
- Data assimilation models to compute carbon balances.
- First *State of the Carbon Cycle Report* (SOCCR) for North America.

Operational Phase of the NACP

The NACP Plan called for an operational phase of NACP in which the observational and analysis infrastructure would be available, as a “legacy” to “produce periodic, reliable estimates of net sources and sinks for CO_2, CO, and CH_4 and of changes in carbon stocks.”

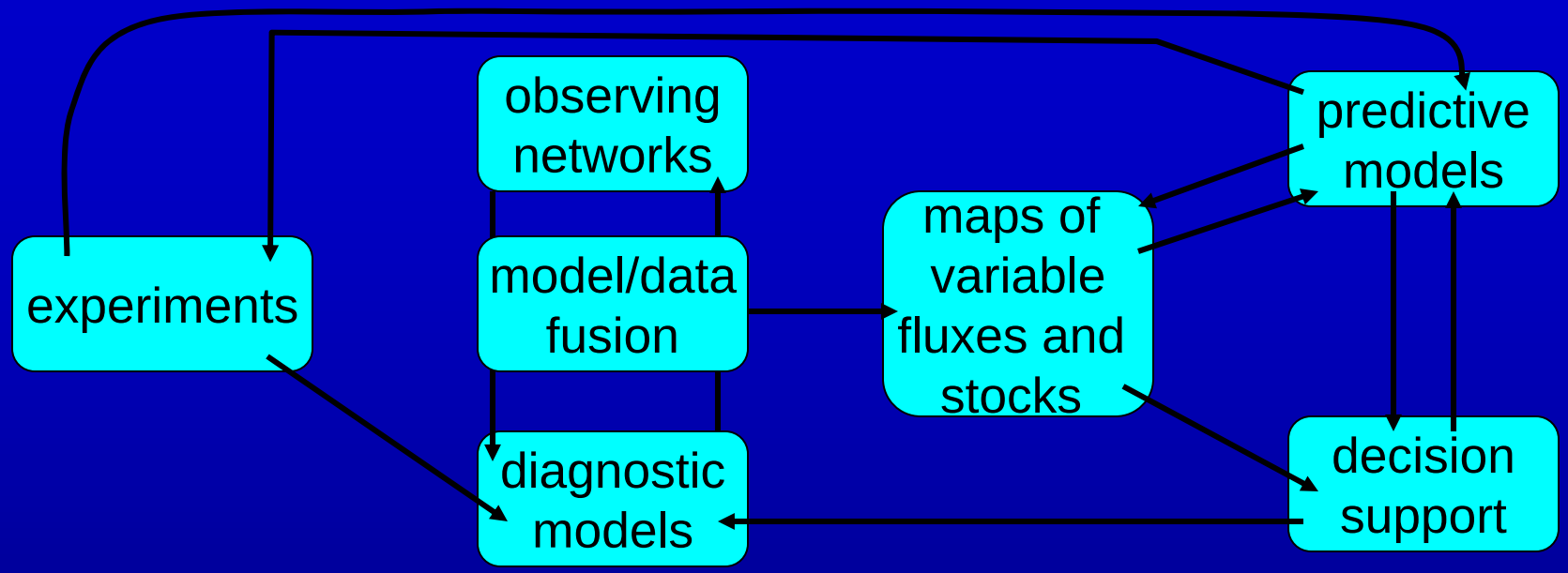
NACP Questions

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***")



Implementation Strategy, 2005

(modified) NACP Integration Strategy



- Process studies and manipulative experiments inform improved models
- Systematic observations of land, ocean, and atmosphere used to evaluate models
- Innovative model-data fusion techniques produce optimal estimates of time mean and spatial and temporal variations in fluxes and stocks
- Improved models used to predict future variations, and tested against ongoing diagnostic analyses
- Models provide feedback on design of additional experiments
- Predictive models and continuing analyses used to enhance decision support

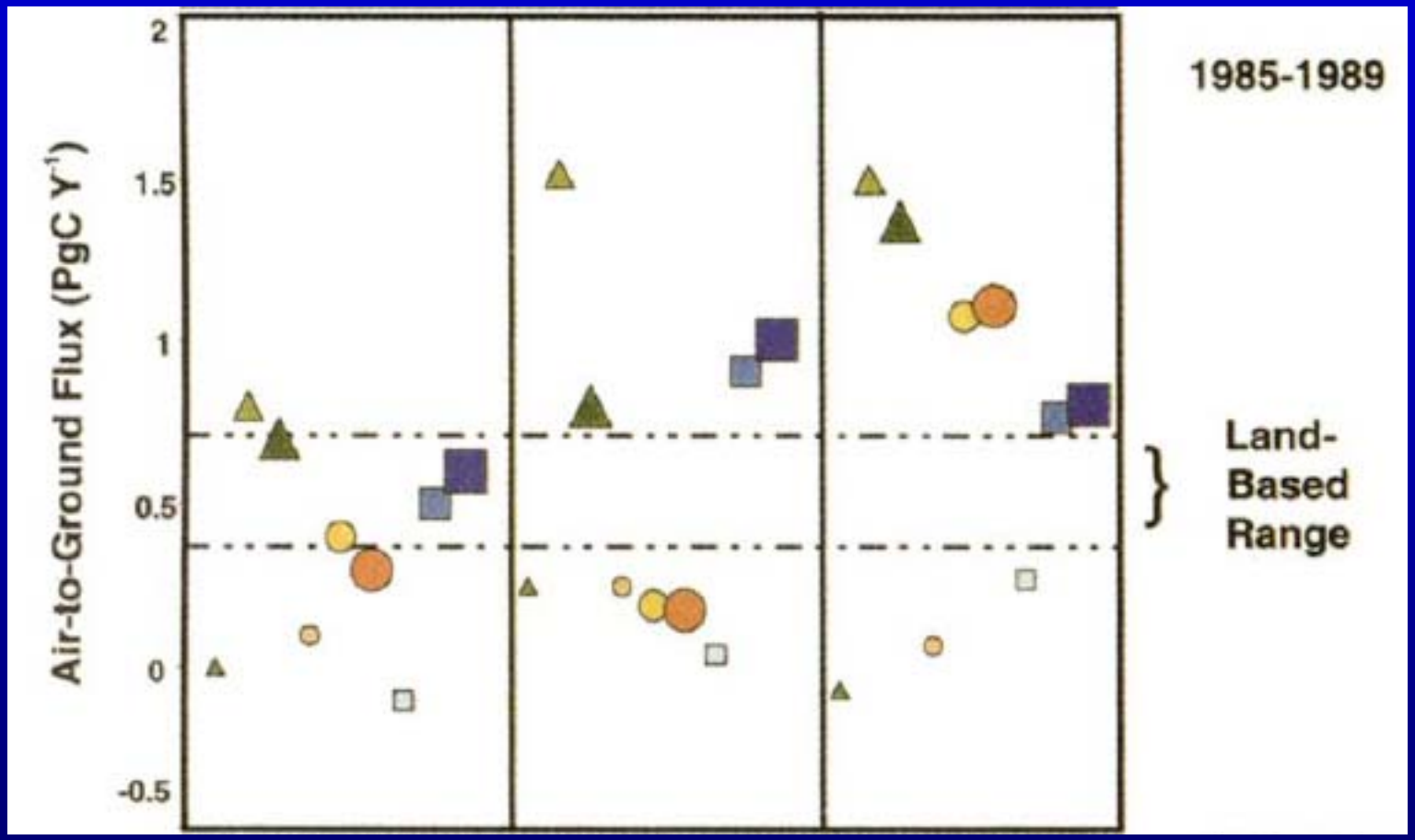
State of the science

State of the science

- Pre-NACP
- Examples of recent progress
- Ongoing work, future progress

Pre-NACP

Atmospheric-biomass inventory comparison

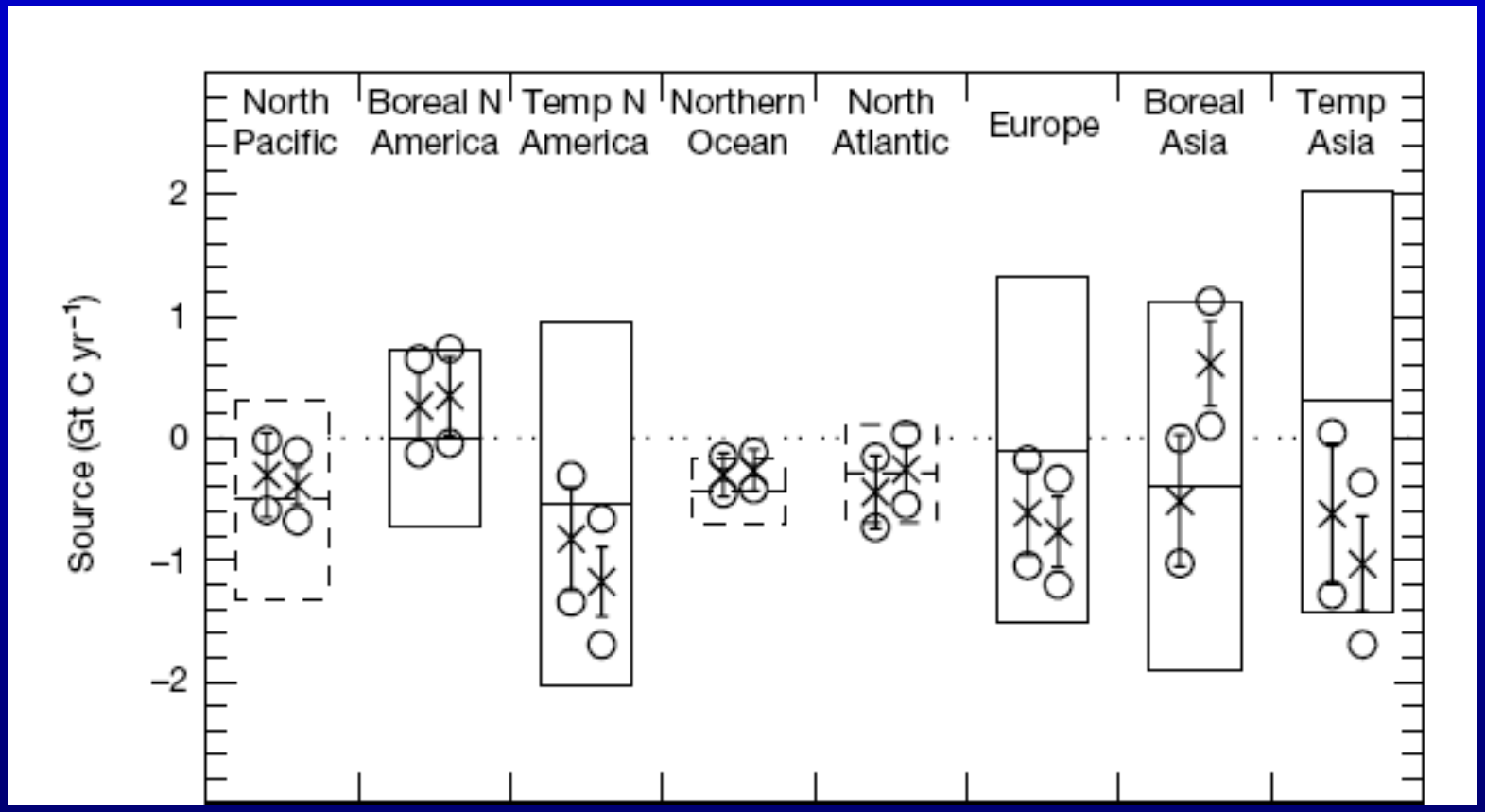


Results demonstrate rough agreement between atmospheric and biomass inventories over the coterminous United States.

Pacala et al, 2001, Science.

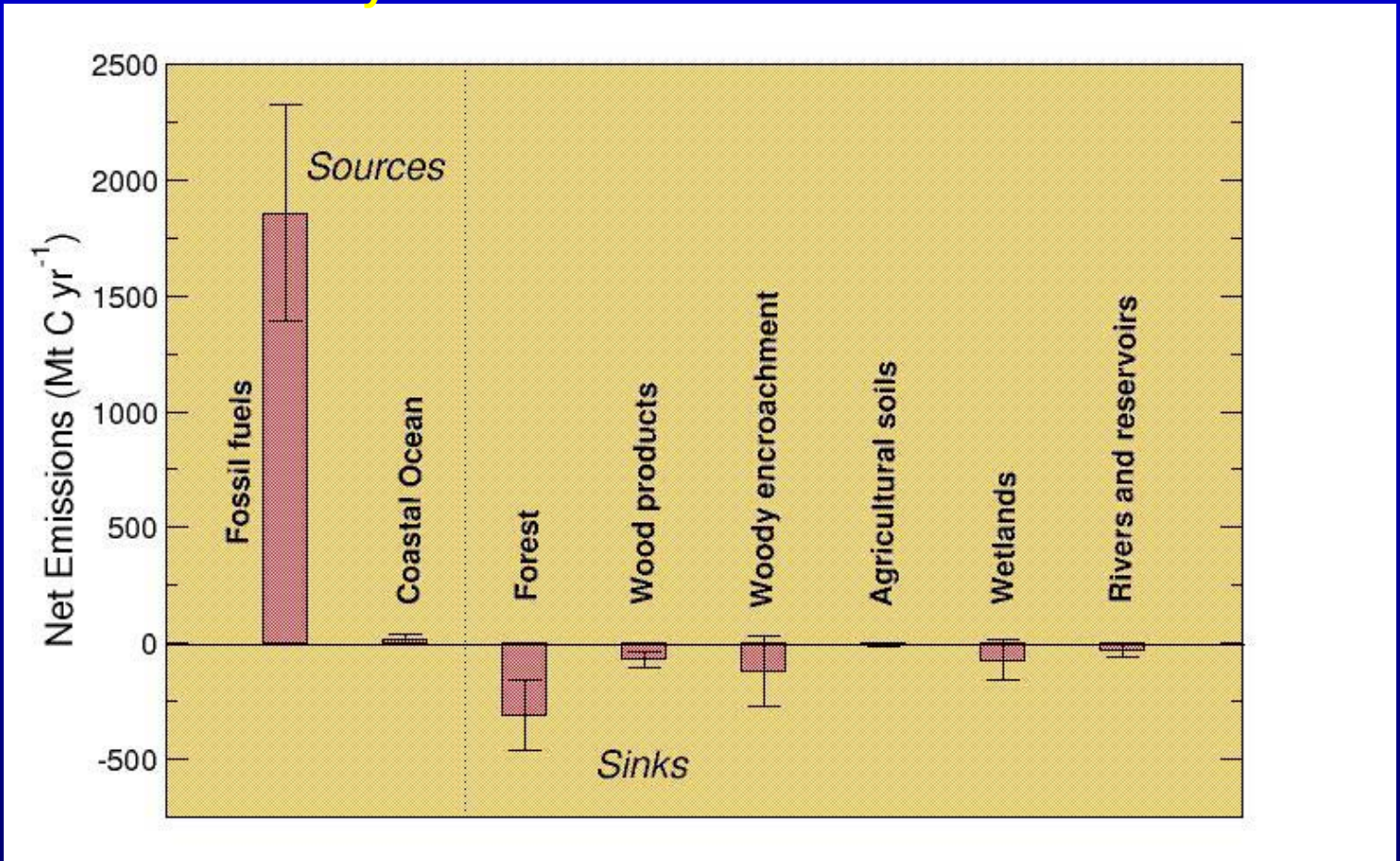
Points represent various methods of performing the atmospheric inverse estimate.

Atmospheric inventory results



Gurney et al, 2002, Nature

North America is currently a net source of CO_2 (1264 Mt C yr^{-1}), with 30% of fossil fuel emissions (1856 ± 464 Mt C yr^{-1} in 2003) offset by a net terrestrial sink of 592 ± 296 Mt C yr^{-1}.



Pre-NACP results

- Consistency in N. American net CO_2 flux among methods.
- Coarse temporal (multi-year) and spatial (continental) resolution.
- “Large” uncertainty in the continental CO_2 balance.

Examples of recent progress

“Operational” Atmospheric Budgets

Global Monitoring Division

http://chinook.cmdl.noaa.gov/ccgg/carbontracker/index.php

News ▾ NOAA/CIRES ▾ Search ▾ Carbon Cycle Research ▾ Climate Data ▾ Journals (14) ▾ HP Computing ▾ Headlines (64) ▾ Personal ▾ Elog GMD CarbonTracker

Global Monitoring Divisi... | Superscript and Subscript | Python: module pycdf.py... | 2007 NACP Meetings | Pavement's gone to pot :...

Earth System Research Laboratory
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Data

CarbonTracker

- Home
- Introduction
- Latest Results
  - Carbon Weather
  - Flux Maps
  - Flux Time Series
  - Product Evaluation
- Description
- Documentation
- Summary

Data

- Observations
  - Download
  - IADV
- Model

Participation

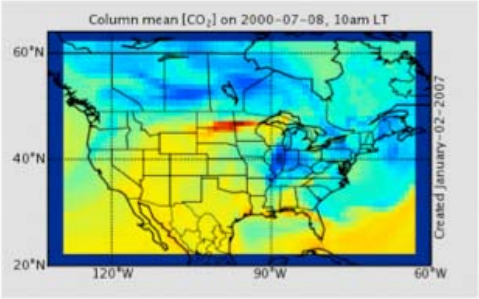
- Contact
- Membership

Resources

- Site Map
- FAQ
- Glossary
- Performance Goals

CarbonTracker

CarbonTracker is a tool designed to keep track of time dependent emissions and uptake of atmospheric carbon dioxide (CO_2), both natural and manmade. CarbonTracker is global, but the emphasis is on North America because that is where we currently have the most data. We expect to update this product once a year, with results through the end of the previous year. The atmospheric CO_2 data is still very sparse, and we invite additional organizations to join and make this an evolving community project by bringing in new data and model improvements. [read more]



Plumes of Carbon Dioxide move with the weather

Products >> CarbonTracker

U.S. Department of Commerce | National Oceanic and Atmospheric Administration
Earth System Research Laboratory | Global Monitoring Division
http://chinook.cmdl.noaa.gov/ccgg/carbontracker/index.php

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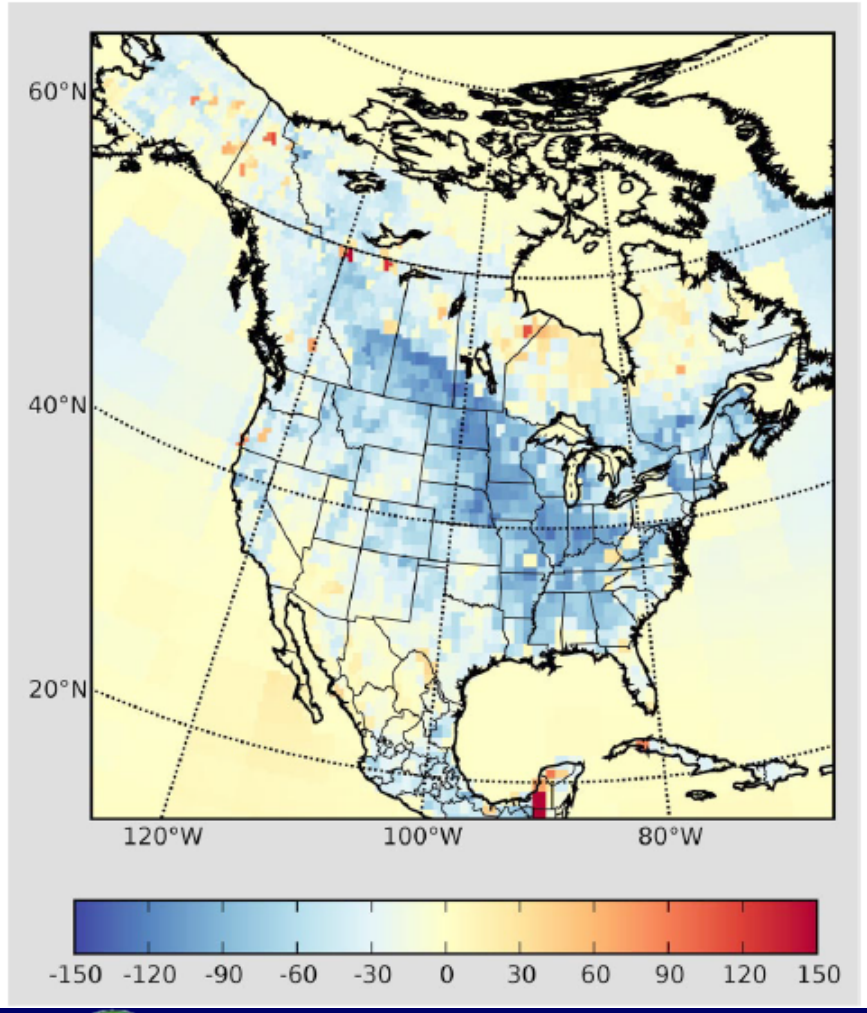
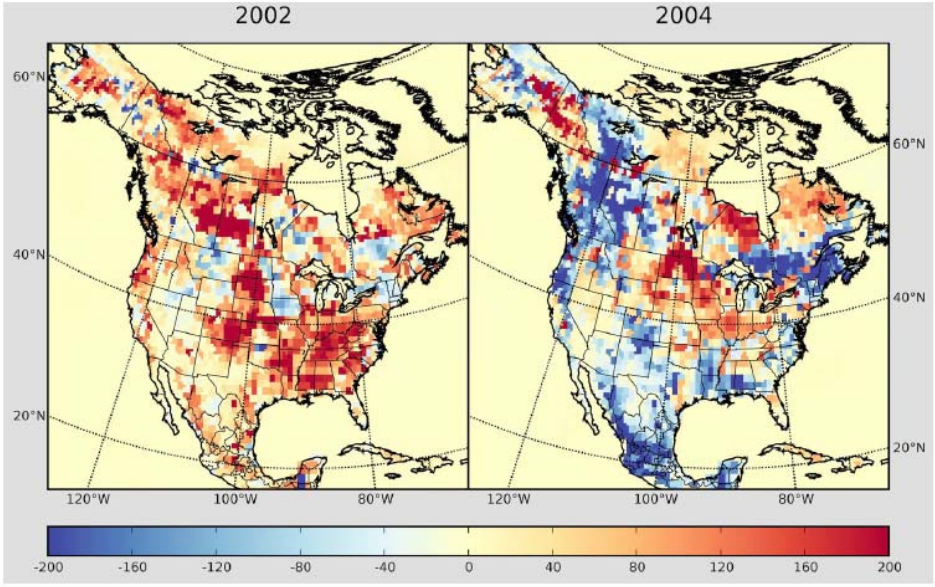
Carbon tracker results





Annual NEE (gC m^{-2} yr^{-1}) for 2000-2005 (left).
Summer NEE for 2002, 2004 (above).
Peters et al, 2007, PNAS

“Bottom-up” continental carbon flux estimate: Potter et al, 2007

- CASA and MODIS synthesis
- Net Ecosystem Productivity (NEP) for the coterminous U.S., 2001-2004
- Interannual variability in fluxes correlated with climate patterns
- Comparison to four AmeriFlux towers to evaluate flux diagnostic

“Bottom-up” flux estimate example: Potter et al., 2007

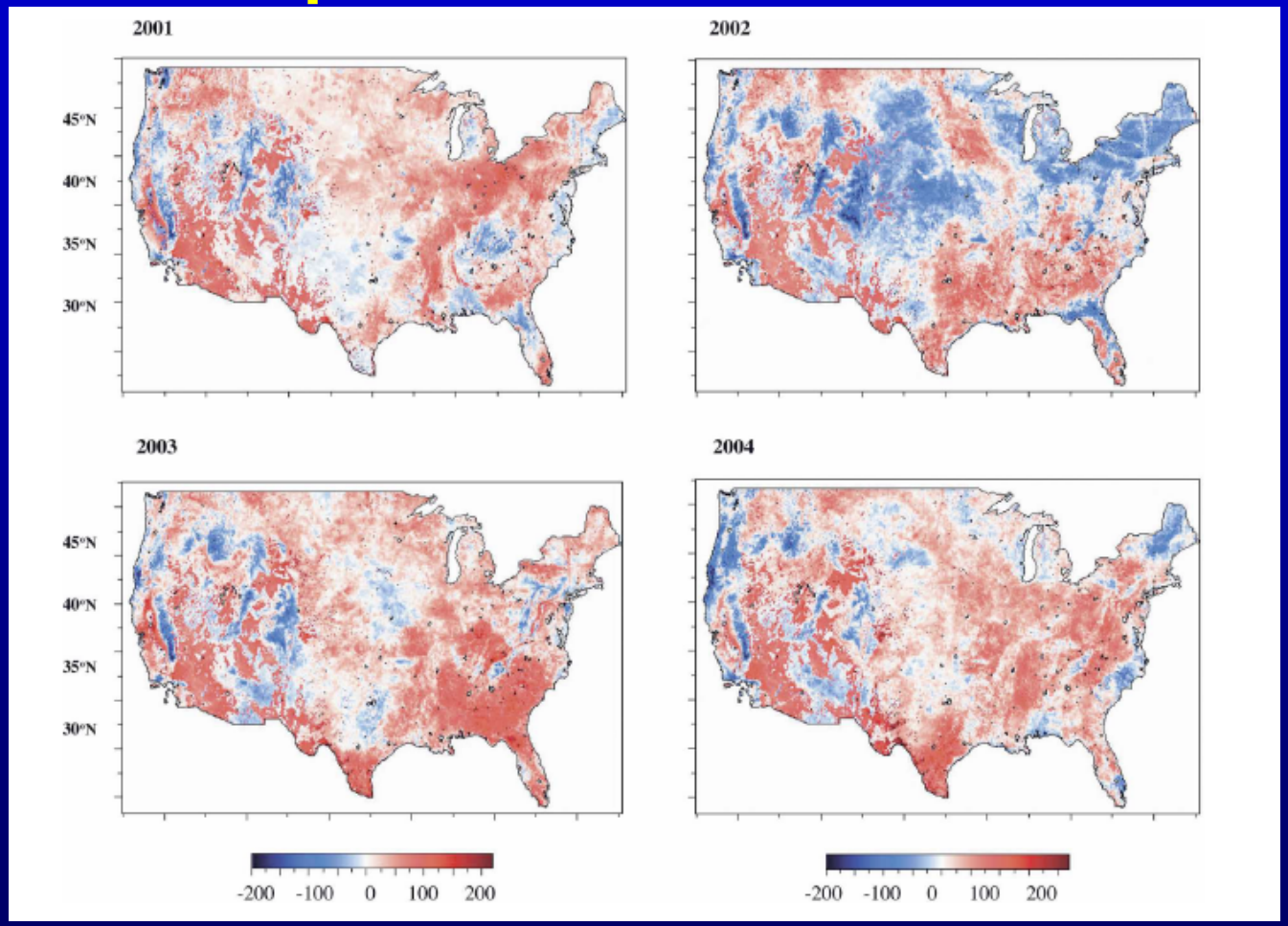
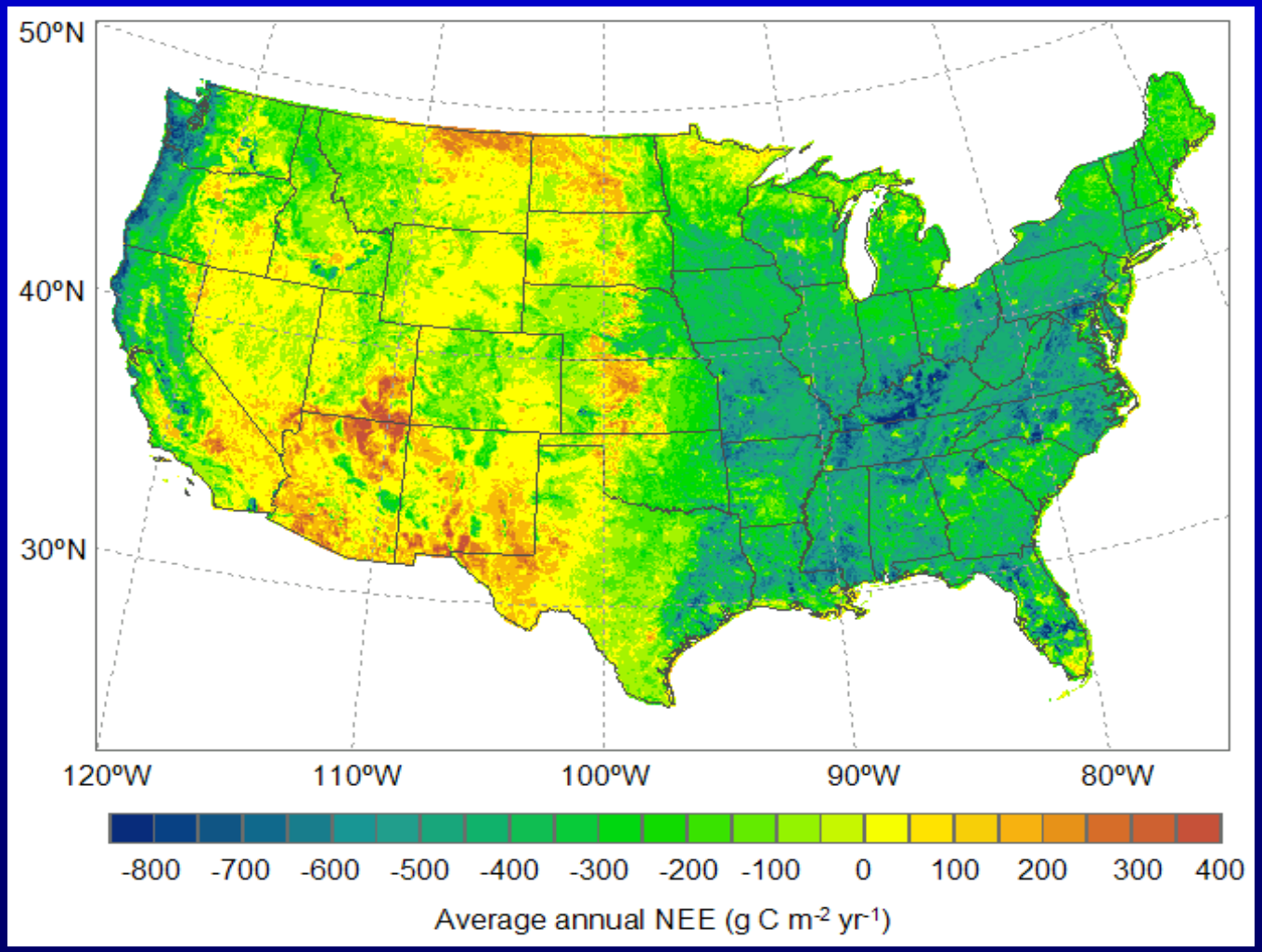


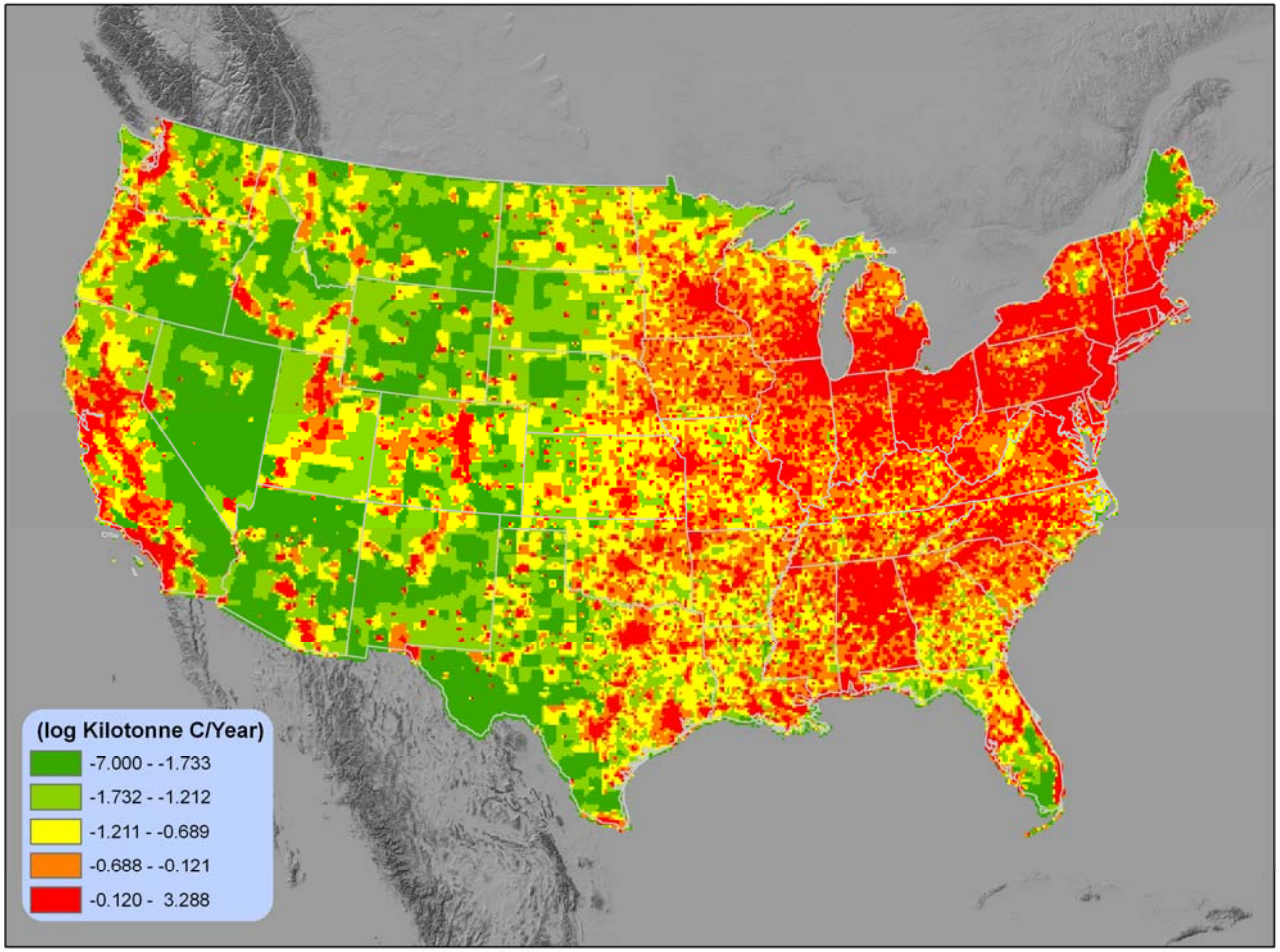
Figure 8.
Annual NEP.

Flux Tower Upscaling



Xiao et al, 2008, Agr. and F. Met.

Project VULCAN fossil fuel emissions estimates (Area sources)



Road and point sources also mapped

Courtesy Kevin Gurney, Purdue Univ.

Ongoing work, future progress

Interim syntheses underway

- Regional/continental comparison
  - Post, Jacobson, Huntzinger
- Site-based model-data comparison
  - Schaefer, Thornton, Ricciuto, Davis
- Midcontinent intensive regional syntheses
  - Ogle, Schuh
- Non-CO_2 greenhouse gas synthesis
  - Wofsy
- Coastal ocean carbon cycle synthesis
  - Coble et al

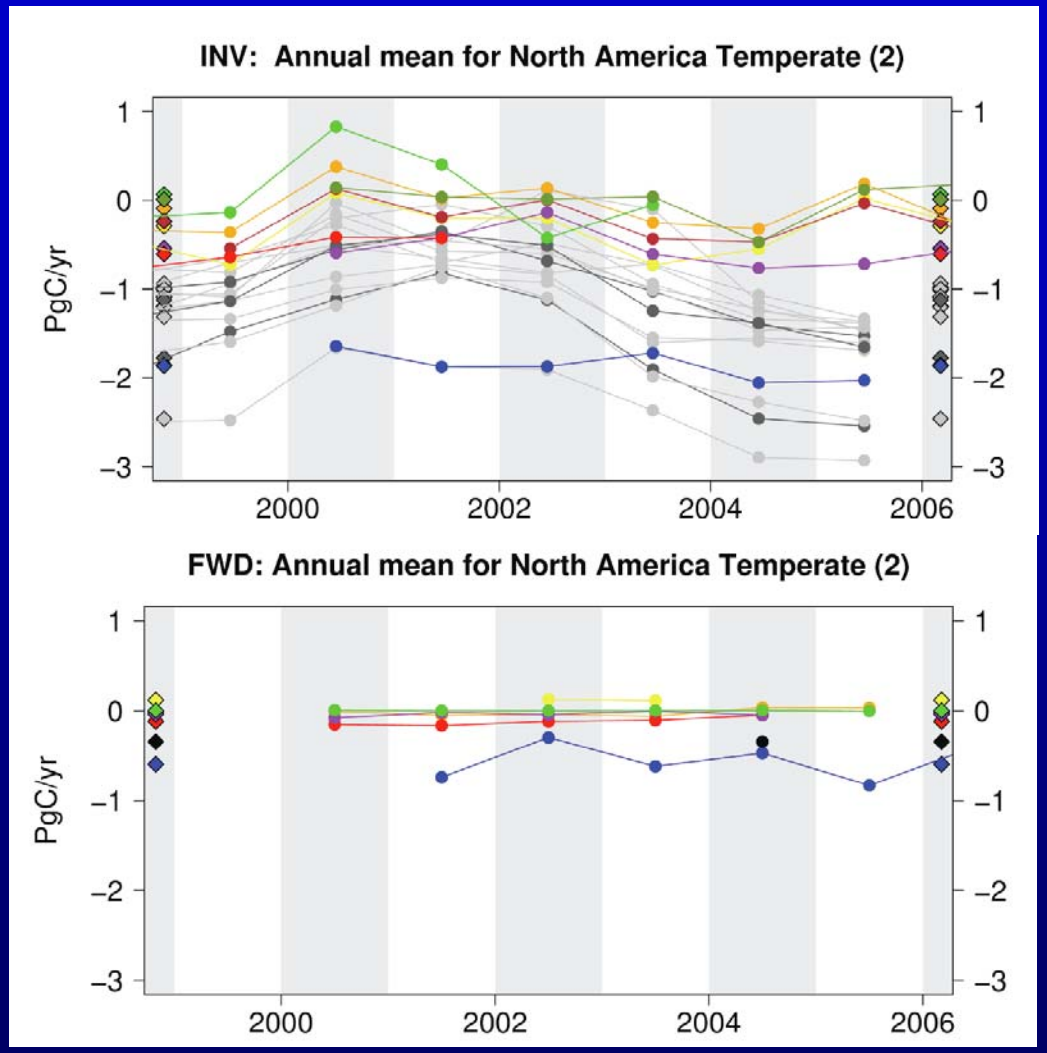
Overall goals of the interim syntheses

- Evaluate current ability to
  - diagnose carbon fluxes at site, regional and continental scales using multiple methods.
  - attribute magnitude and variability in fluxes to governing processes.

  Provide a benchmark for future progress.

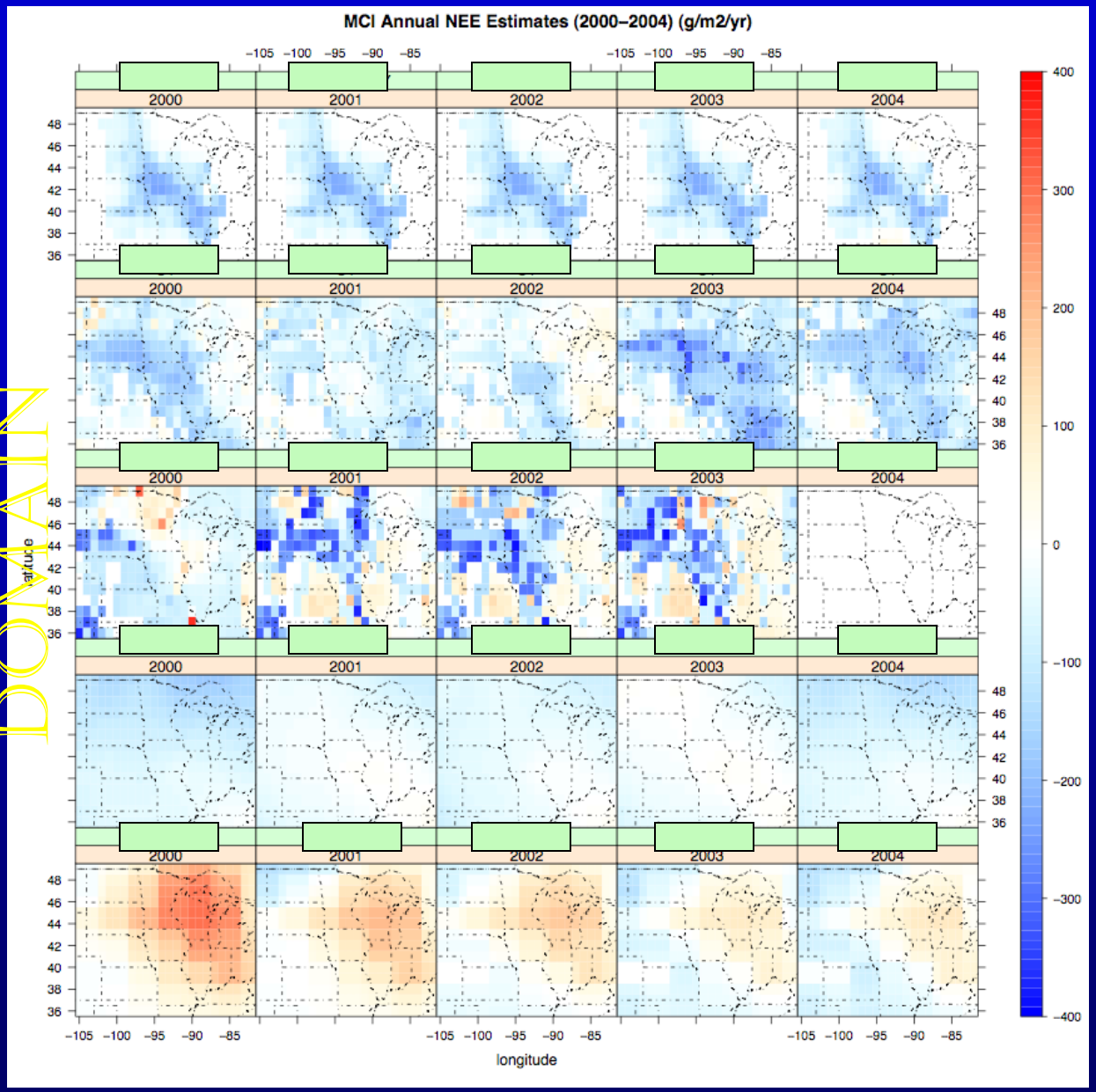
  (Temporal focus: 2000-2005)

Continental Aggregate Flux: Multi-Model Comparison



Preliminary findings: "Inversions" show much more interannual variability and a larger N. American sink vs. "forwards" models.

REGIONAL MULTI-MODEL COMPARISON: MCI DOMAIN



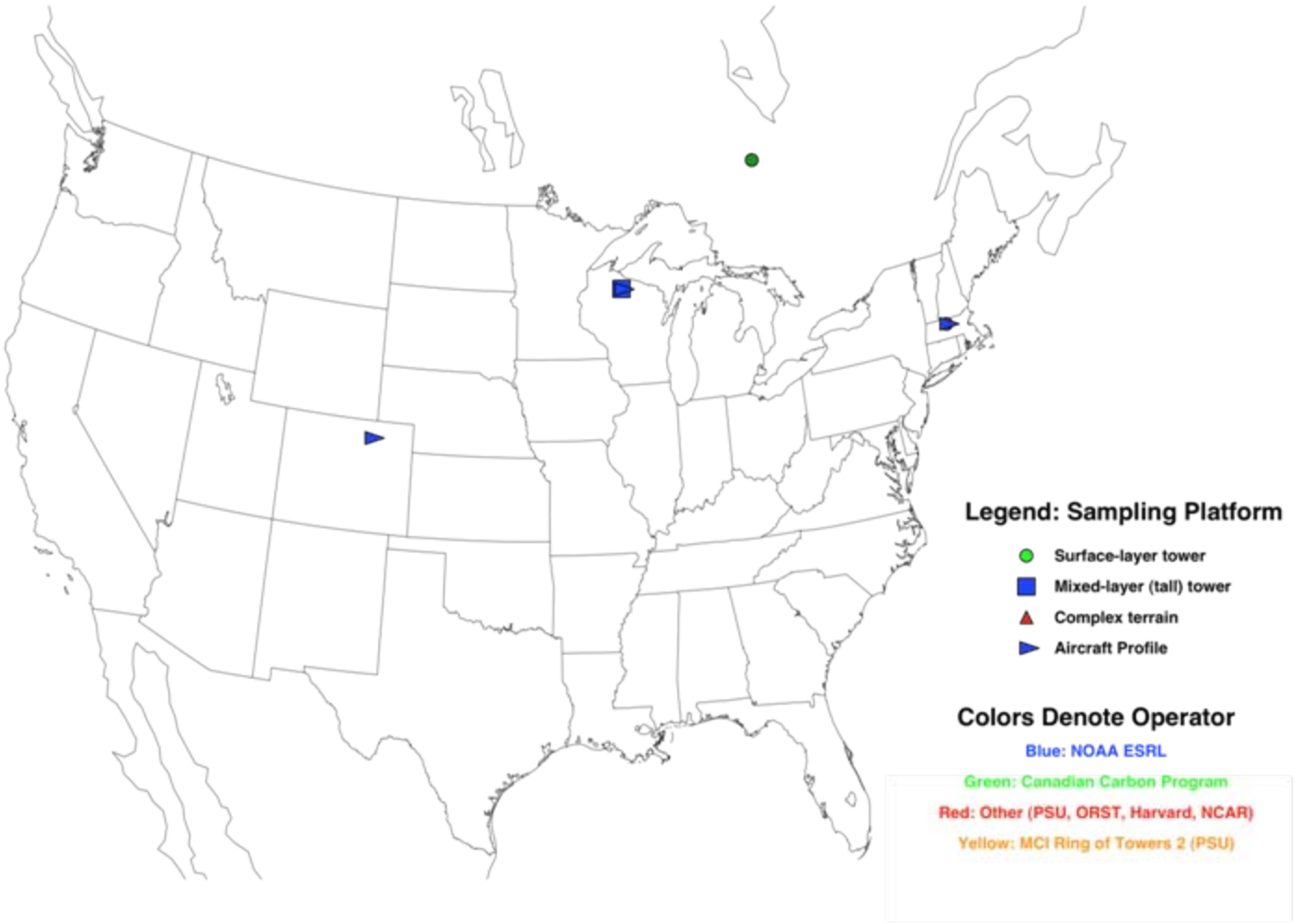
EXTREMELY VARIABLE RESULTS ACROSS MODELS.

NOTE: DATA CONSTRAINT FOR INVERSIONS IS WEAK.

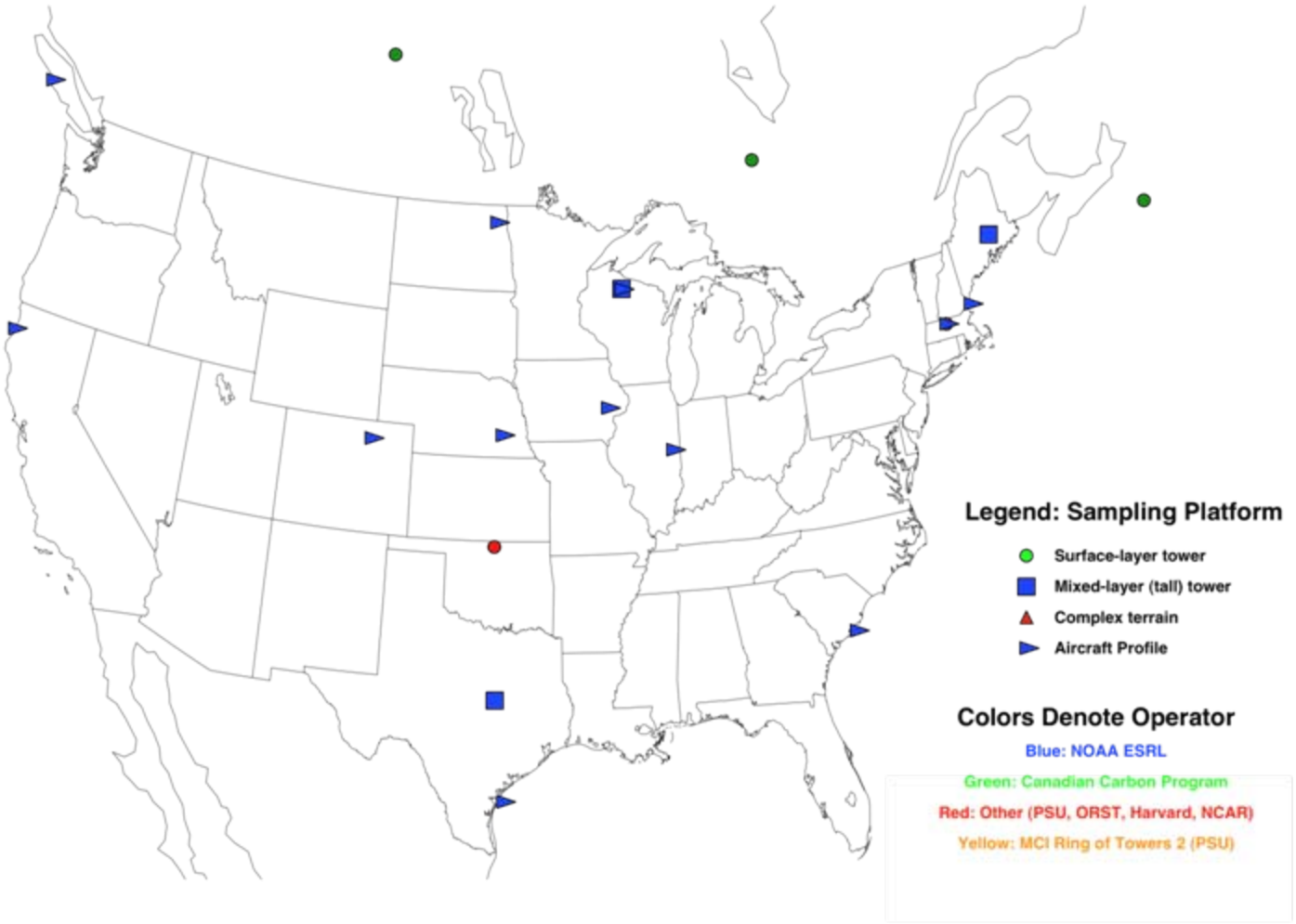
Confusion? Loss of hope? No…

- Recall that:
  - Atmospheric data constraint in N. America was quite weak prior to 2006.
  - "Forwards" models do not all simulate the same thing (e.g. fire fluxes, agricultural harvest, soil carbon equilibrium).
  - We learn by doing. We emphasize the need for model comparisons, uncertainty analyses, and continued core observations.

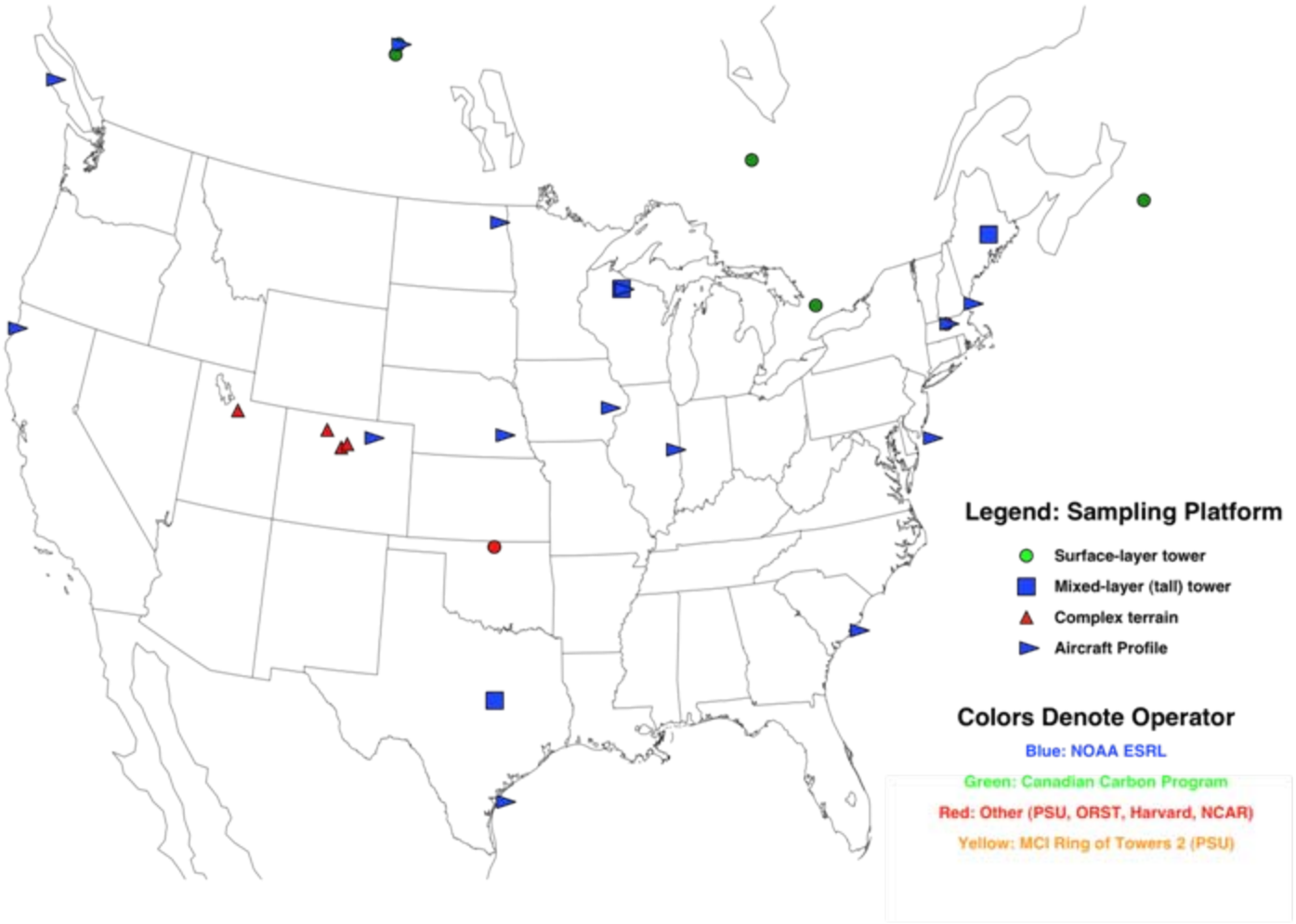
CO_2 Concentration Network: 2000



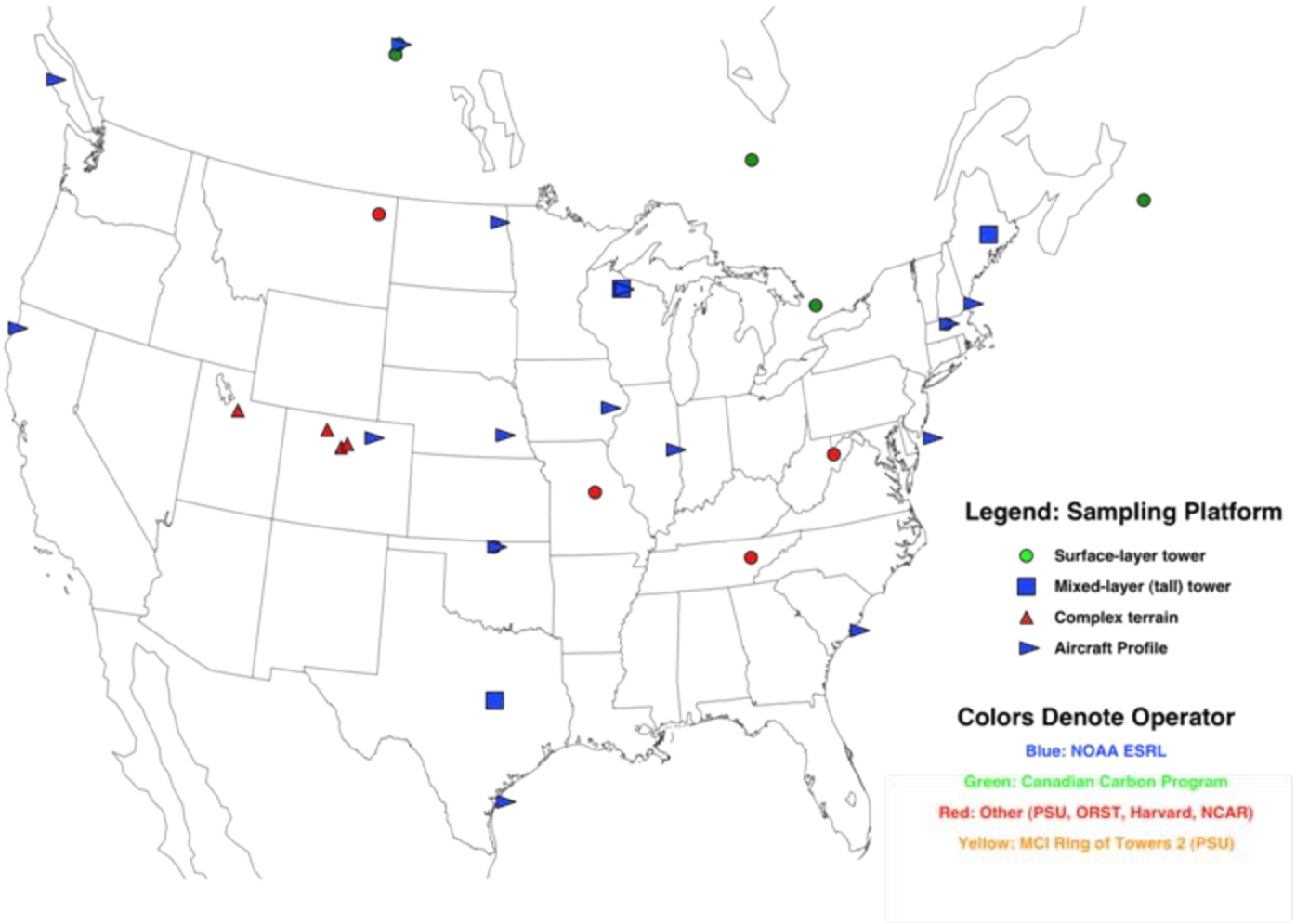
CO_2 Concentration Network: 2004



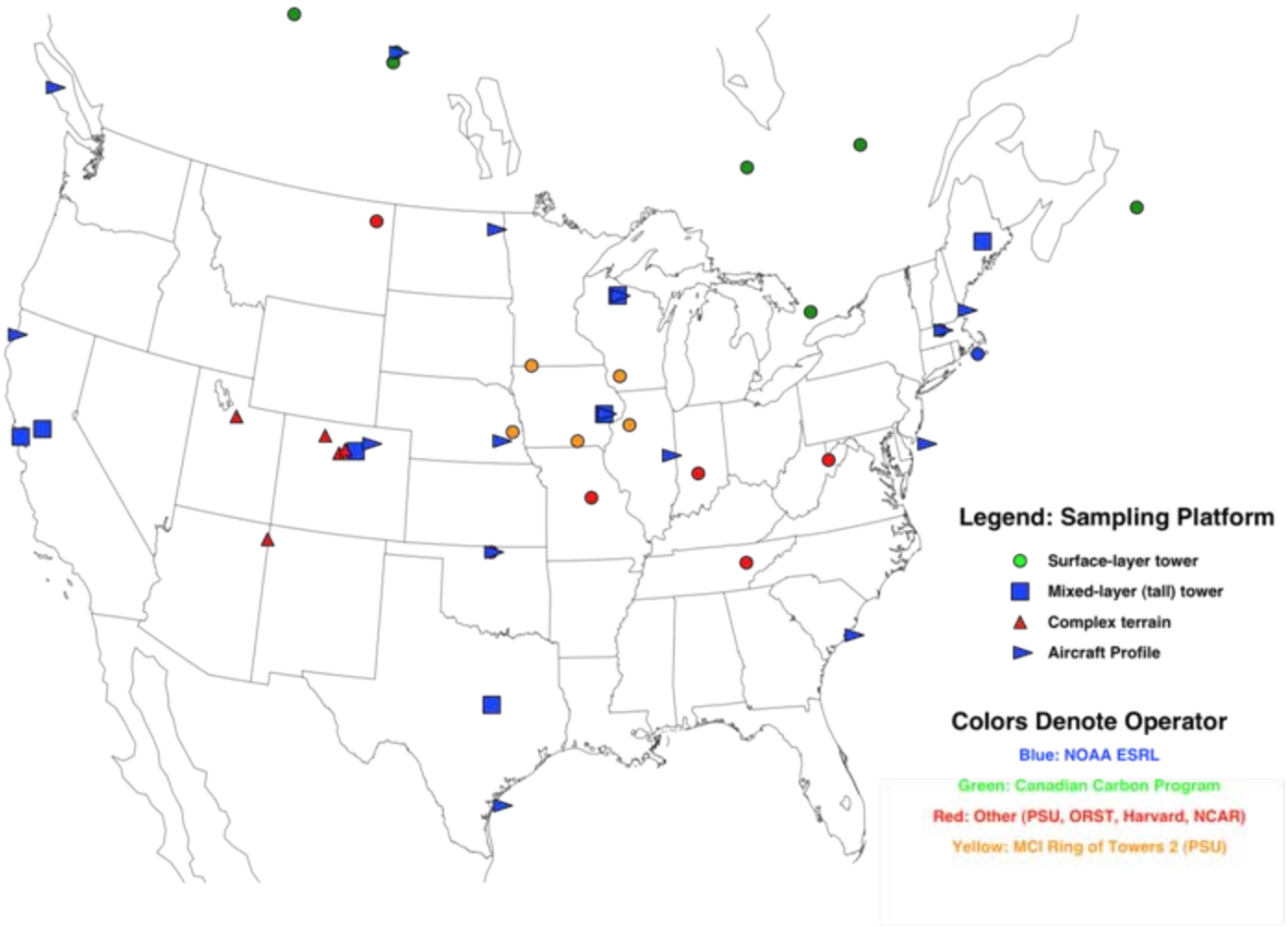
CO_2 Concentration Network: 2005



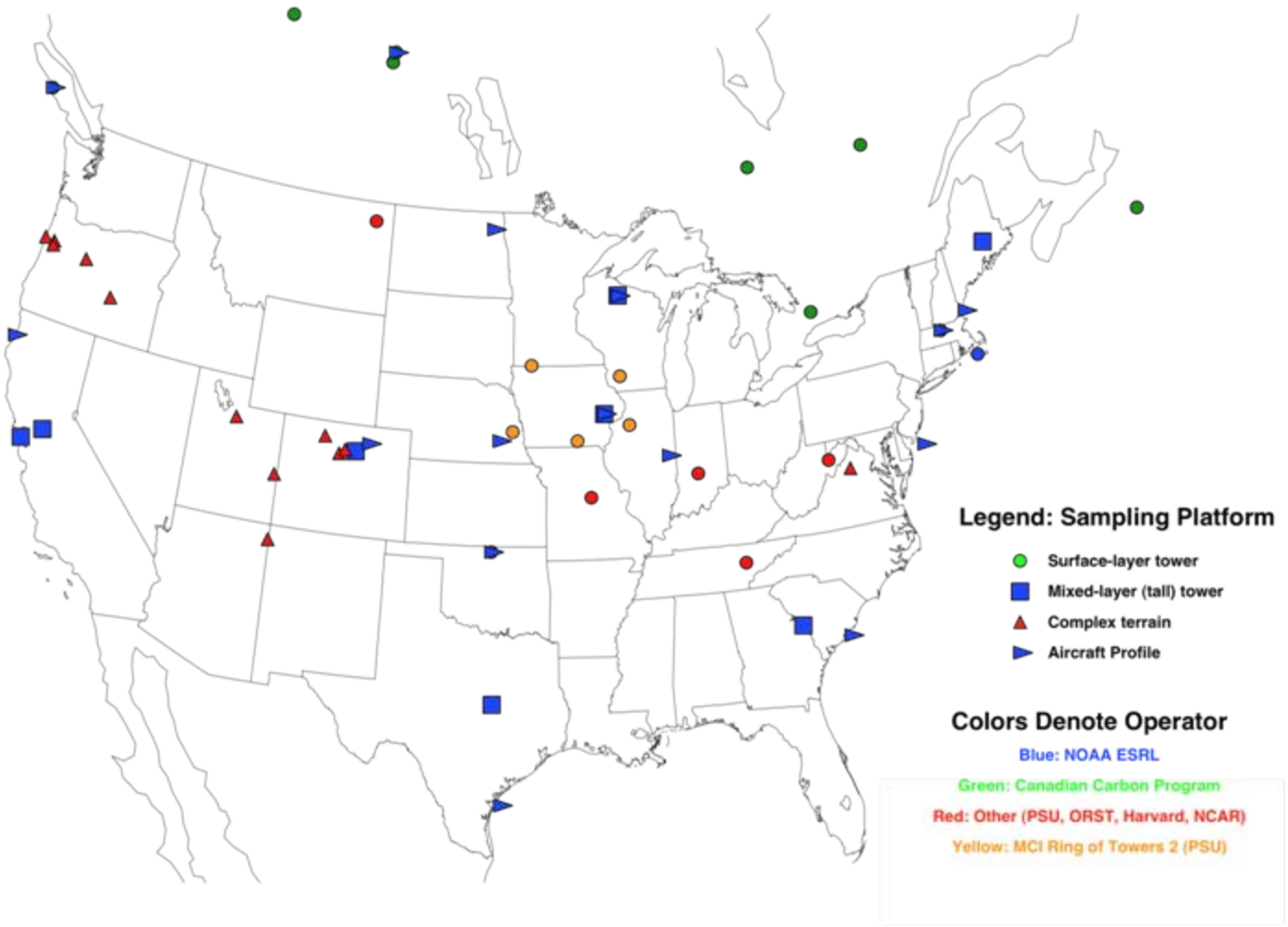
CO_2 Concentration Network: 2006



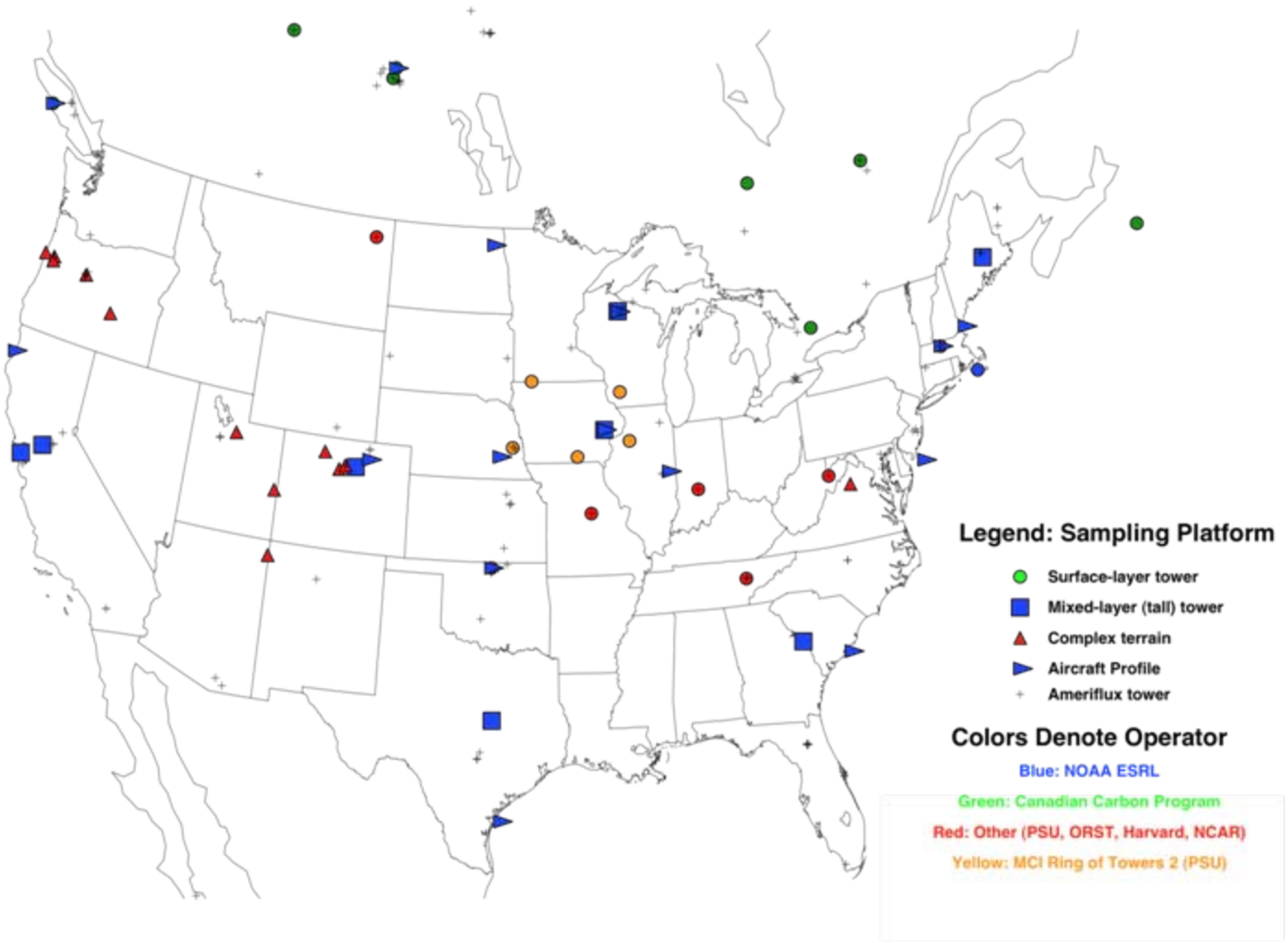
CO_2 Concentration Network: 2007



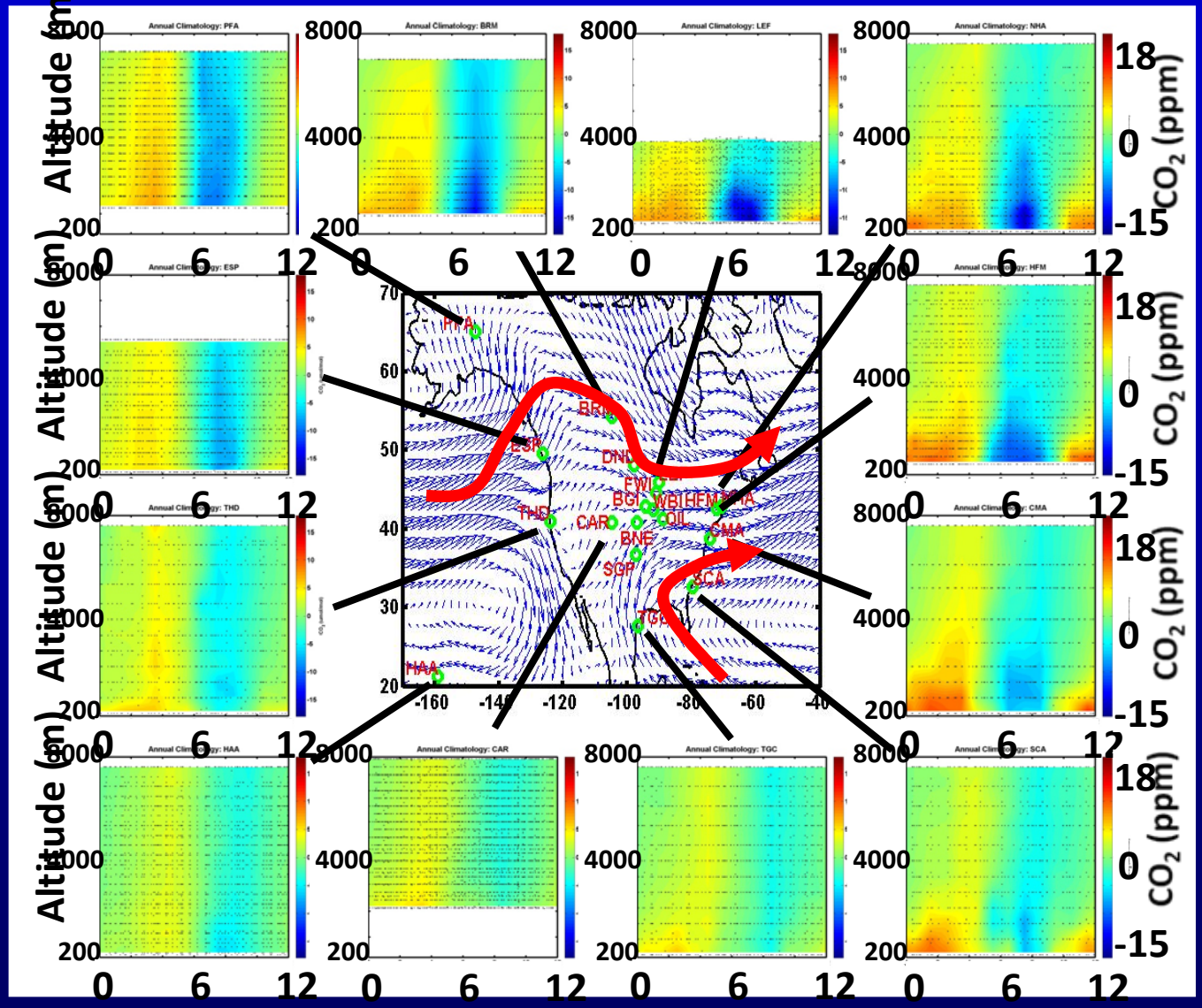
CO_2 Concentration Network: 2008



CO_2 Concentration Network: 2008



CONTINENTAL AIRBORNE PROFI

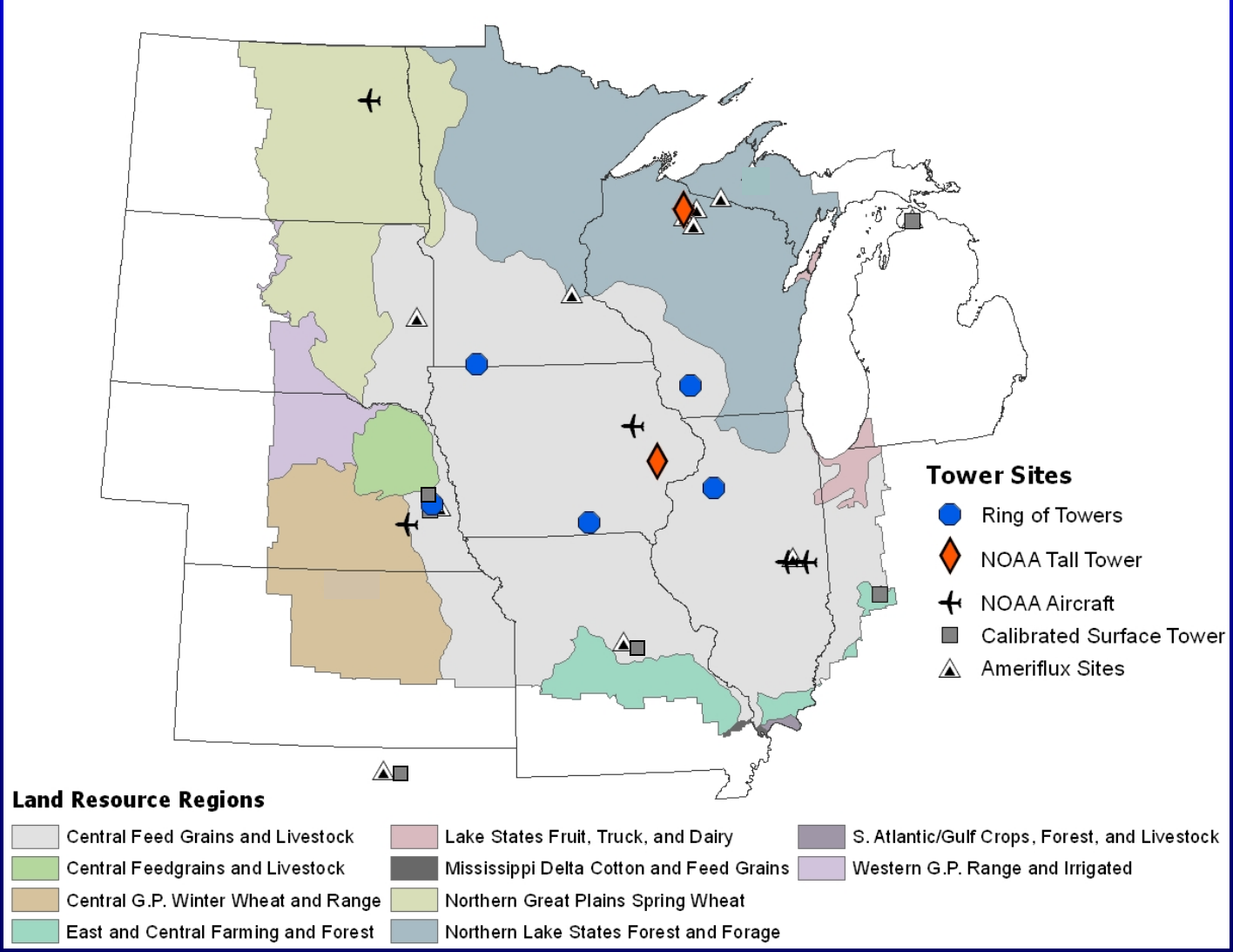


Deviation from global trend

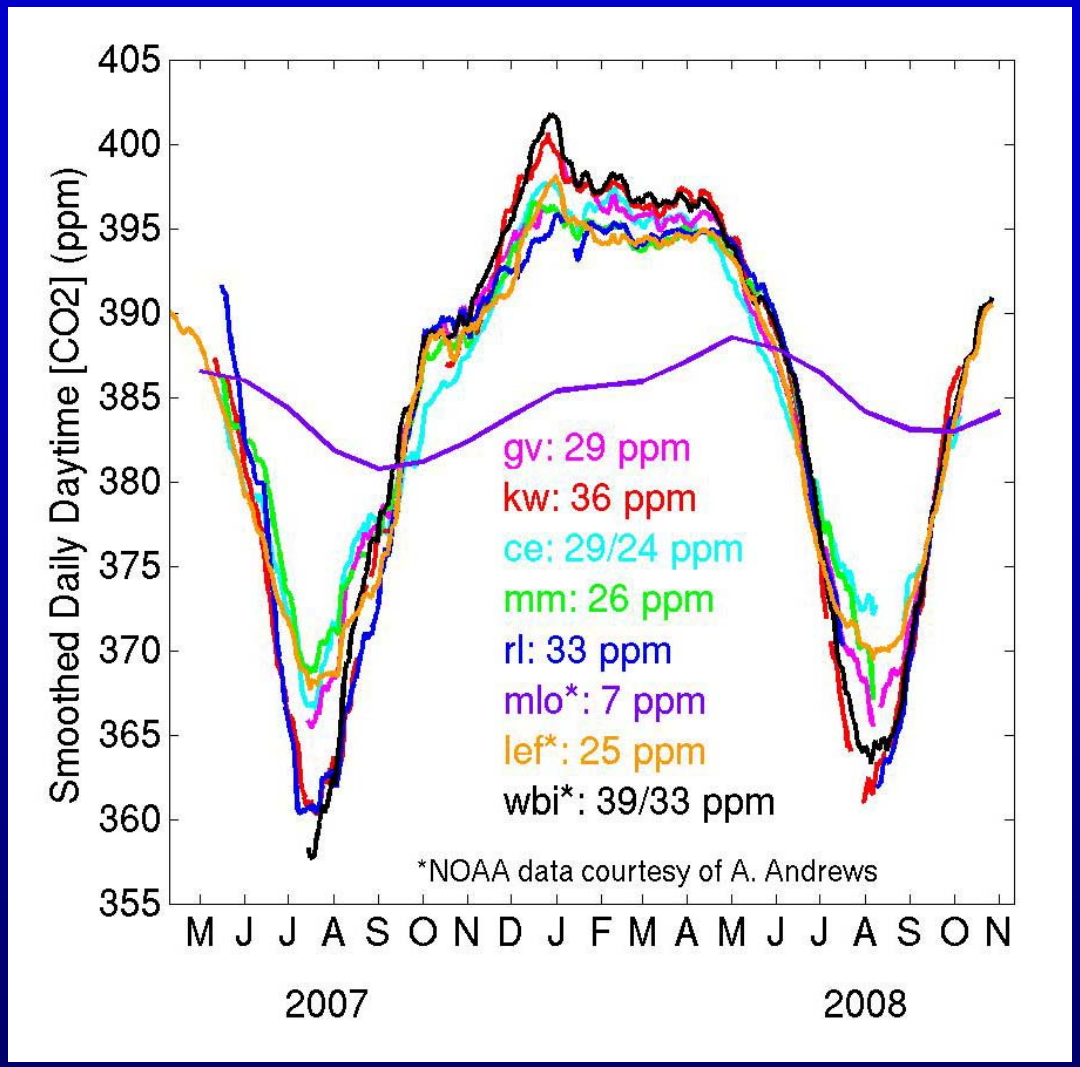
Mid-continent intensive (MCI) Overarching Goal

Compare and reconcile to the extent possible, regional carbon flux estimates from “top-down” inverse modeling with the “bottom-up” inventories

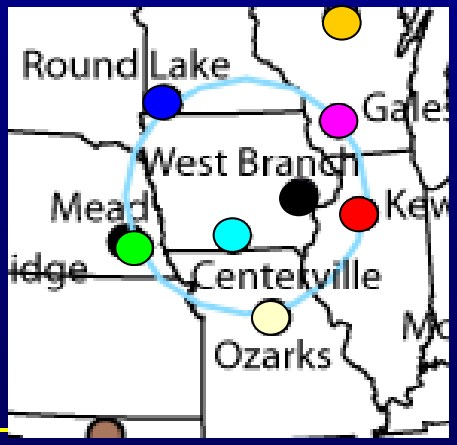
OBSERVATION SITES: CAMPAIGN (200



MCI region CO_2 seasonal cycle

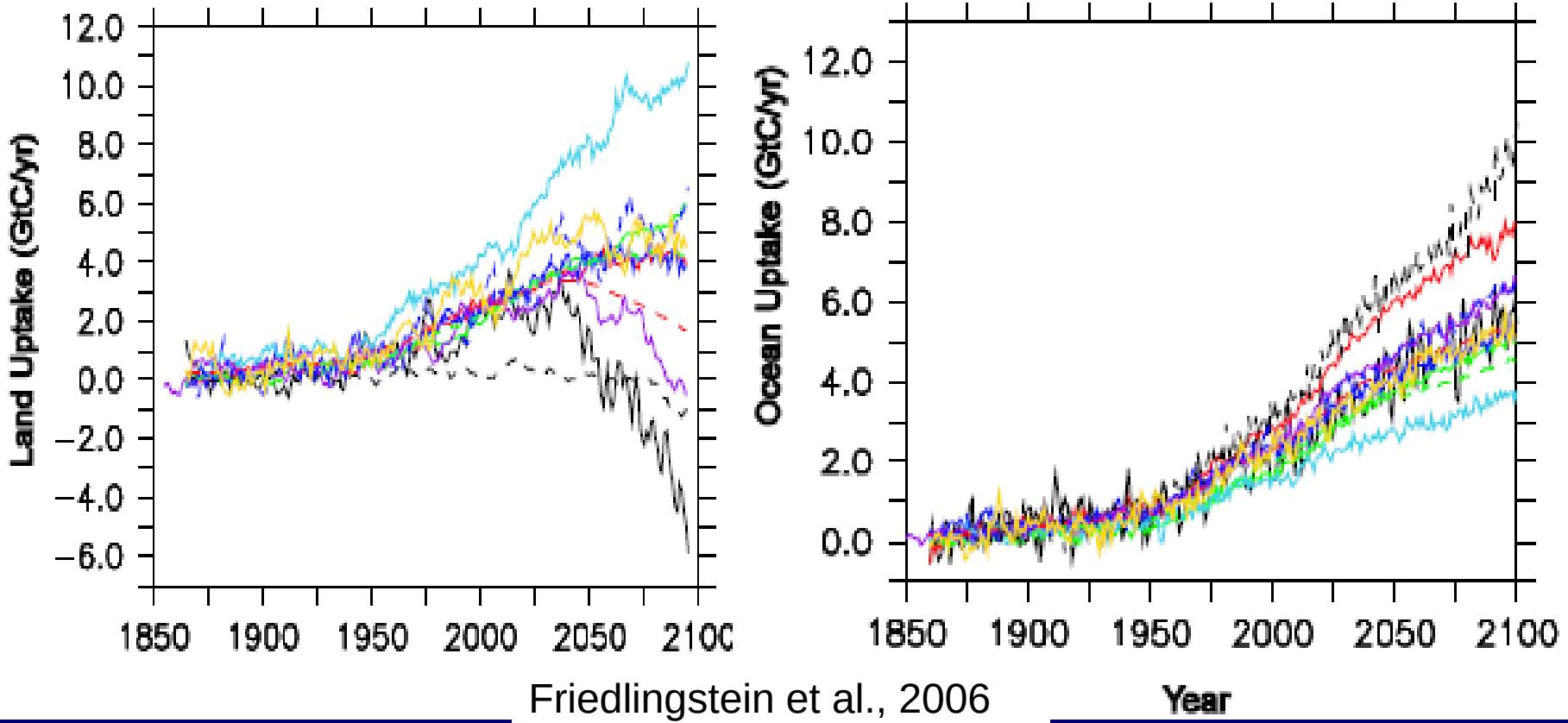


- 31-day running mean
- Strong coherent seasonal cycle across stations
- West Branch (wbi) and Centerville (ce) differ significantly from 2007 to 2008
- Large variance in seasonal drawdown



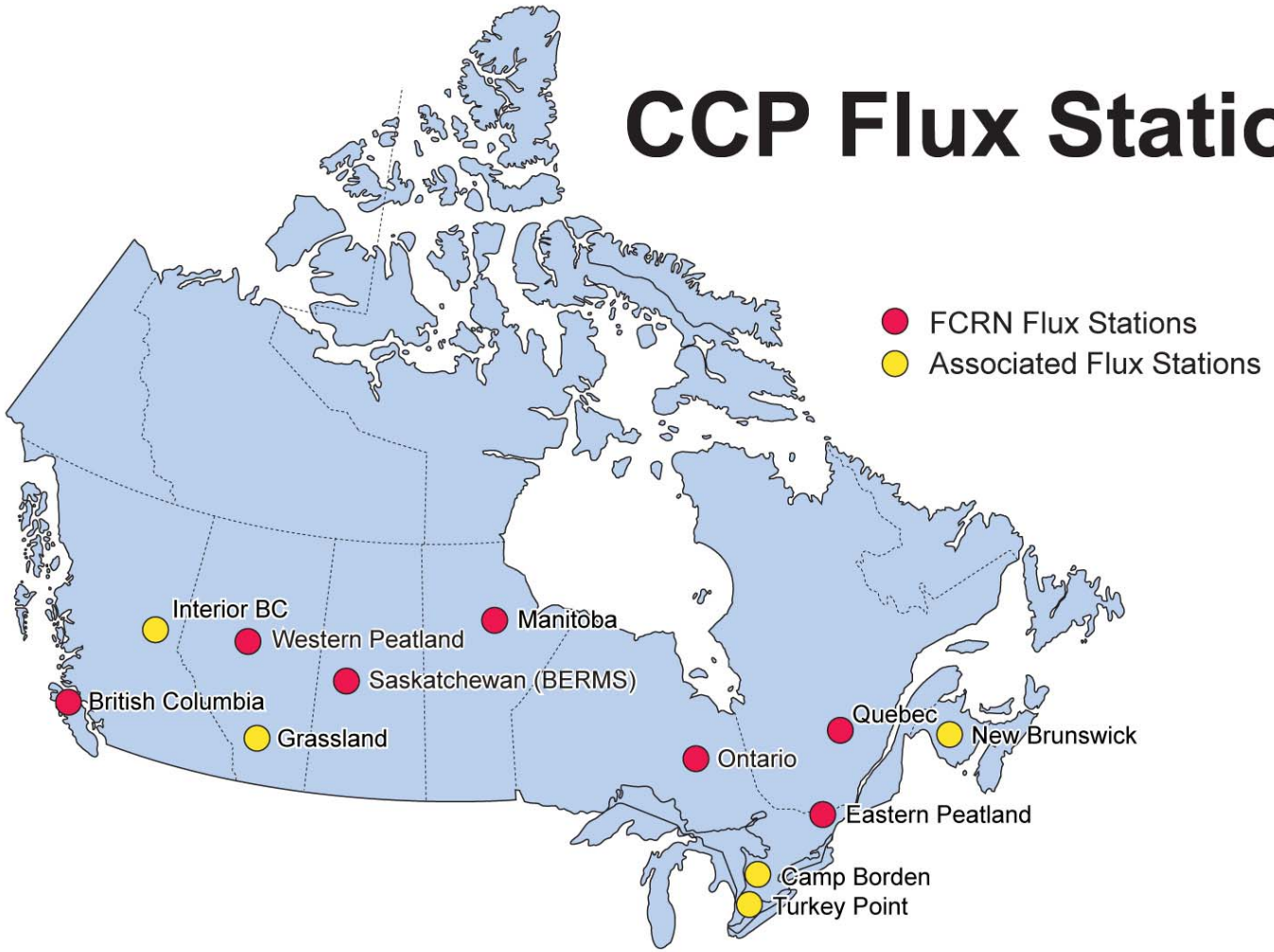
Uncertain prediction of future carbon fluxes

C^{4}MIP: comparison of coupled climate/carbon models



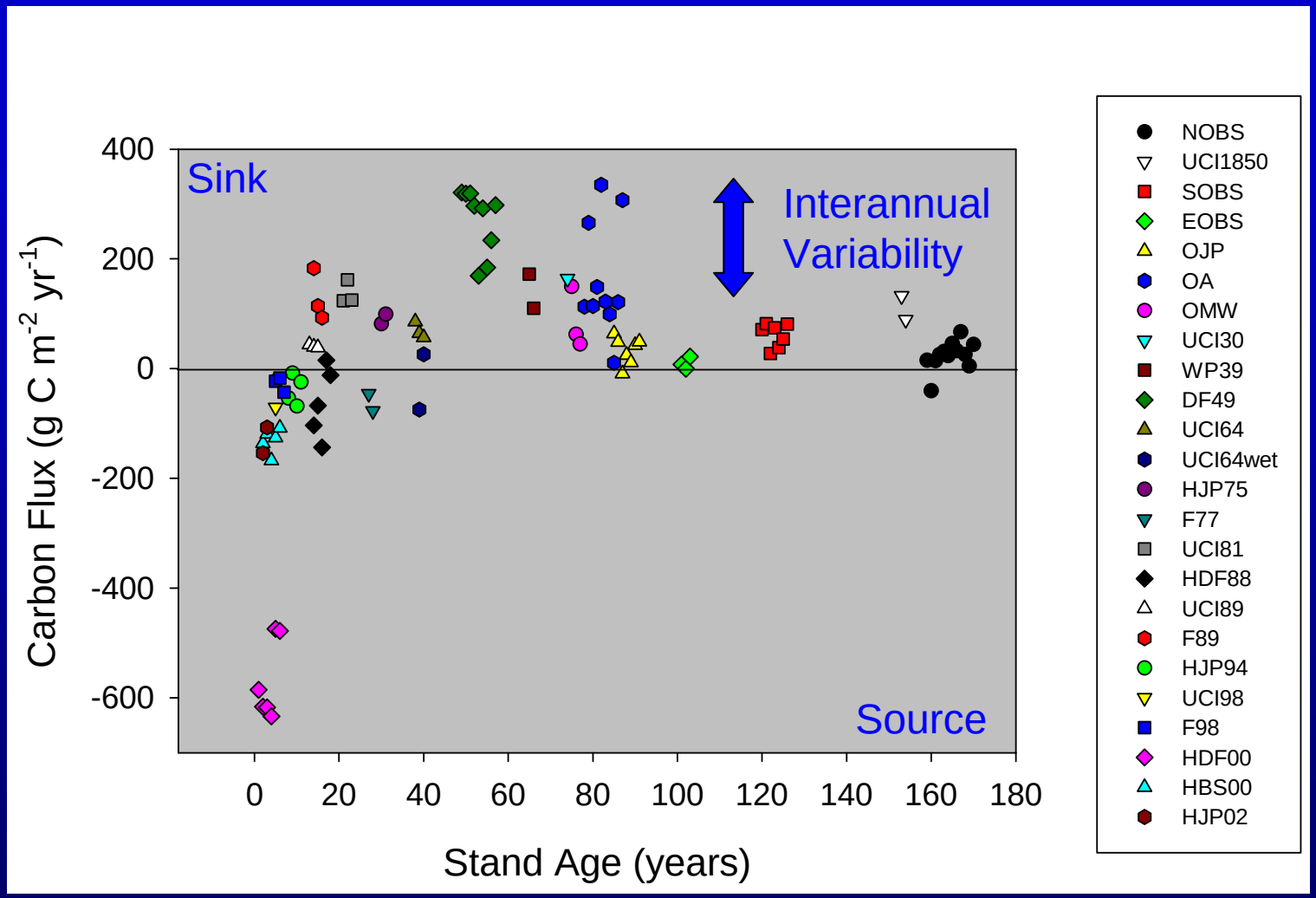
Friedlingstein et al., 2006

CCP Flux Stations

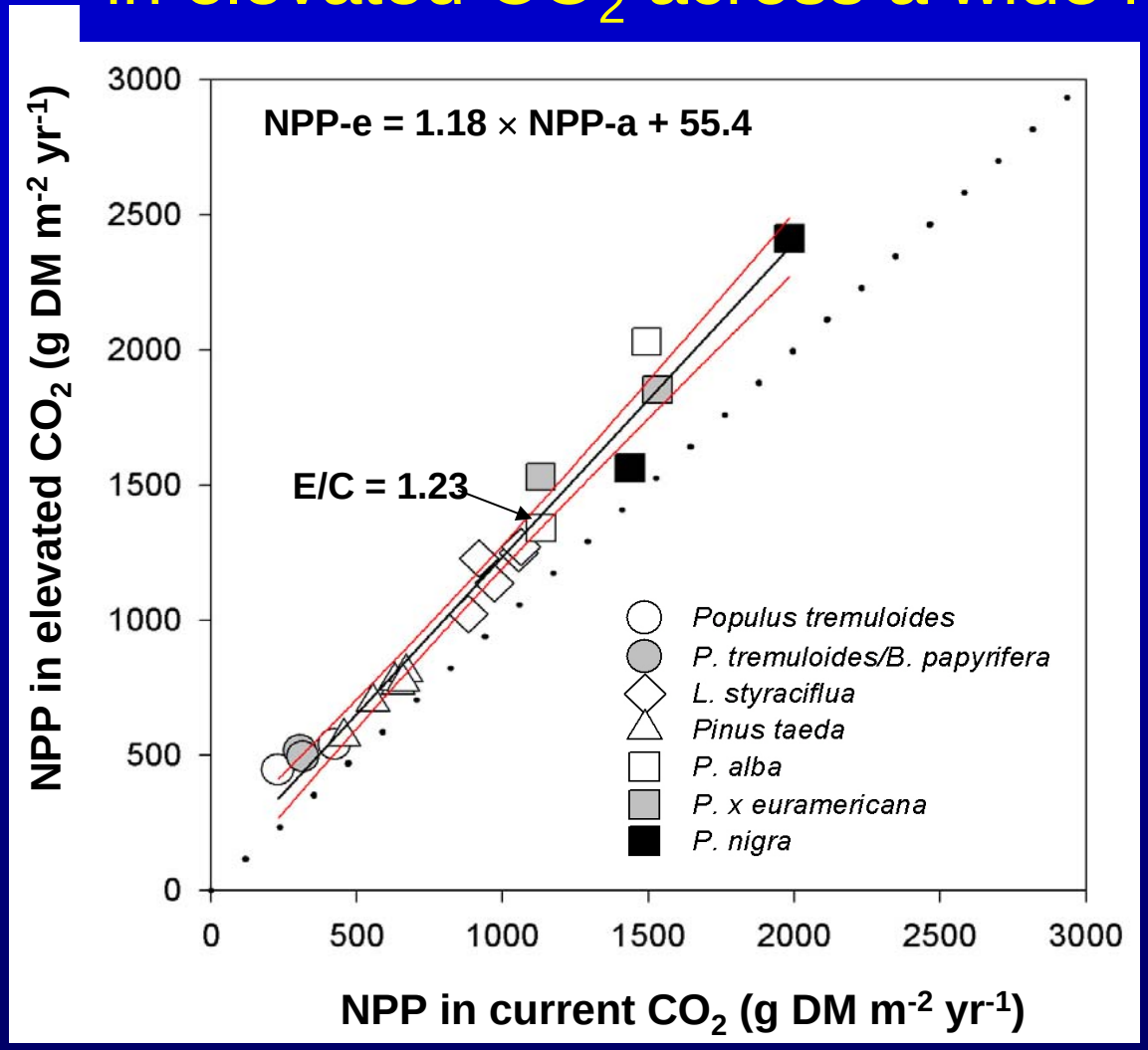


Fluxnet-Canada: 2002-2007
Canadian Carbon Program (CCP): 2007-2010

Attribution: Stand age vs. NEP



Experiments to aid prediction: FACE. NPP increased in elevated CO_2 across a wide range of NPP



- Regression defines a median response of 23% enhancement of NPP in eCO_2
- Response is robust across a wide range of NPP
- Provides a critical benchmark for ecosystem and global models
- But the data all are from temperate forests
- Have the experiments been long enough to reveal nitrogen limitations?

Norby et al. (2005) *PNAS* 102: 1805

Experimental results provide a benchmark for global models

	NPP enhancement (%)
FACE experiments	23 +/- 2
Global forests	24.5 +/- 0.06
Boreal forests	15.1 +/- 0.06
Temperate forests	25.7 +/- 0.14
Tropical forests	35.1 +/- 0.09

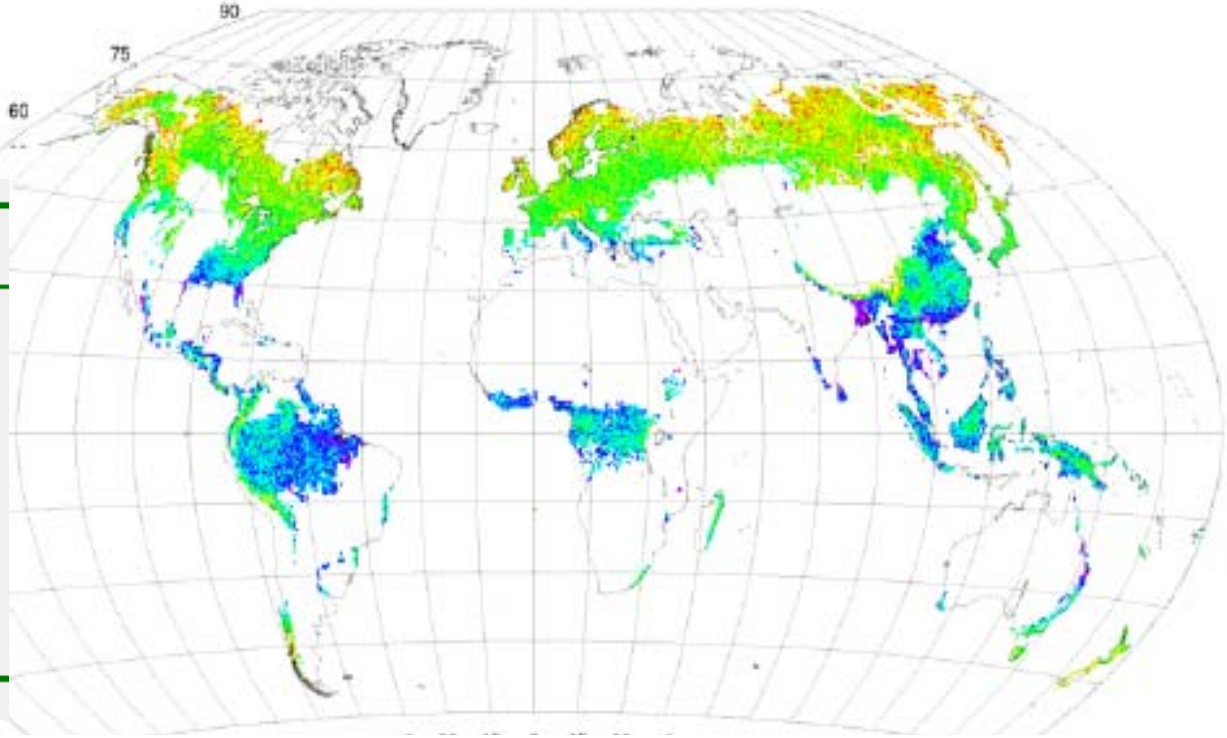


Fig. 2 Geographic pattern of the simulated NPP enhancement resulting from a step increase of CO_2 from ambient to 550 ppmv; NPP values averaged over 1996-2002.

T. Hickler et al. 2008. *Global Change Biology*, 14:1531-1542

Experiments in tropical and boreal ecosystems may be an important priority

C-LAMP Results & Diagnostics

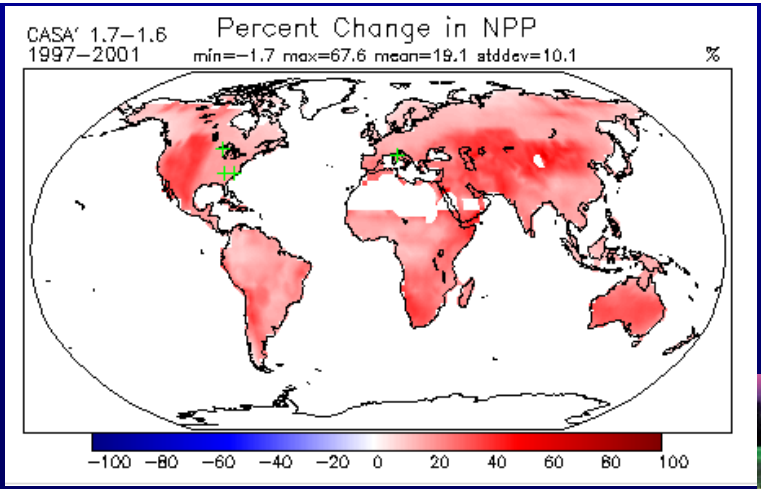
Home | Protocol & Metrics | Datasets | Results & Diagnostics | Models | Publications | Contacts

C-LAMP Free Air CO_2 Enrichment (FACE) Simulations

Forrest Hoffman and Jim Randerson
Updated September 9, 2008

Site Name	Longitude (°E)	Latitude (°N)	Measurement		CASA' Model		CN Model	
			NPP Increase	β_L	NPP Increase	β_L	NPP Increase	β_L
DukeFACE	-79.08333	35.96666	28.0%	0.69	16.4%	0.41	6.2%	0.15
AspenFACE	-89.61666	45.66666	35.2%	0.87	15.6%	0.39	12.4%	0.31
ORNL-FACE	-84.33333	35.90000	23.9%	0.59	17.3%	0.43	5.2%	0.13
POP-EUROFACE	11.80000	42.36666	21.8%	0.54	20.0%	0.49	5.7%	0.14
		4 Site Mean	**27.2%**	**0.67**	**17.3%**	**0.43**	**7.4%**	**0.18**

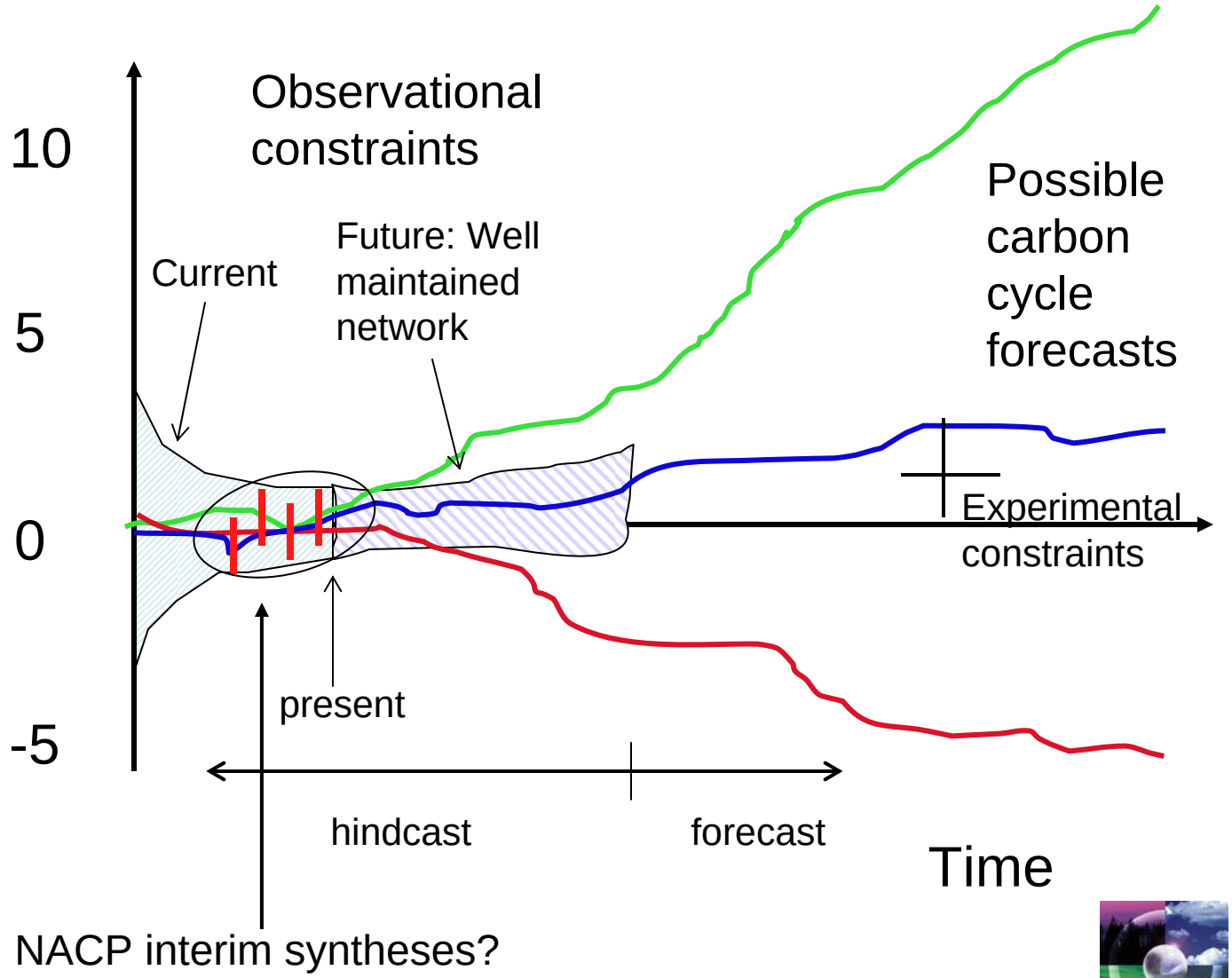
- Simulations are for grid cells, not the experimental plantations
- Inclusion of N feedbacks in CN model reduces NPP response
- Recent observations from FACE support the effect of N limitation in reducing NPP response



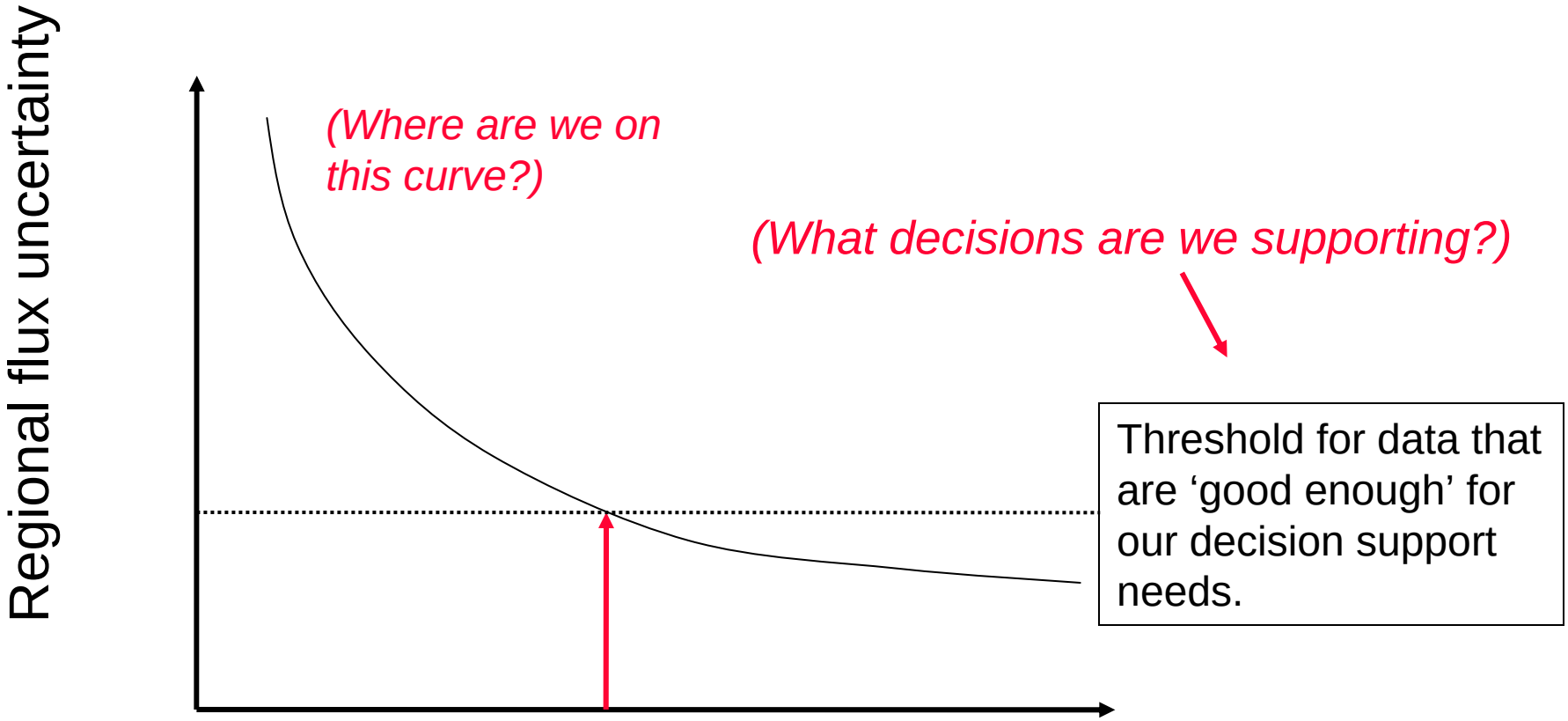
Vision

Terrestrial uptake of carbon (__C yr^{-1})

(details of flux magnitude and observations left ambiguous - could be applied to many regions or observations)



What is “good enough?”



This is when we are done.
(What is this number?)

Investment in science to improve knowledge

Needs, challenges and opportunities:

A state of transition

There are transitions…

…and there are transitions

Conclusions

- We are nearing "success" at regional and continental diagnoses of the CO_2 budget.
- Essential elements of our continental observation and analysis system are endangered.
- We need to engage whole-heartedly in research that is integrated with decision support. This will require:
  - Increased emphasis on prediction, model-data syntheses and model comparisons.
  - Increased emphasis on uncertainty assessment, network design, and data/metadata management.
  - Increased focus on human emissions of carbon and study of the mechanisms governing these emissions.
- We need to articulate which decisions we are supporting.

“Essential elements”

1. [CO2] observational system
2. Non-CO2 GHG observational network
3. Flux tower network
4. Forest and agricultural inventory data
5. Fossil fuel inventory data
6. Remote sensing of the land surface (MODIS, Landsat)
7. Manipulative experiments
8. Coastal ocean observations and lake/river carbon observations
9. Analytic systems for ‘operational’ diagnosis and attribution
10. Human, ecosystem and coastal ocean prognostic models
11. Decision support systems
12. Data management and model-data synthesis systems

“Essential elements”

Some elements are: well developed, broadly used, and soundly embraced by an agency mission. *Examples…*

1. [CO2] observational system
2. Non-CO2 GHG observational network
3. Flux tower network
4. Forest and agricultural inventory data
5. Fossil fuel inventory data
6. Remote sensing of the land surface (MODIS, Landsat)
7. Manipulative experiments
8. Coastal ocean observations and lake/river carbon observations
9. Analytic systems for ‘operational’ diagnosis and attribution
10. Human, ecosystem and coastal ocean prognostic models
11. Decision support systems
12. Data management and model-data synthesis systems

“Essential elements”

Some elements are: well developed, broadly used, but not assured of stable, long-term support. *Examples…*

1. [CO2] observational system
2. Non-CO2 GHG observational network
3. Flux tower network
4. Forest and agricultural inventory data
5. Fossil fuel inventory data
6. Remote sensing of the land surface (MODIS, Landsat)
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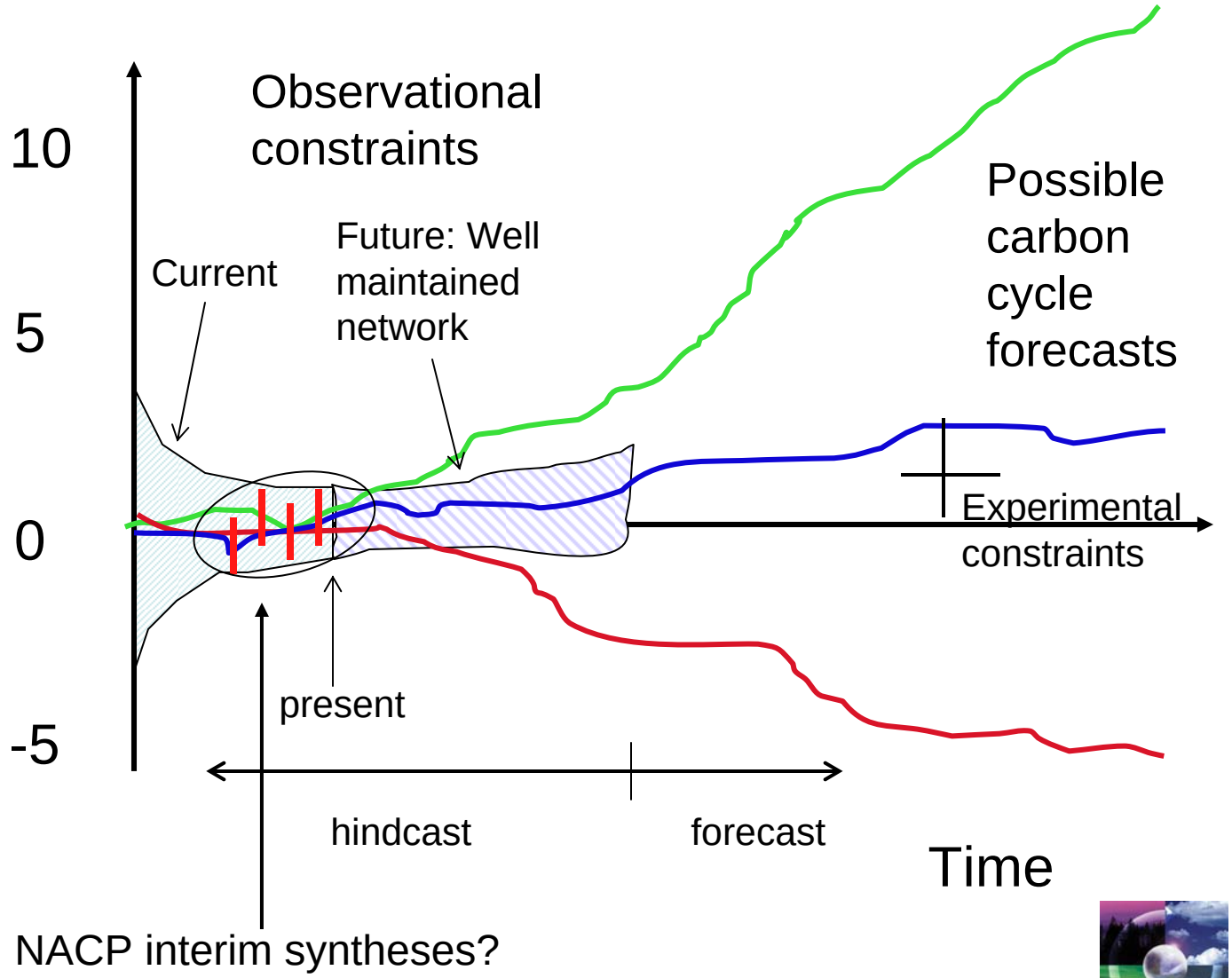
TRANSITION: Climate science isn’t done in 3-5 years. If…

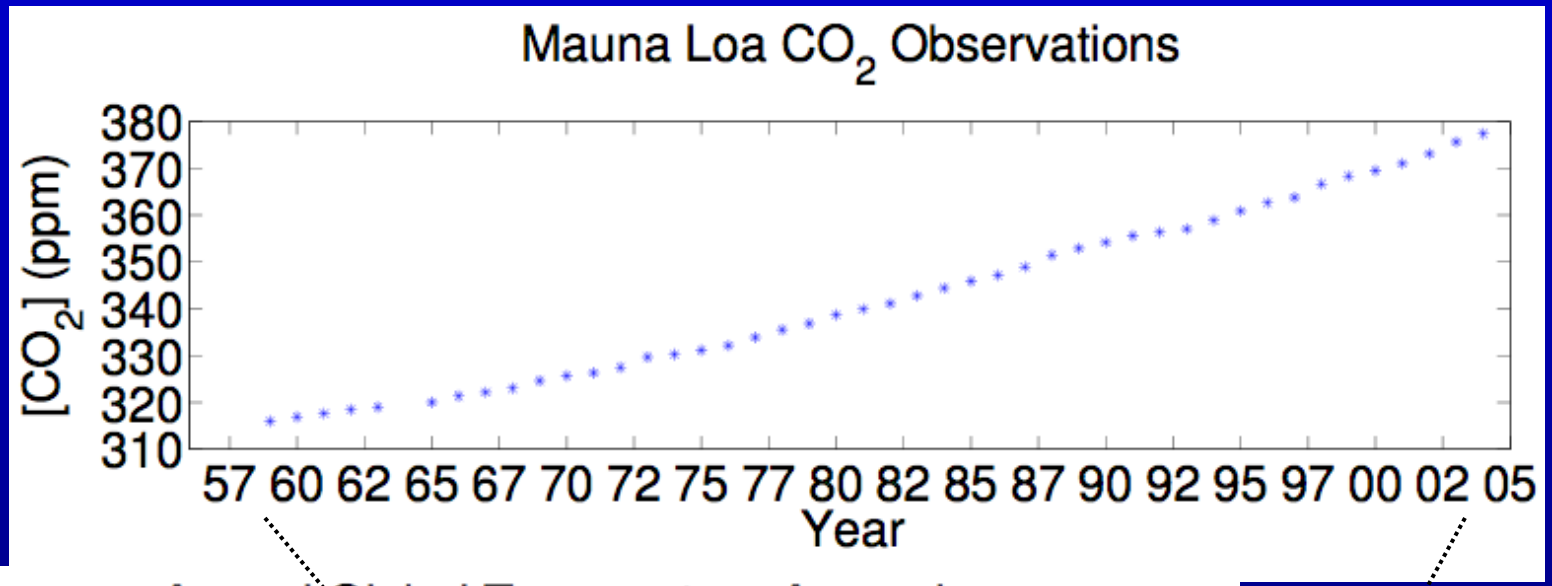
Vision

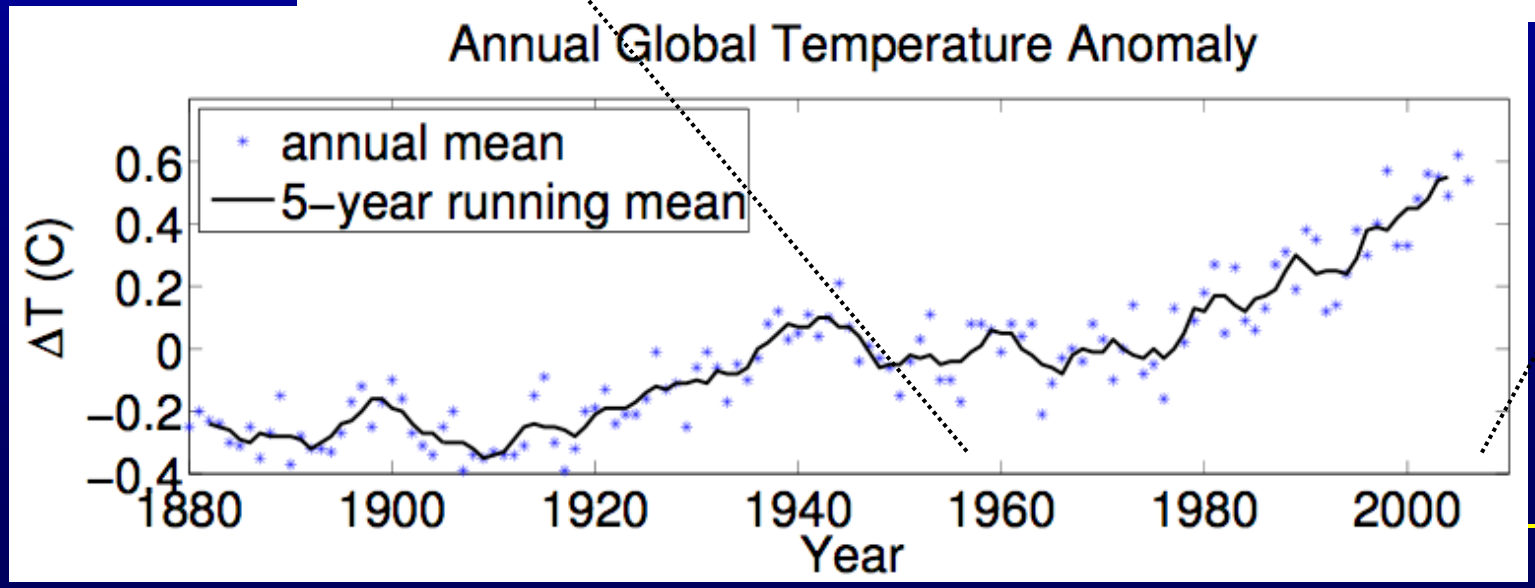
Terrestrial uptake of carbon (__C yr^{-1})

(details of flux magnitude and observations left ambiguous - could be applied to many regions or observations)

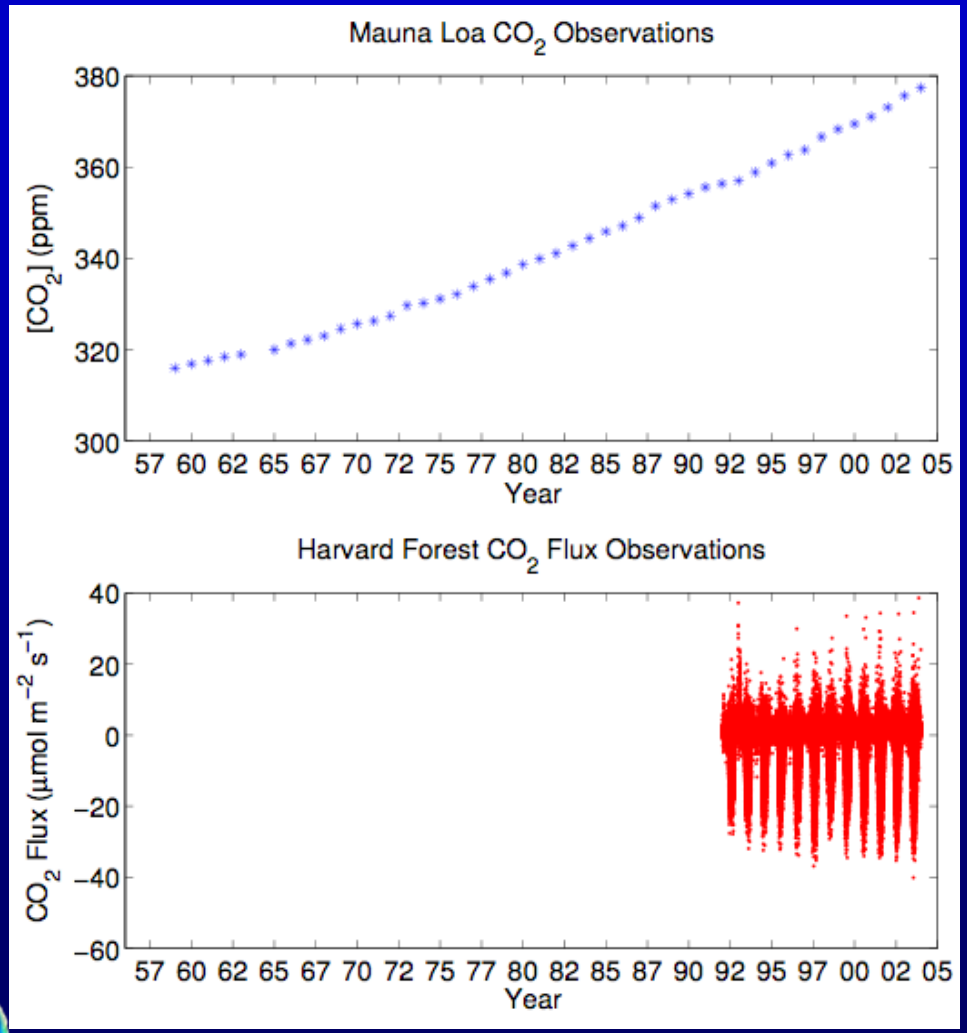


Essential carbon cycle time series: Data records that can be used to establish predictive skill

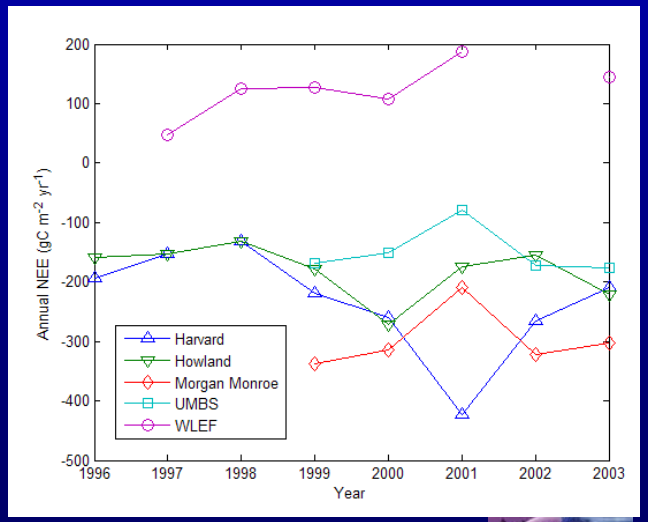




Essential carbon cycle time series: Data records that can be used to establish predictive skill



Causal chain:
CO_2 fluxes
CO_2 mixing ratio
Surface temperature
Note: A single flux measurement does not capture a global value



A well-known example of establishing predictive skill

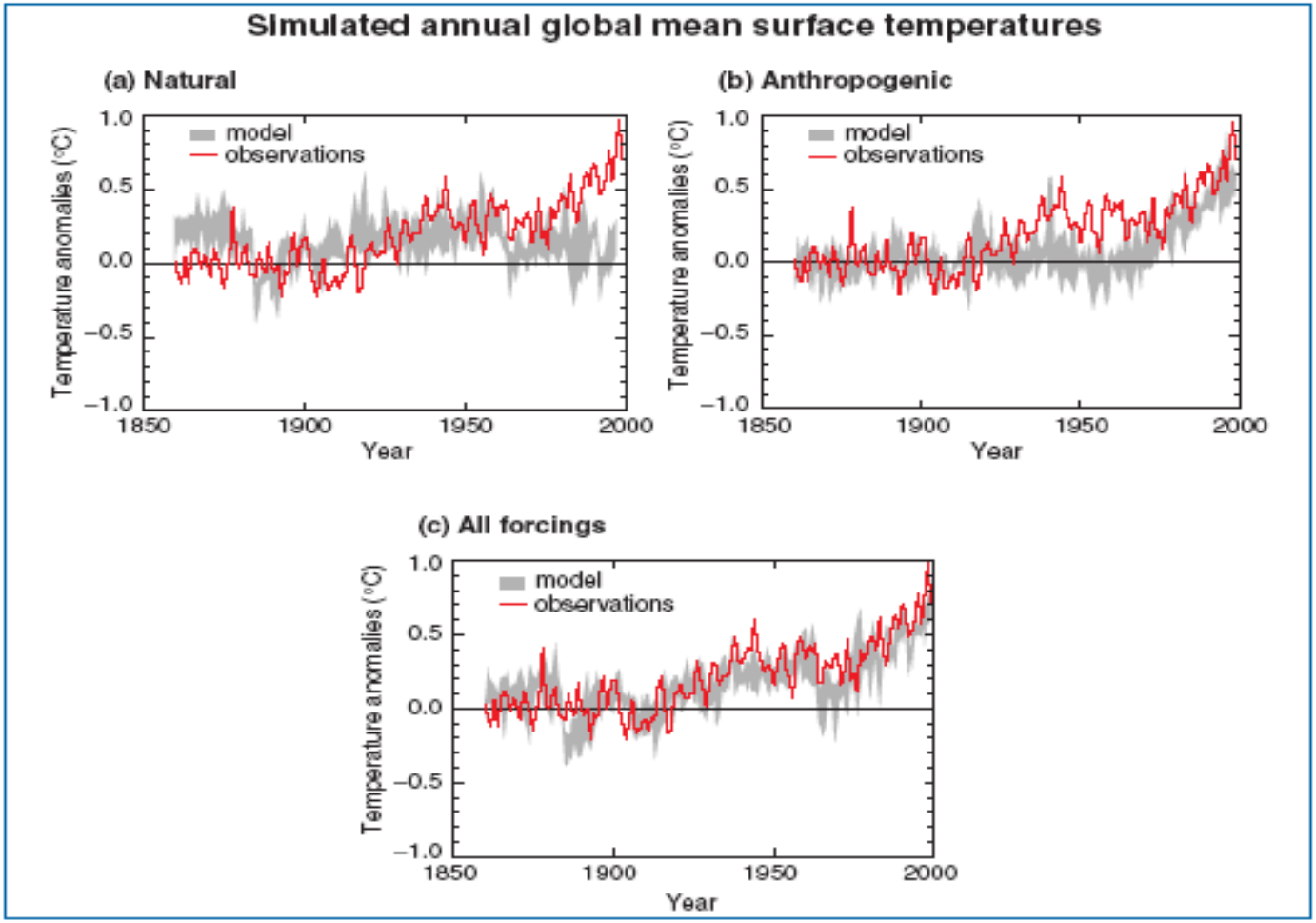


Figure 4: Simulating the Earth's temperature variations, and comparing the results to measured changes, can provide insight into the underlying causes of the major changes.

3rd IPCC report

Draft updates of the 2005 NACP SIS

1. We need to transition essential elements of the observational, data management and analytic system to stable, long-term support.
   - What elements need to make this transition?
   - What can we afford?
   - How can this transition be accomplished?

“Essential elements”

Some elements are: Not yet well developed, but essential. *Examples…*

1. [CO2] observational system
2. Non-CO2 GHG observational network
3. Flux tower network
4. Forest and agricultural inventory data
5. Fossil fuel inventory data
6. Remote sensing of the land surface (MODIS, Landsat)
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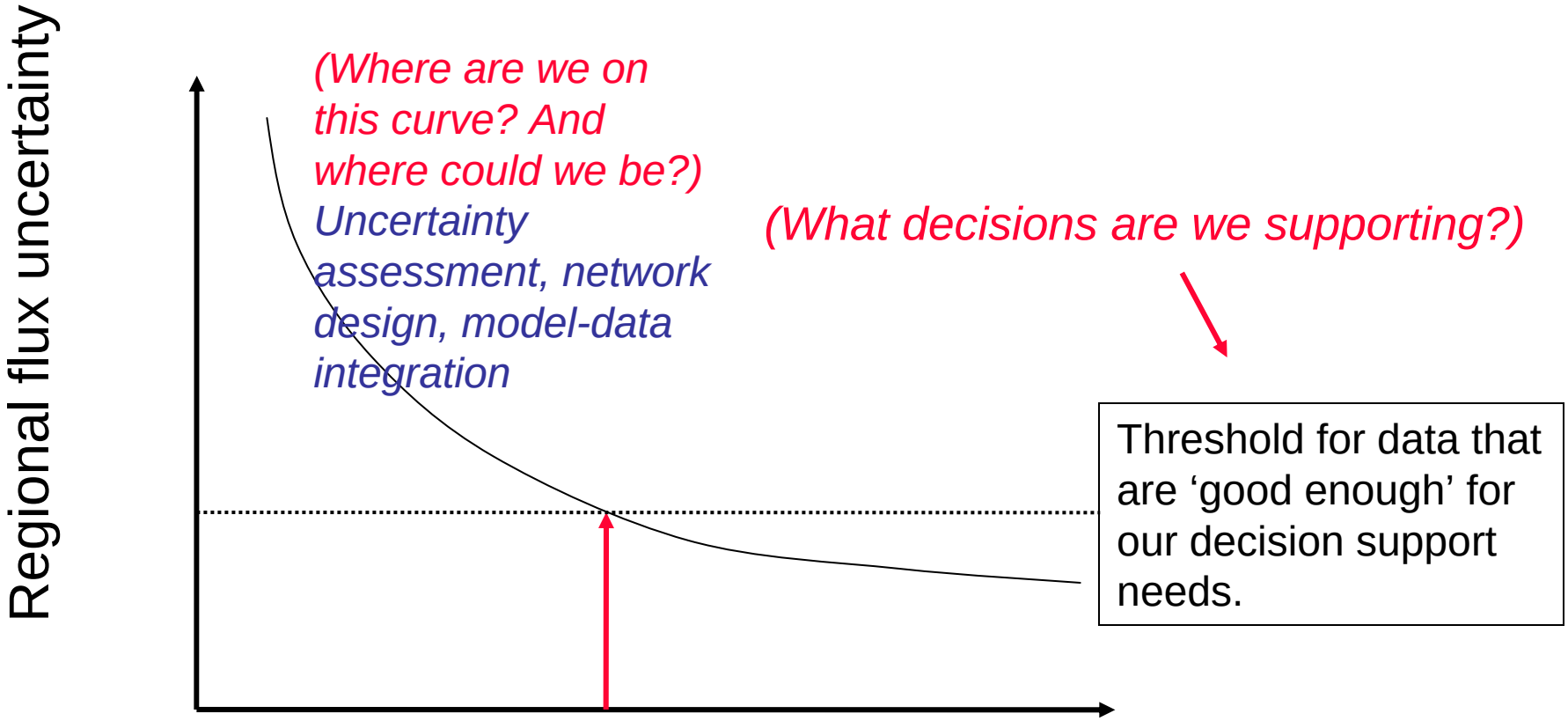
Conclusions

- We are nearing "success" at regional and continental diagnoses of the CO_2 budget.
- Essential elements of our continental observation and analysis system are endangered.
- We need to engage whole-heartedly in research that is integrated with decision support. This will require:
  - Increased emphasis on prediction, model-data syntheses and model comparisons.
  - Increased emphasis on uncertainty assessment, network design, and data/metadata management.
  - Increased focus on human emissions of carbon and study of the mechanisms governing these emissions.
- We need to articulate which decisions we are supporting.

What is “good enough?”



This is when we are done.

(What is this number?)

Research integrated with decision support, ethics & values

Investment in science to improve knowledge

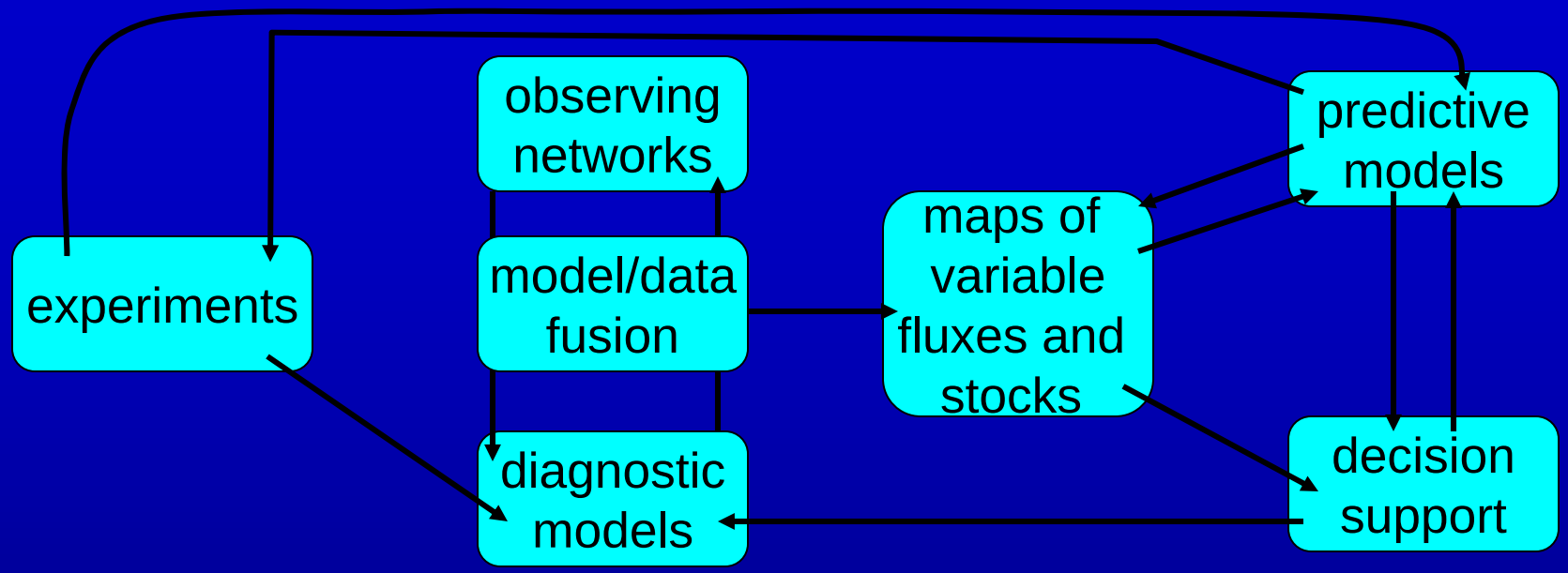
(ideal) path

- Decision needs identified
- Ethical system identified (perhaps with uncertainty)
- Cost-benefit analyses (cost of science vs. cost of uncertainty) conducted
- Scientific research proceeds to reduce uncertainty
- Appropriate decisions implemented

(more realistic) path

- Future research is more fully integrated with decision making goals, integrated assessments, and ethicists, so that we develop the ability to answer the question "when are we done?"
- We proceed iteratively towards our goals.

(modified) NACP Integration Strategy



- Process studies and manipulative experiments inform improved models
- Systematic observations of land, ocean, and atmosphere used to evaluate models
- Innovative model-data fusion techniques produce optimal estimates of time mean and spatial and temporal variations in fluxes and stocks
- Improved models used to predict future variations, and tested against ongoing diagnostic analyses
- Models provide feedback on design of additional experiments
- Predictive models and continuing analyses used to enhance decision support

Conclusions

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  - Increased focus on human emissions of carbon and study of the mechanisms governing these emissions.
- We need to articulate which decisions we are supporting.

More specific decision support objectives: examples

1. Climate and carbon management
   - Reduce the uncertainty in current and future carbon fluxes so that policies can be set that will successfully:
     - cap atmospheric CO2 at a given maximum acceptable mixing ratio,
     - limit climate change to a given level of warming,
     - limit ocean acidification to a minimum acceptable pH.
2. Regulatory support
   - Provide an analysis system that can quantify regional fossil fuel emissions to within X% independent of inventories.
   - Provide tools for evaluating potential carbon management strategies (potential storage, stability of storage) to within specified uncertainty.
   - Provide tools for verifying sequestration of carbon.

Draft updates of the 2005 NACP SIS

1. We need to transition essential elements of the observational, data management and analytic system to stable, long-term support.
2. We need a more explicit and precise discussion of the decision support goals to be integrated into the NACP. We need to transition to a more objective-oriented program.
   - Which decisions should we support?
   - Do you think that this is a mistake?

Draft updates of the 2005 NACP SIS

1. We need to transition essential elements of the observational, data management and analytic system to stable, long-term support.
2. We need a more explicit and precise discussion of the decision support goals to be integrated into the NACP. We need to transition to a more objective-oriented program.
3. We need new intensives to accelerate:
   - Integration of decision support into the NACP
   - Network design, uncertainty assessment and reduction
     - Potentially including new field or experimental work
   - Model-data syntheses and comparisons, including prediction

Possible intensives

- Model comparisons/model-data syntheses
- Network design/predictive skill
- Intensive oriented around a decision support problem
- Urban emissions
- Gulf of Mexico
- Northern latitudes/soil C thresholds

Charge

- Update the ‘state of the science’ in the posters and talks
- Discuss in the breakouts:
  - Do you agree with these conclusions?
  - Are the proposed updates to the SIS on target?
  - What are the ‘essential elements’ that are in need of more stable support, and how do we do this?
  - What ‘new intensives’ would you propose?
  - How can we integrate decision support more fully?
  - What decisions should we be supporting?
  - How much can we promise?

thank you!