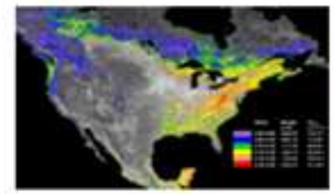
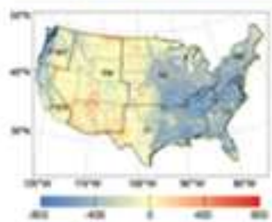
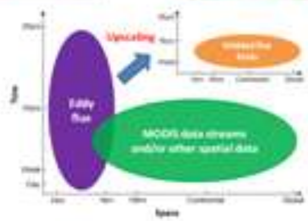
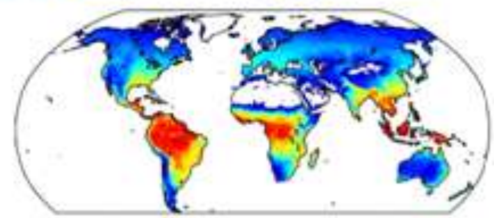
Success and Failure of Implementing Data-driven Upscaling Using Flux Networks and Remote Sensing









Jingfeng Xiao

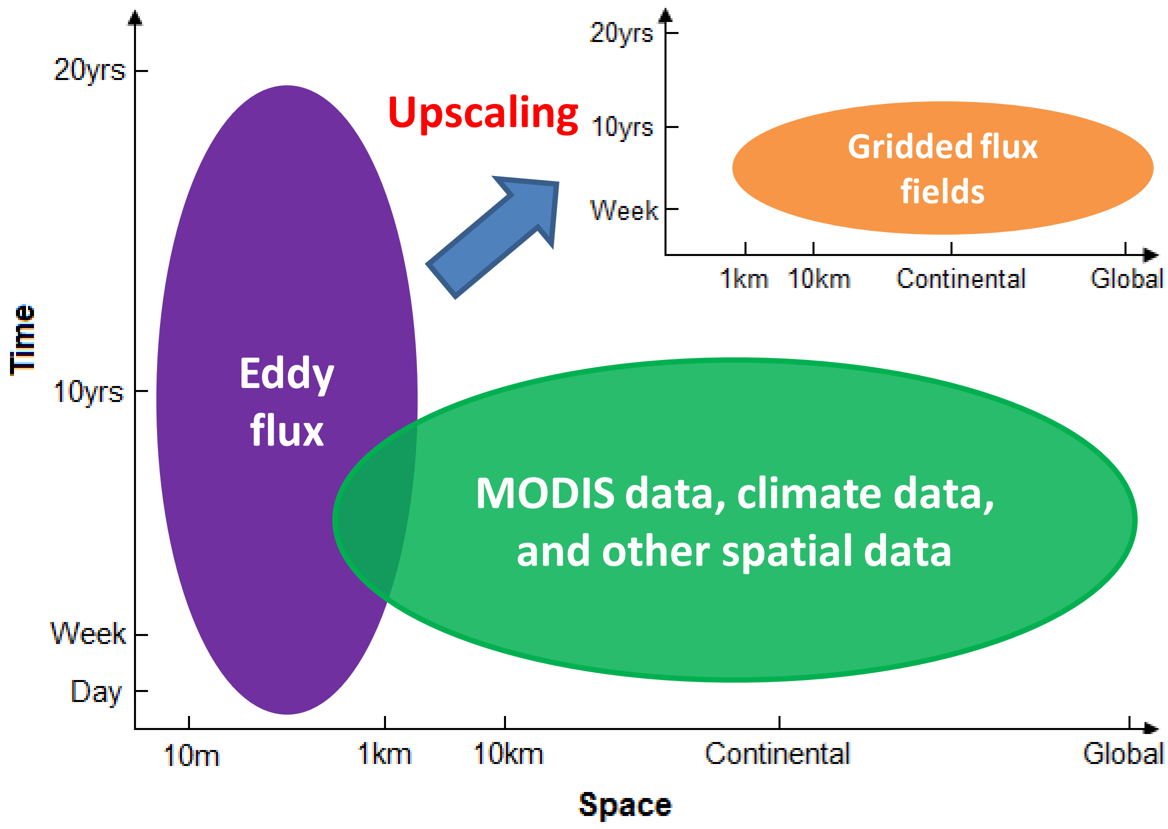
Complex Systems Research Center, University of New Hampshire

FLUXNET and Remote Sensing Open Workshop

June 7-9, 2011, Berkeley, CA

Outline

- Progress
- Applications
- Challenges and directions


Upscaling
20yrs
10yrs
Week
1km
10km
Continental
Global
Gridded flux fields
Time
20yrs
10yrs
Week
Day
Eddy flux
MODIS data, climate data, and other spatial data
10m
1km
10km
Continental
Global
Space

Upscaling methods

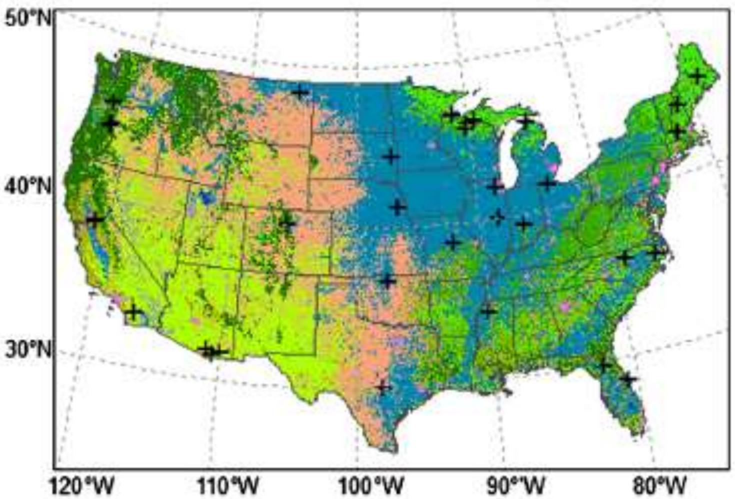
- Data-driven approaches
  - Neural networks (e.g., Papale and Valentini et al. 2003)
  - Ensemble of regression models (e.g., Xiao et al. 2008, Jung et al. 2009, Zhang et al. 2011)
  - Support vector machine (e.g., Ichii et al. 2010)
- Data assimilation techniques
  - Ecosystem models (e.g., Beer et al. 2010; Xiao et al., JGR, accepted)
  - Parameter estimation methods (e.g., Markov chain Monte Carlo, MCMC)

An example for data-driven methods

This model achieved slightly higher performance than the full model (relative error = 0.66, average error = 1.01, $r = 0.72$). The selected model consisted of five committee models, each of which was made of a number of rule-based submodels. For example, the first committee model was made of 26 rule-based submodels:

Rule 1: if land cover = croplands, daytime LST > 30.07, EVI > 0.40, then

$$NEE = 20.24 - 430.3B_3 + 431.7B_4 + 80.8B_1 - 108.7B_5 - 23.4EVI + 0.22L_d + 11.4NDWI - 27.6B_6 + 4B_2$$



Rule 2: if land cover in {deciduous forests, savannas}, $B_2 > 0.34$, $NDWI <= -0.36$, $L_d > 18.06$, $L_n > 11.13$, then

$$NEE = -5.94 + 47.2B_4 - 35B_1 - 12.7B_2 - 7B_3 - 3.6NDWI + 8.4B_6 + 4.4B_5 - 0.4EVI$$

⋮

Rule 25: if land cover in {deciduous forests, mixed forests, croplands}, $NDWI > 0.02$, $L_n <= 9.68$, then

$$NEE = 0.40 - 37.6B_4 + 15.1B_1 + 8.9B_2 + 0.046L_n + 0.9B_5 + 0.4B_3$$

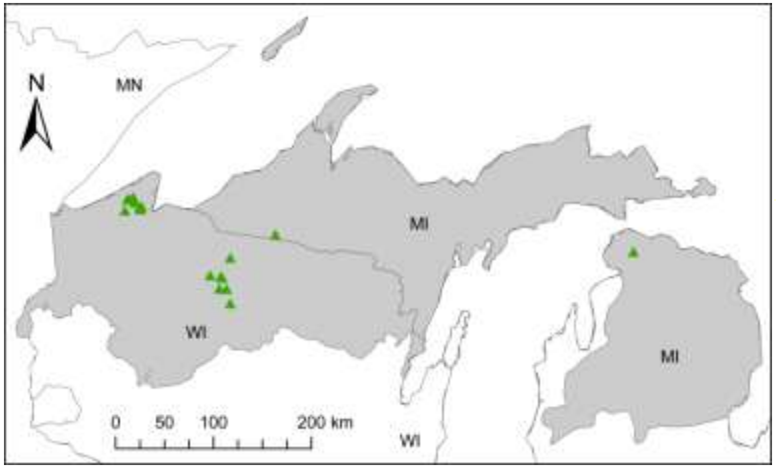
Rule 26: if land cover in {deciduous forests, mixed forests, croplands}, $NDWI > 0.02$, $L_n > 9.68$, then

$$NEE = -2.86 + 56.5B_5 - 50.5B_6 + 14.9NDWI - 2.9B_1 - 0.5B_4 - 0.5B_2$$

where B_1–B_6 are surface reflectance bands 1–6, L_d is daytime LST, and L_n is nighttime LST.

Xiao et al., 2008

An example for data assimilation methods

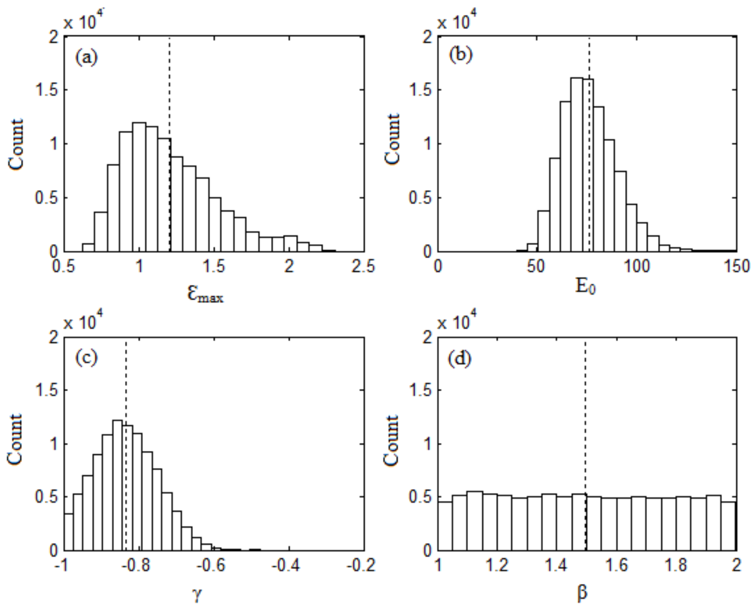


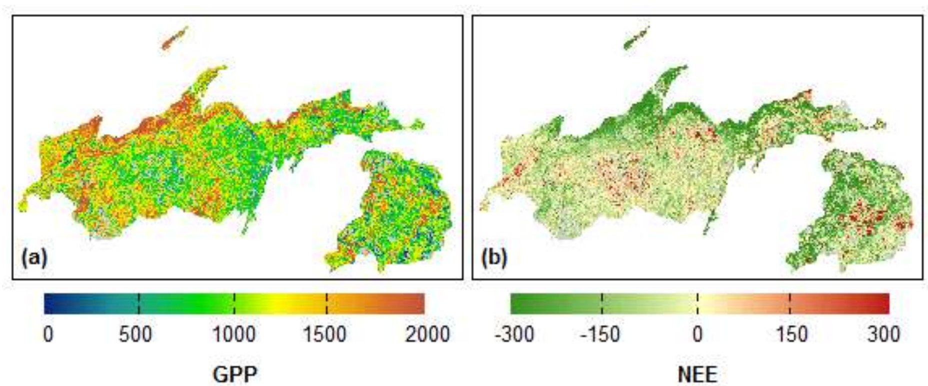
Diagnostic model

$$NEE = -\varepsilon_{\max} \times PAR \times (\alpha + \beta \times EVI) \times W_s \times T_s$$
$$+ (R'_{ref} + \gamma \times AGB + \lambda \times GPP) \times e^{E_0(1/(T_{ref}-T_0)-1/(T-T_0))}$$

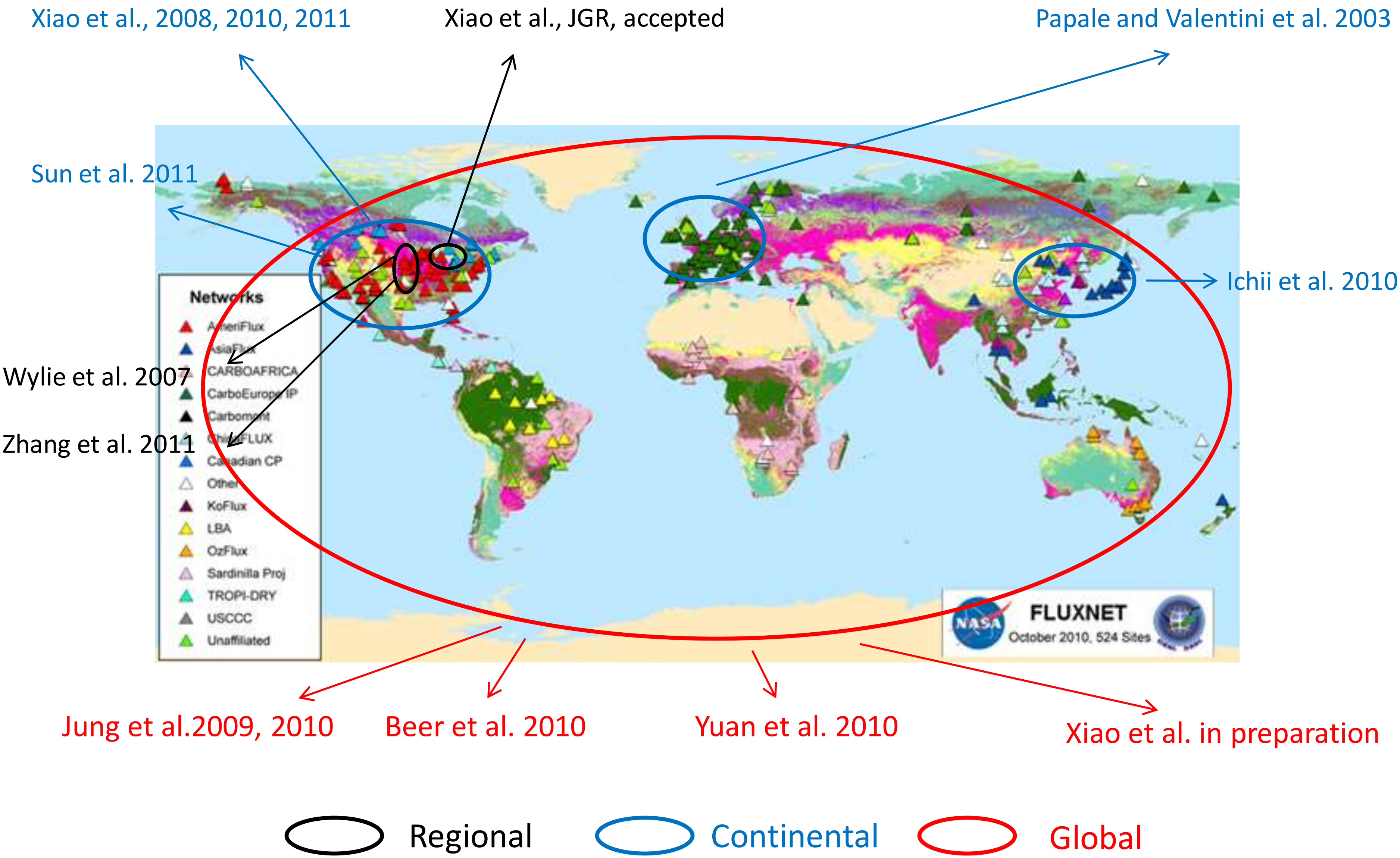
Parameter estimation:

- Differential evolution (DE)
- Markov chain Monte Carlo (MCMC)





Xiao et al., JGR, accepted; Xiao et al., in preparation


Xiao et al., 2008, 2010, 2011
Xiao et al., JGR, accepted
Papale and Valentini et al. 2003
Sun et al. 2011
Ichii et al. 2010
Wylie et al. 2007
Zhang et al. 2011
Networks
AmeriFlux
AsiaFlux
CARBOAFRICA
CarboEurope IP
Carbomont
ChinaFLUX
Canadian CP
Other
KoFlux
LBA
OzFlux
Sardinilla Proj
TROPI-DRY
USCCC
Unaffiliated
NASA
FLUXNET
October 2010, 524 Sites
Jung et al.2009, 2010
Beer et al. 2010
Yuan et al. 2010
Xiao et al. in preparation
Regional
Continental
Global

"Advances in Upscaling of Eddy Covariance Measurements of Carbon and Water fluxes", a special issue in *JGR – Biogeosciences*, guest-editors: Jingfeng Xiao, Kenneth J. Davis, Markus Reichstein, Jiquan Chen

1. Climatic and phenological controls on coherent regional interannual variability of carbon dioxide flux in a heterogeneous landscape, *Desai, A. R.*

2. Upscaling carbon fluxes over the Great Plains grasslands: sinks and sources, *Zhang, L. et al.*

3. Upscaling key ecosystem functions across the conterminous United States by a water-centric ecosystem model, *Sun, G. et al.*

4. Assessing and improving the representativeness of monitoring networks: The European flux tower network example, *Sulkava, M. et al.*

5. Characterizing vegetation structural and topographic characteristics sampled by eddy covariance within two mature aspen stands using LiDAR and a flux footprint model: Scaling to MODIS, *Chasmer, L. et al.*

6. Global patterns of land biosphere - atmosphere fluxes derived from upscaling FLUXNET observations, *Jung, M. et al.*

7. Upscaling carbon fluxes from towers to the regional scale: influence of parameter variability and land cover representation on regional flux estimates, *Xiao, J. et al.*

FluxLetter

VOL 3 NO. 3, DECEMBER, 2010

THE NEWSLETTER OF FLUXNET

ISSUE DEVOTED TO SCALING FLUXES

An examination of methods and tools for using remote sensing data and FLUXNET measurements to enable modeled estimates of grid-scale fluxes 'everywhere all the time"

Scaling Carbon and Water Fluxes from Patches to the Globe: A Challenge and an Opportunity for the Future

An Editorial by Dennis Baldocchi, Rodrigo Vargas and Laurie Koteen

Today, a new scientific revolution is emerging among the FLUXNET community where groups of scientists are producing global scale information on carbon and water fluxes. They are doing so by merging of information from networks of flux towers, biophysical models, ecological databases and satellite-based remote sensing to produce a new generation of flux maps on monthly, yearly and decadal intervals. The success of this effort is only possible by the altruistic sharing of data by each and every one of us, and represents a joint effort. This issue of the FLUXLETTER profiles several groups who are leading the global upscaling charge with a combination of statistical and biophysical models. The effort to produce flux information with a global extent grew out of a general desire to solve problems related to perturbations to the Earth's terrestrial carbon and water cycles. A consensus is now emerging that to be most effective, scientists must produce a measurement and modeling system that is 'everywhere, all of the time'. The global network of networks, FLUXNET, is a step in this direction because it produces a system of flux measurement towers that are 'many places, most of the time'. But is this good enough?

An alternative is to model carbon and water fluxes across the globe and to use the flux towers to validate and test the models. But this task requires quantifying a set of coupled and highly non-linear equations that explain biophysical processes that span 14 orders of magnitude in time and space (Osmond 1989, Jarvis 1995).

Looking back, it is interesting to see how our orientation towards scaling approaches has changed. Such an enterprise would not have arisen in the early days of scaling, when there was much resistance to develop models that span more than 3 'levels', (scales), let alone fourteen. In the proceedings of the famous Trebon, Czechoslovakia workshop of 1969, the pioneering modeler C.T. deWit (de Wit 1970) wrote:

*'now I believe that the simulation in the biological sciences has to be used to fill the gap that exists between specialists at various 'levels' and that we may come to a strategy of model-building in biology when we keep this purpose in mind. To build a model we have to consider and join **two levels of knowledge**. The level with the sort of relaxation times is then the level which provides the explanation or the*

In This Issue:

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Editorial: Scaling Carbon and Water Fluxes from Patches to the Globe: A Challenge and an Opportunity for the Future
DD Baldochhi, R. Vargas, Laurie Koteen ....Pages 1-3

FLUXNET- From Point to Globe
M. Reichstein, M. Jung, N. Carvalhais, M. Mahecha, C. Beer, E. Tomelleri..................Pages 4-8

Global remote sensing in a PC: Cloud computing as a new tool to scale land surface fluxes from plot to the globe
Youngryel Ryu, Jie Li, Catharine van Ingen, Deb Agarwal, Keith Jackson, You-Wei Cheah, Marty Humphrey...................Pages 9-13

FLUXNET Young Scientist:
Rodrigo Vargas ....Pages 14-15

Upscaling Fluxes from Towers to Regions, Continents and Global Scales Using Data-Driven Approaches
Jingfeng Xiao.........Pages16-22

Outline

- Progress
- Applications
- Challenges and directions

Applications

- Examine spatial and temporal patterns of carbon and water fluxes and water use efficiency

- Assess impacts of extreme climate events and disturbance

- Estimate ecosystem services (e.g., ecosystem carbon sequestration, food and wood production, water yield)

- Evaluate simulations of ecosystem models and inversions

- Provide background fluxes for atmospheric inversions

An example for assessing ecosystem carbon dynamics

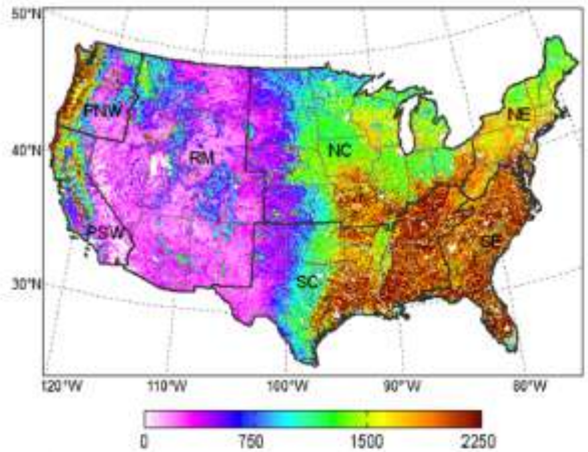


Fig. 8. Average annual GPP ($g\,C\,m^{-2}\,yr^{-1}$) of the conterminous U.S. over the period 2001–2006. The gray lines indicate state boundaries. The black lines indicate boundaries of geographical regions: Northeast (NE), Southeast (SE), North Central (NC), South Central (SC), Rocky Mountain (RM), Pacific Northwest (PNW), and Pacific Southwest (PSW).

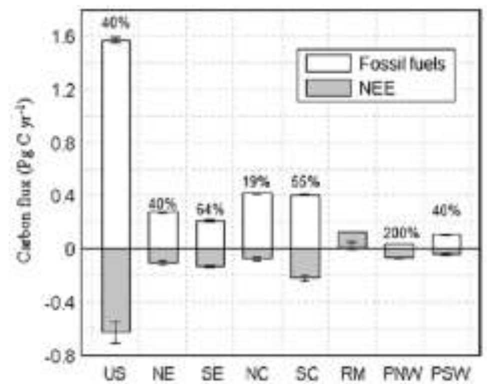


Fig. 7. Mean annual NEE per region for the period 2001–2006. White bars are the fossil fuel fluxes (Energy Information Administration, Department of Energy, http://www.eia.doe.gov), and gray bars are annual NEE. Units are $Pg\,C\,yr^{-1}$. The error bars denote the standard deviation from the mean. The labels refer to the regions: Northeast (NE), Southeast (SE), North-Central (NC), South-Central (SC), Rocky Mountain (RM), Pacific Northwest (PNW), and Pacific Southwest (PSW). Numbers are the percentages that the fossil fuel fluxes were offset by ecosystem carbon uptake. No percentage was provided for the Rocky Mountain region because this region was a minor carbon source.

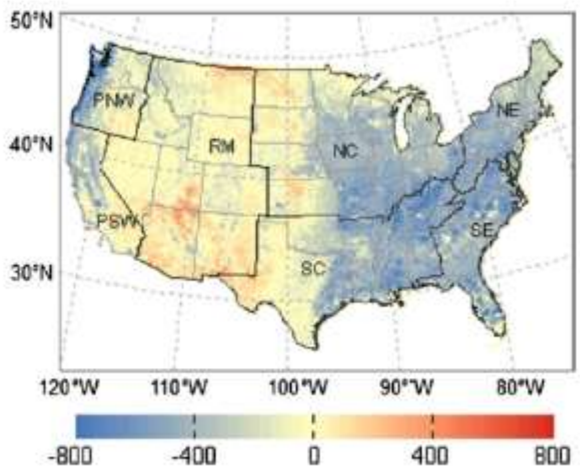


Fig. 5. Mean annual NEE for the conterminous U.S. over the period 2001–2006. Units are $g\,C\,m^{-2}\,yr^{-1}$. Positive values indicate carbon release, and negative values indicate carbon uptake. Gray lines indicate state boundaries. Black lines indicate boundaries of geographical regions: Northeast (NE), Southeast (SE), North Central (NC), South Central (SC), Pacific Northwest (PNW), and Pacific Southwest (PSW).

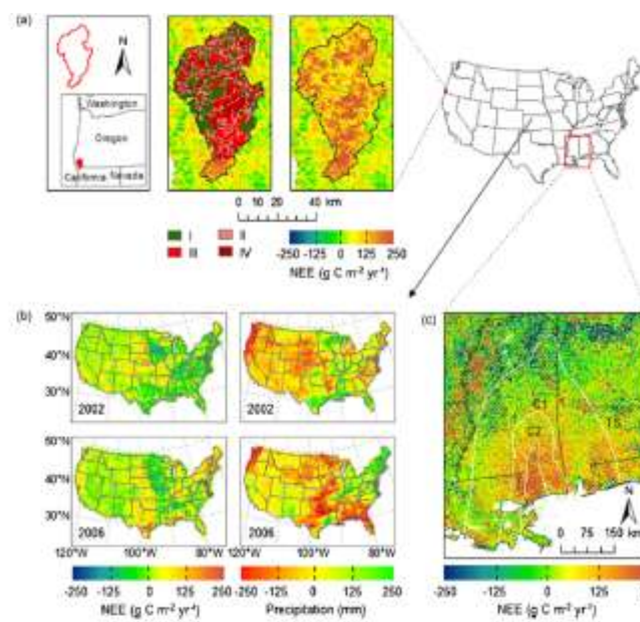


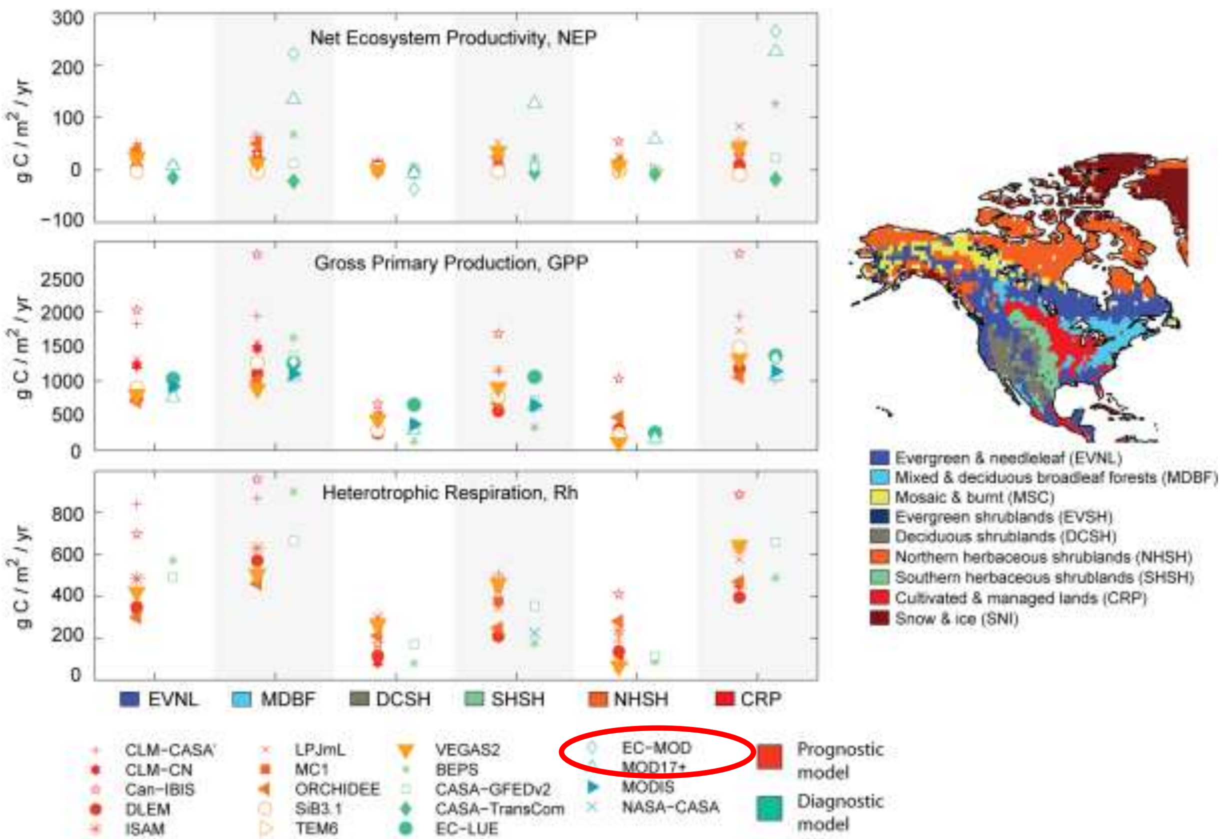
Fig. 9. Effects of extreme climate events and disturbances on annual NEE. (a) Impact of the Biscuit Fire on annual NEE: burned area, fire severity, and anomalies of annual NEE in 2003. Fire severity was based on the difference normalized burn ratio (dNBR) from Landsat Thematic Mapper (TM) data acquired before and immediately after the fire: little or no change (I), green and dead mixed (II), dead trees with needles (III), and dead trees without needles (IV). (b) Anomalies of annual NEE relative to the 6-year period 2001–2006 and anomalies of annual precipitation relative to the 30-year period 1971–2000 taken from the PRISM climate database in 2002 and 2006. (c) Impact of hurricane Katrina on annual NEE in 2006. The white lines indicate the isotachs, including tropical storm, hurricane category 1, and hurricane category 2.

EC-MOD flux fields

Xiao et al., RSE, 2010; Agri. For. Met., 2011

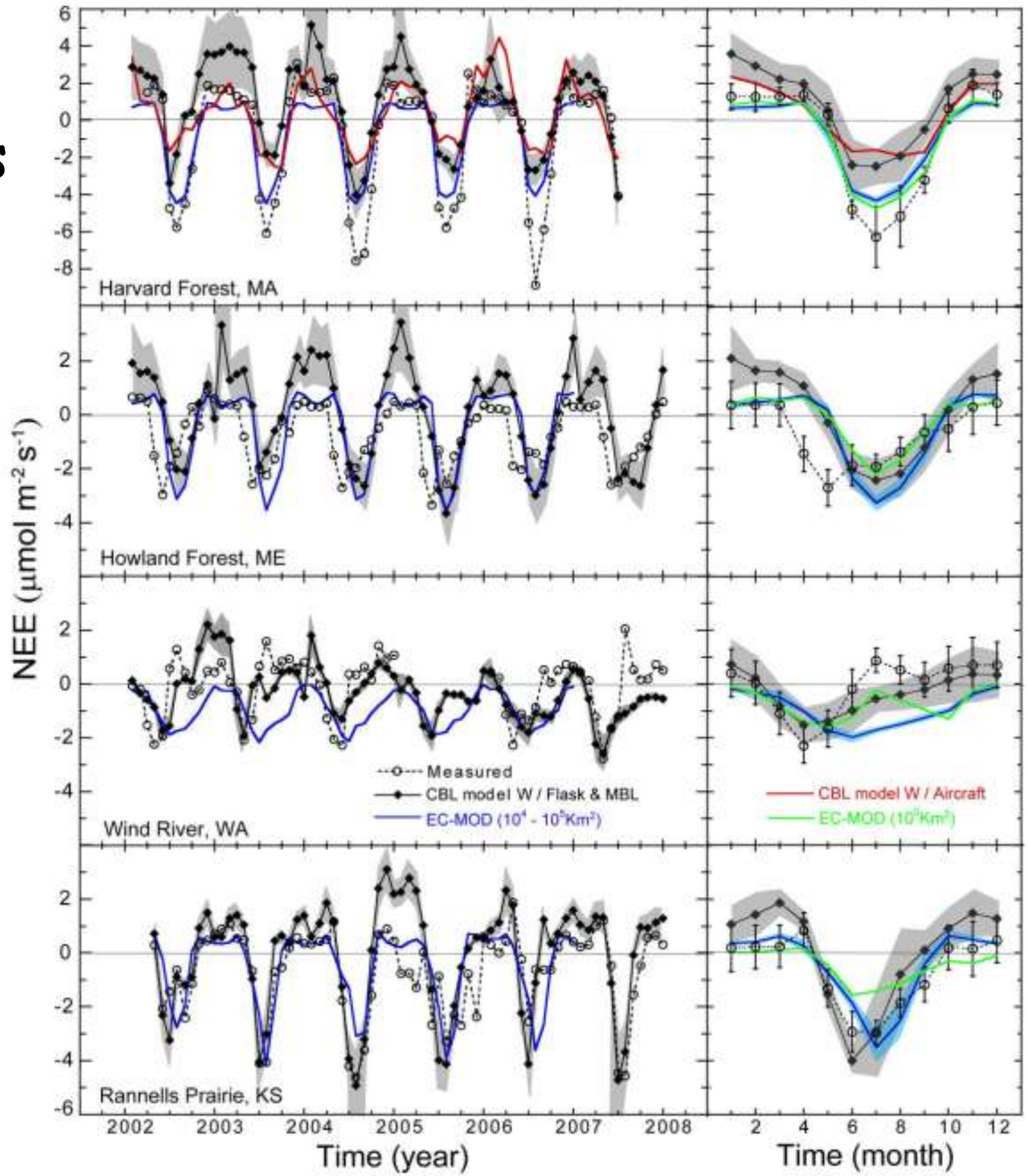
Examples for model evaluations

- Ecosystem models
  - North American Carbon Program (NACP) Interim Synthesis
  - CLM, TEM



Huntzinger et al. in preparation

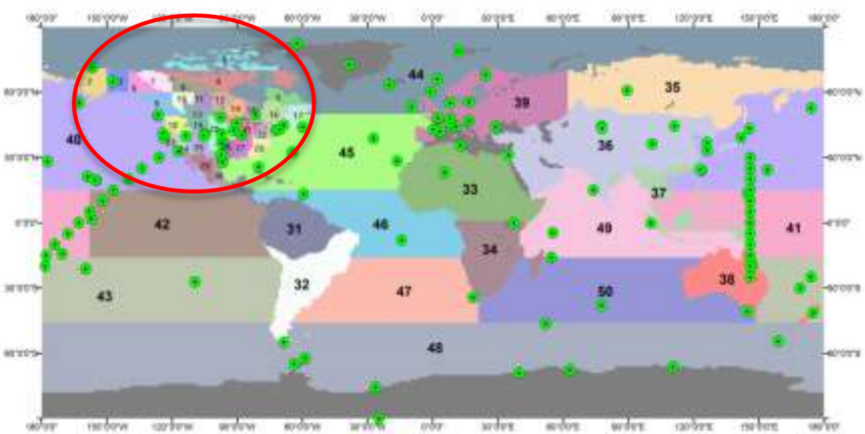
- Atmospheric inversions
  - Boundary layer model
  - 10^4 -10^5 km^2 regions surrounding 4 flux sites

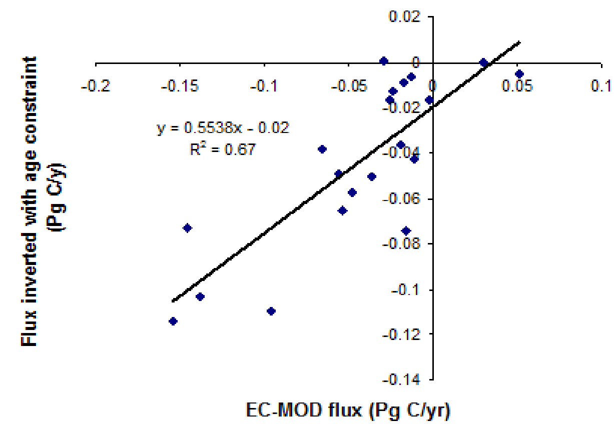


Dang et al., JGR, accepted

Examples for model evaluations

- Atmospheric inversions
  - e.g., a nested inversion model (Deng et al., Tellus, 2007)





Deng et al. in preparation

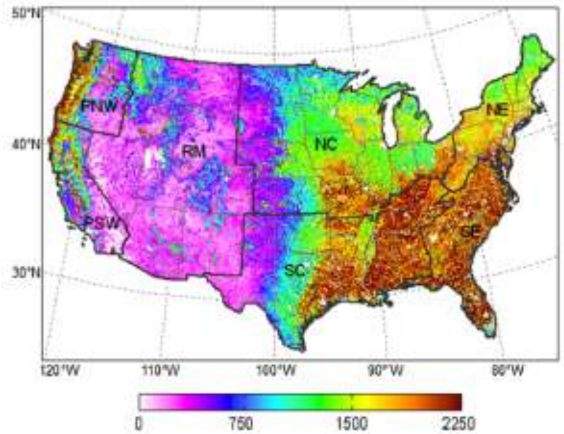
- NASA's Carbon Monitoring System (CMS)
  - Bottom-up and top-down estimates
  - EC-MOD flux fields extending to global scale

Outline

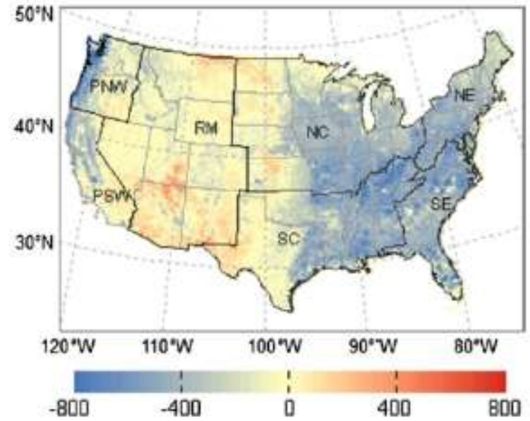
- Progress
- Applications
- Challenges and directions

Challenges

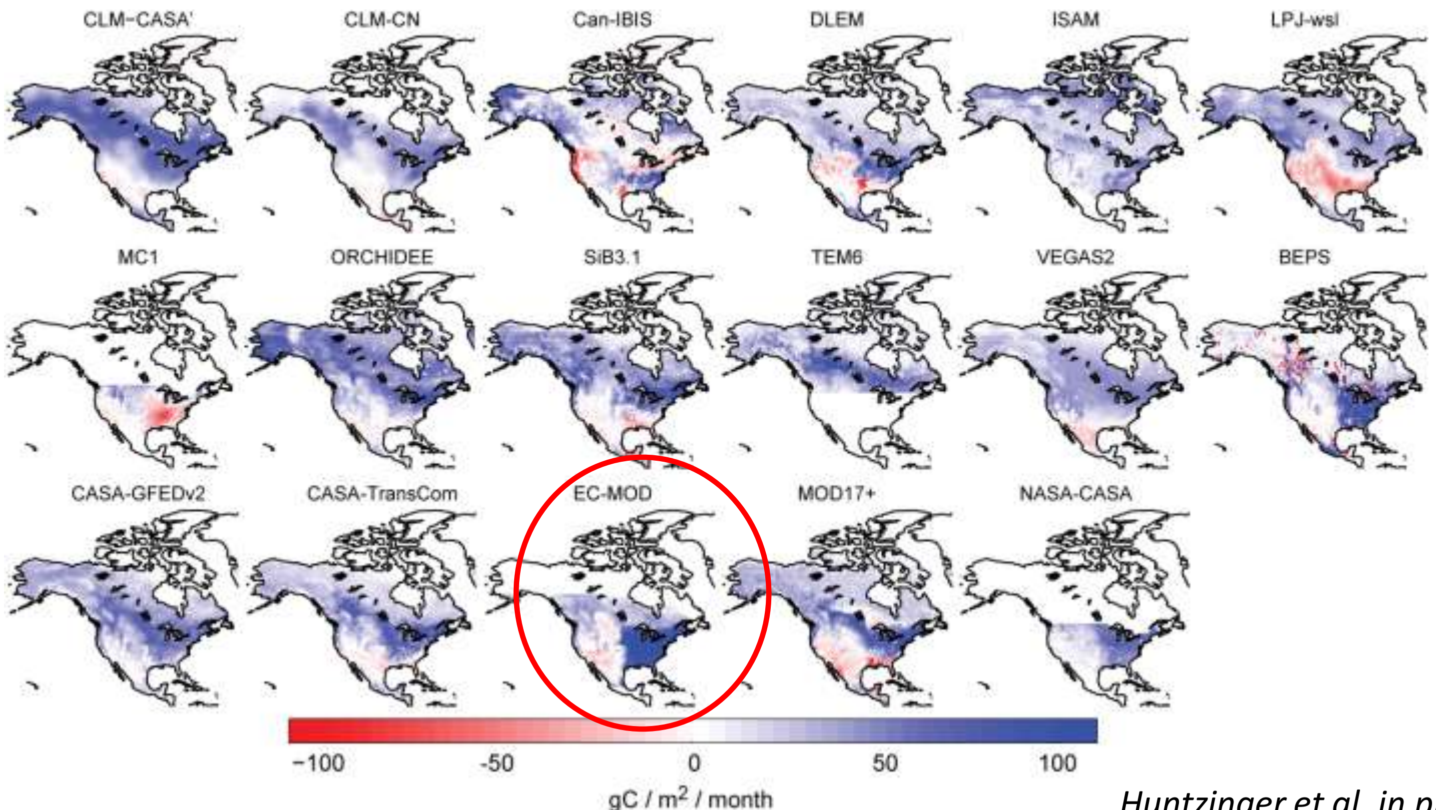
- Accuracy of gridded fluxes
  - Overestimation of carbon fluxes?
- Uncertainty assessment
  - All sources of uncertainty
- Data availability and sharing
  - Some geographical regions
- Sustaining of flux networks
  - Essential for future carbon and water studies



EC-MOD



Xiao et al., 2010, 2011



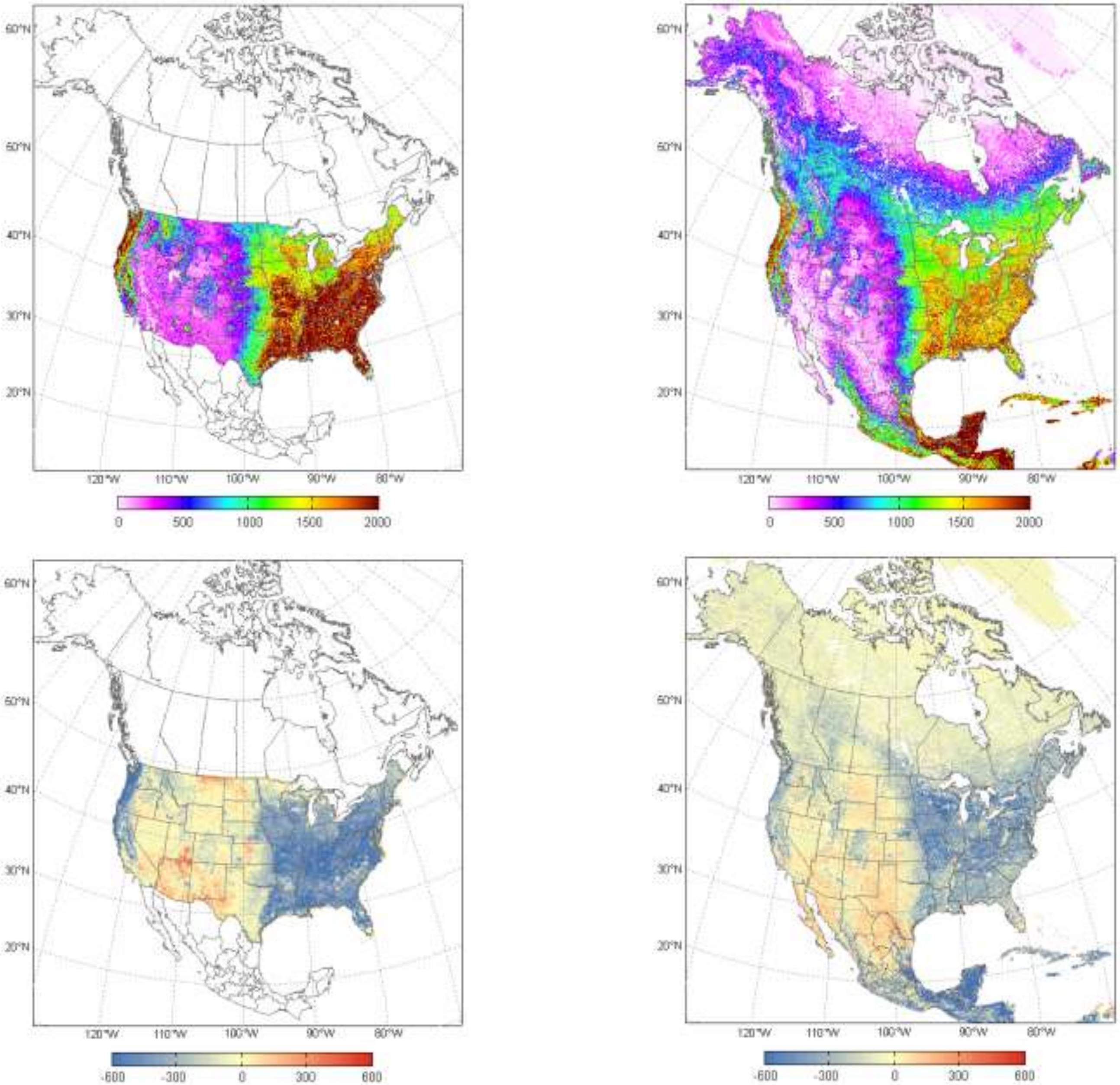
Huntzinger et al. in preparation

Accuracy of gridded fluxes

- Do flux towers tend to be located at productive sites?
  - Possible overestimation of carbon uptake
- Representativeness of flux networks
  - Some regions/ecosystem types are underrepresented
- Difficult to estimate ecosystem respiration
- Failure to fully incorporate disturbance effects

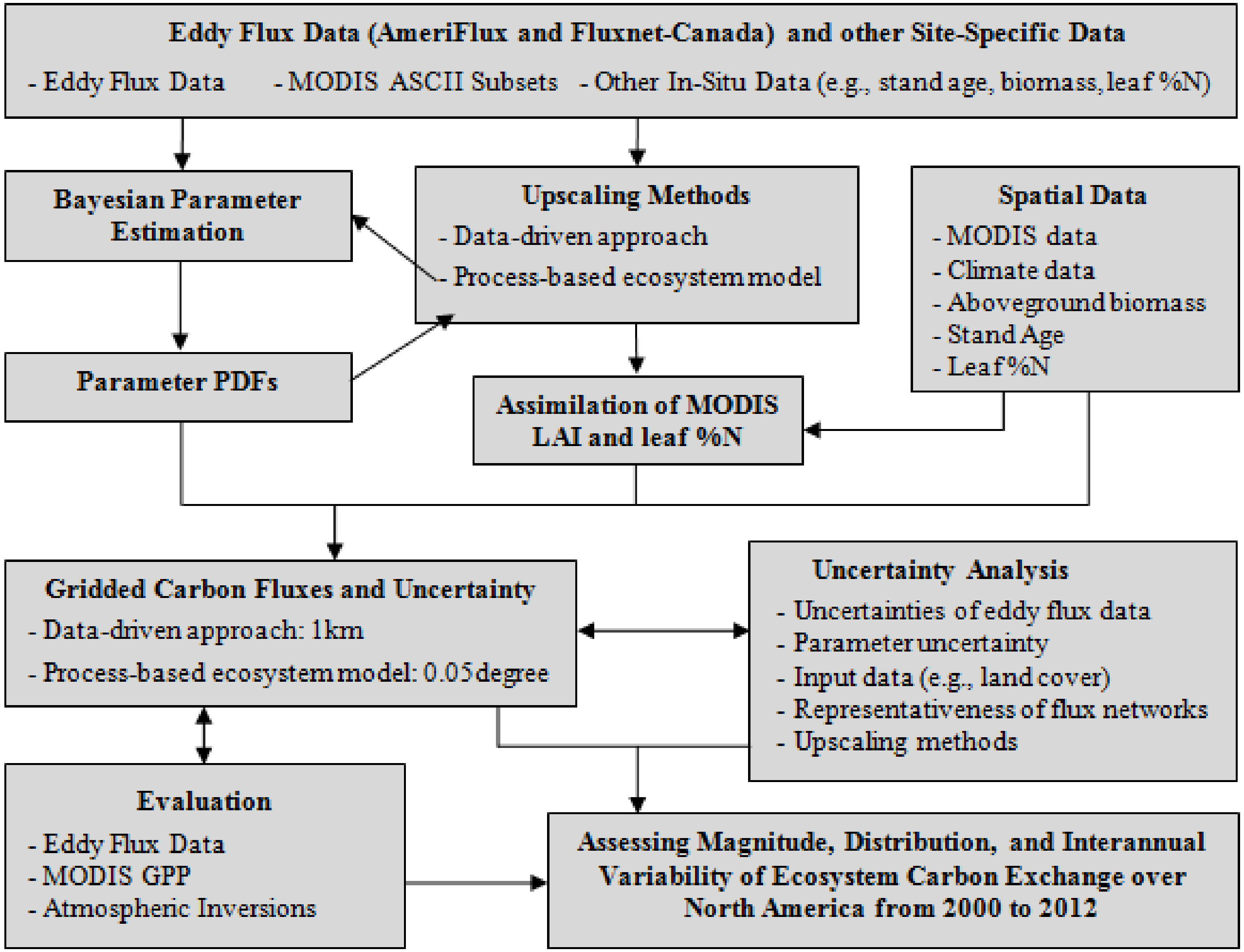
GPP

NEE



EC-MOD v1.0 **EC-MOD v2.0**

Xiao, J., et al. unpublished



"*Assessing Ecosystem Carbon Dynamics over North America by Integrating Eddy Covariance, MODIS, and New Ecological Data through Upscaling and Model-data Synthesis*", NSF, $517,685, 2011-2014, Jingfeng Xiao (PI), Scott Ollinger (Co-PI).

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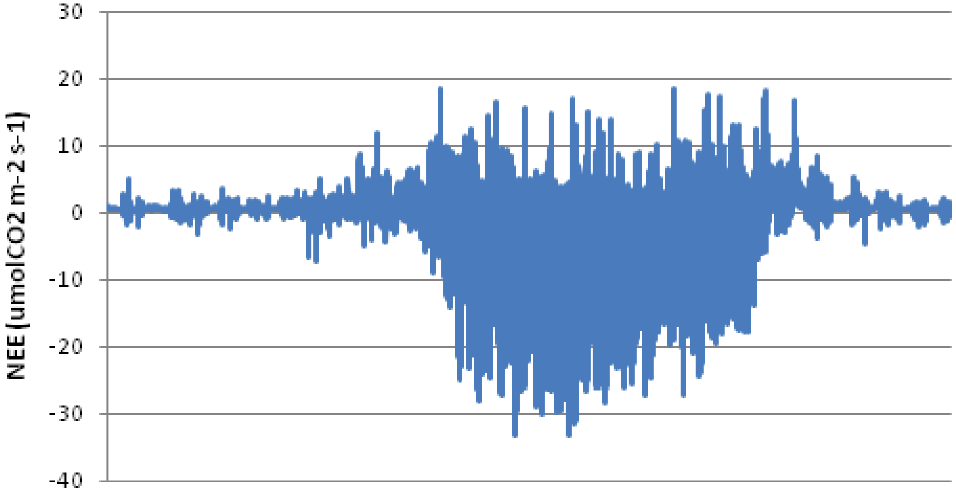
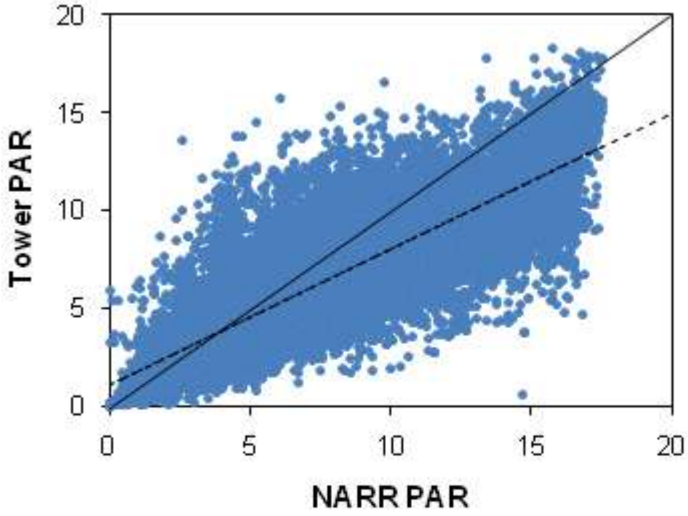
A Postdoctoral Research Associate in Ecosystem Modeling

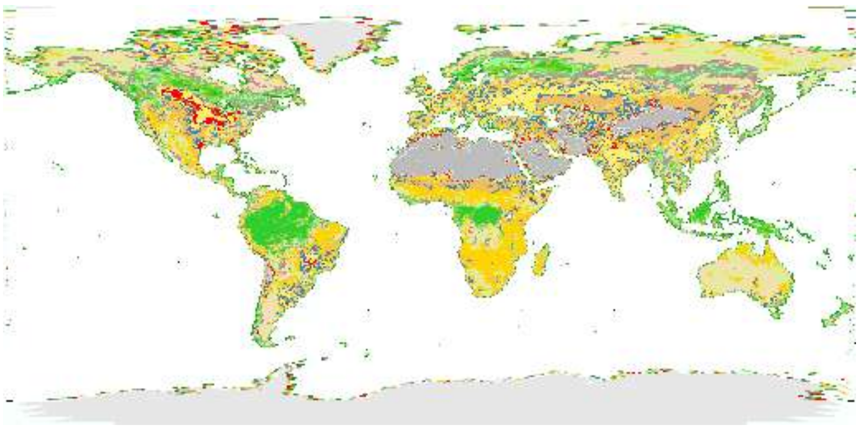
http://www.eos.sr.unh.edu/Faculty/Xiao

Uncertainty assessment

- Input data
  - Some input data may have large biases
- Land cover representation
  - Scaling, heterogeneity, map accuracy
- Model parameters
  - Parameter variability within PFTs
- Model structure
  - Imperfect processes and assumptions



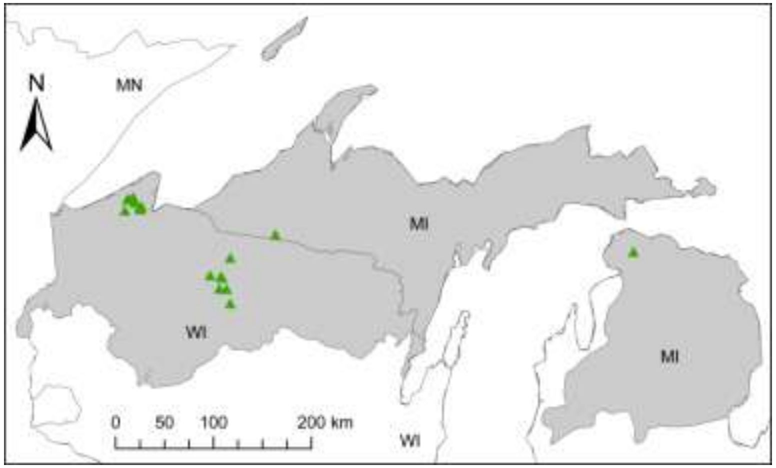


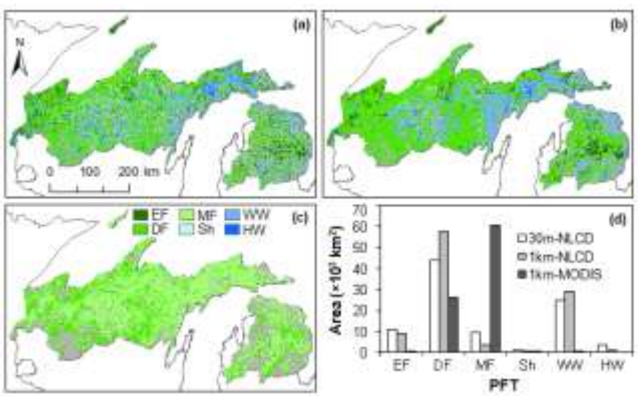


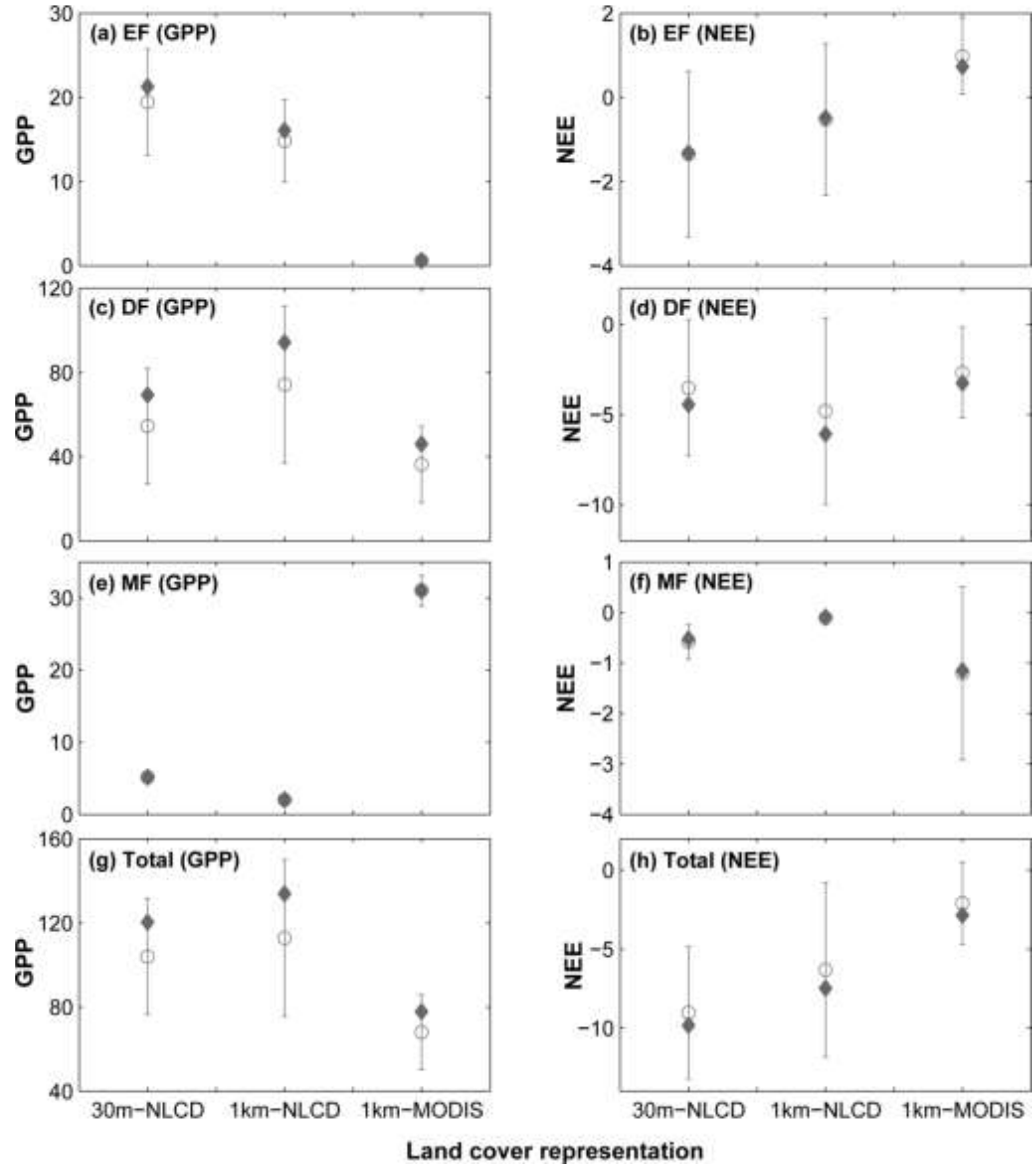
Uncertainty in input data

- Flux observations
- Reanalysis data
- Land cover maps

Example: parameter variability, scaling, and land cover representation







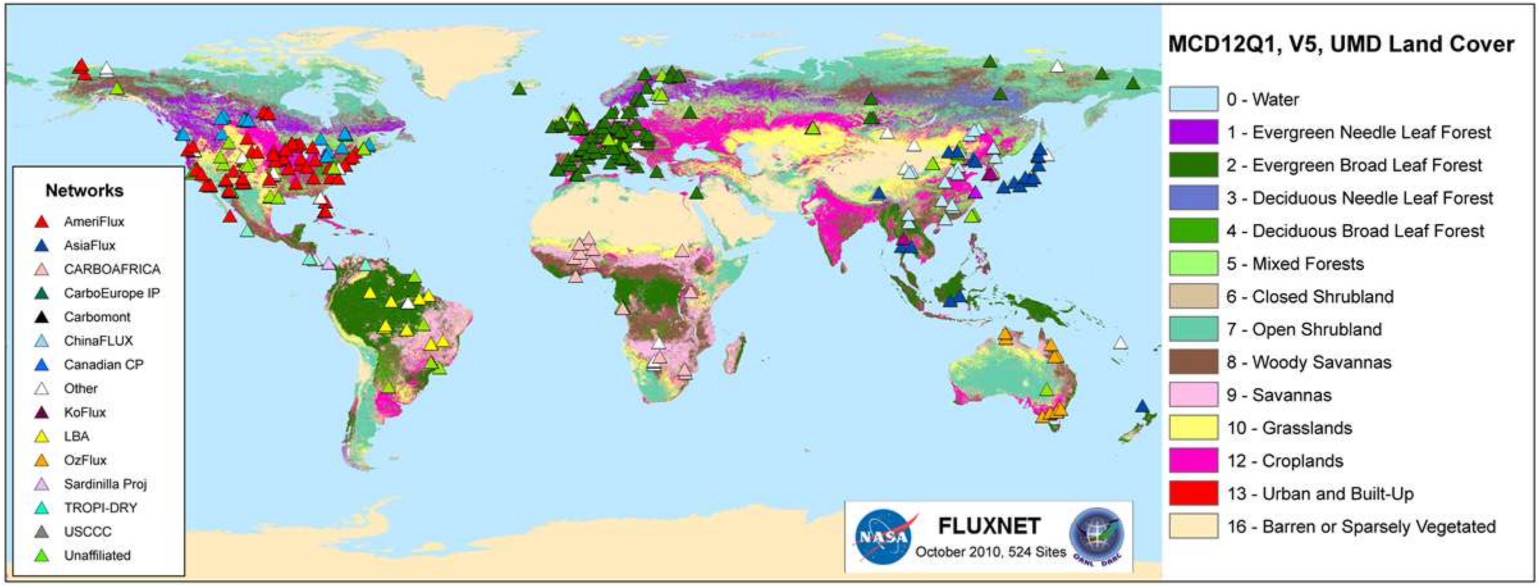
$$NEE = -\varepsilon_{\max} \times PAR \times fPAR \times W_s \times T_s$$

$$+ (R'_{ref} + \gamma \times AGB + \lambda \times GPP) \times e^{E_0(1/(T_{ref}-T_0)-1/(T-T_0))}$$

Xiao et al., JGR, accepted

Data availability and sharing

- Large gaps in flux networks
- Sharing of flux observations in some regions



- Will fair data-use policy and coauthorship help?

Sustaining of flux networks

- A big challenge that flux tower PIs (and modelers) face now
- Large synthesis projects with mini-grants to flux tower PIs?
- Do we really need to maintain all these flux towers?
- Complementary and new networks, e.g., National Ecological Observatory Network (NEON)

Directions

- Account for effects of disturbance and nitrogen limitation and better simulate heterotrophic respiration

- Quantify and reduce uncertainties associated with gridded flux estimates

- Improve and juxtapose various upscaling methods and gridded flux fields

- Play a more important role in studies of carbon and water cycles, ecosystem services, and sustainability and in evaluating Earth System Models