Going from regional flux observation networks to an understanding of changes in the global carbon cycle

Trevor F. Keenan

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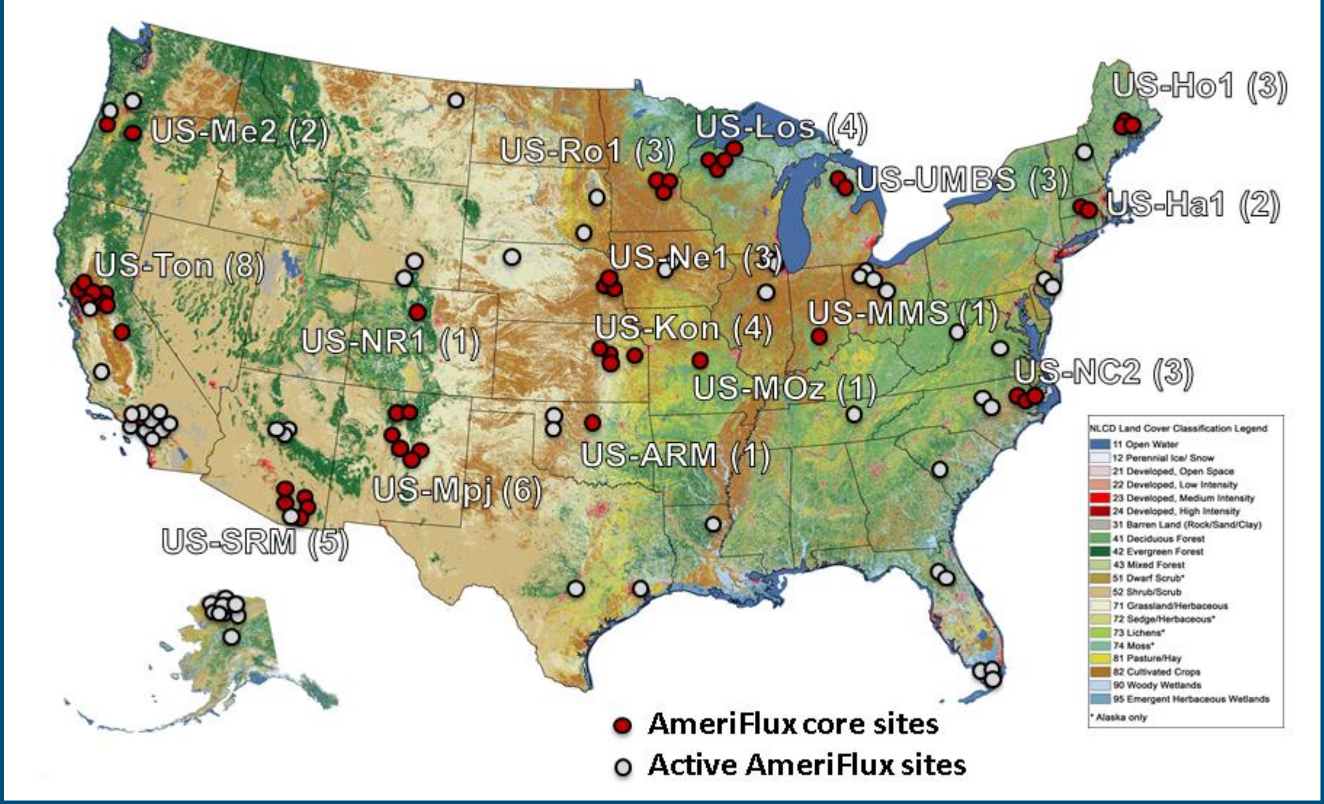
@trevorkeenan

AmeriFlux Management Project



AMP supports 14 Core site clusters that encompass 44 sites

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NEWS FOCUS | CLIMATE CHANGE

New Network Aims to Take the World's CO_2 Pulse

Jocelyn Kaiser

Science 24 Jul 1998:
Vol. 281, Issue 5376, pp. 506-507
DOI: 10.1126/science.281.5376.506

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Vol. 281

DOI: 10.

Global Biogeochemical Cycles

AN AGU JOURNAL

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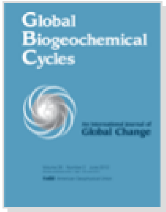
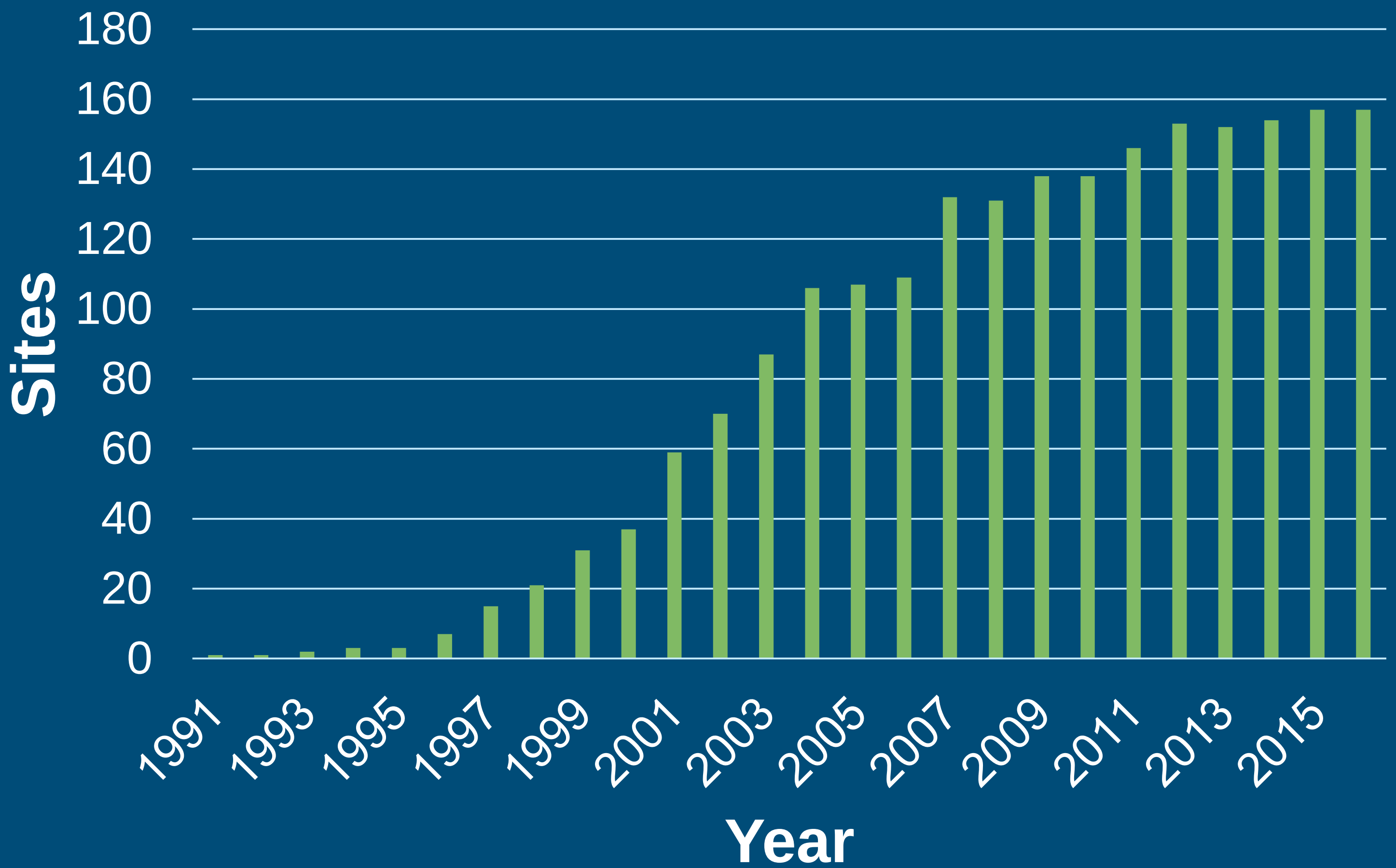
Global net carbon exchange and intra-annual atmospheric CO_2 concentrations predicted by an ecosystem process model and three-dimensional atmospheric transport model

E. Raymond Hunt Jr., Stephen C. Piper, Ramakrishna Nemani, Charles D. Keeling, Ralf D. Otto, Steven W. Running

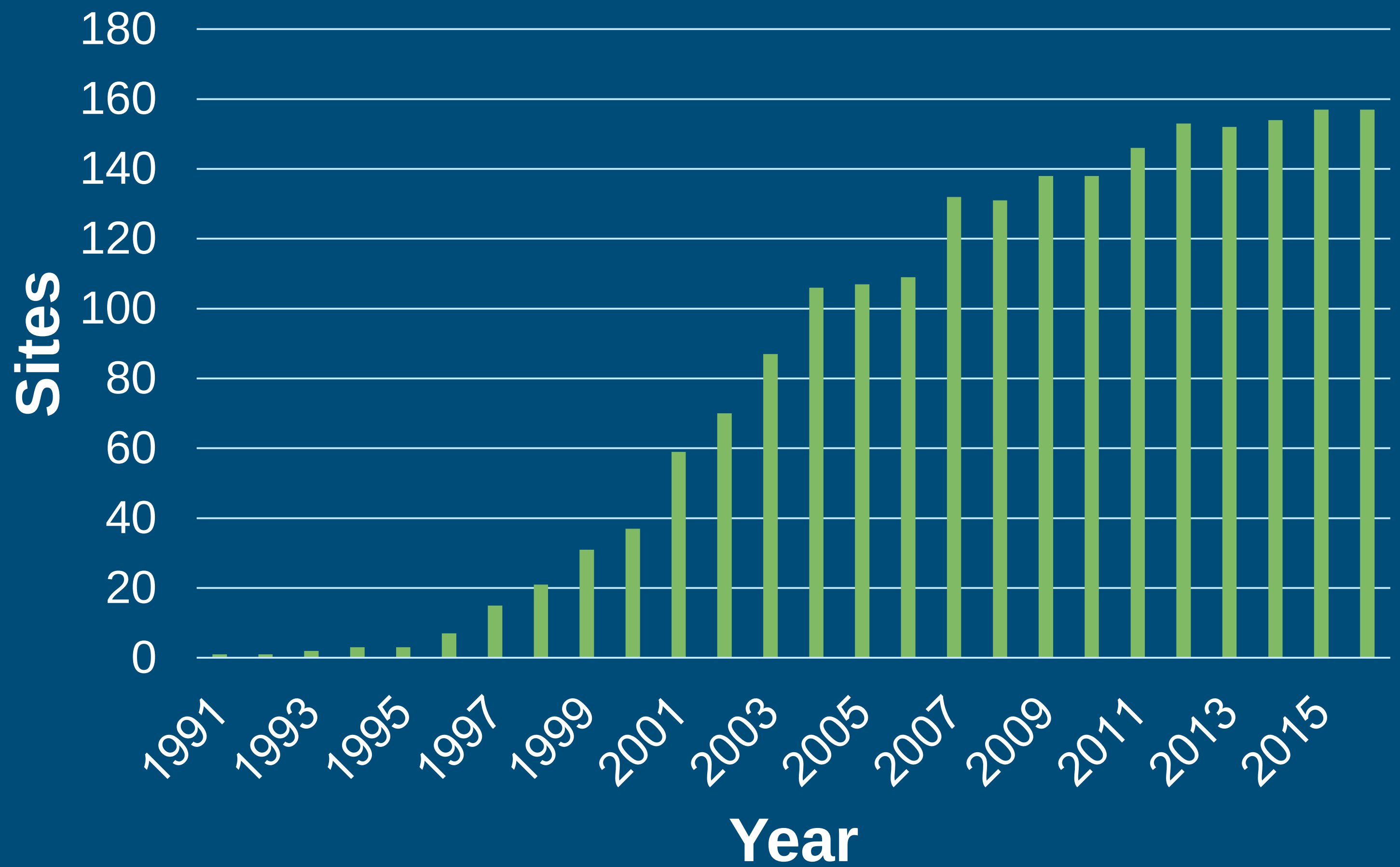
First published: September 1996 Full publication history



View issue TOC
Volume 10, Issue 3
September 1996
Pages 431–456

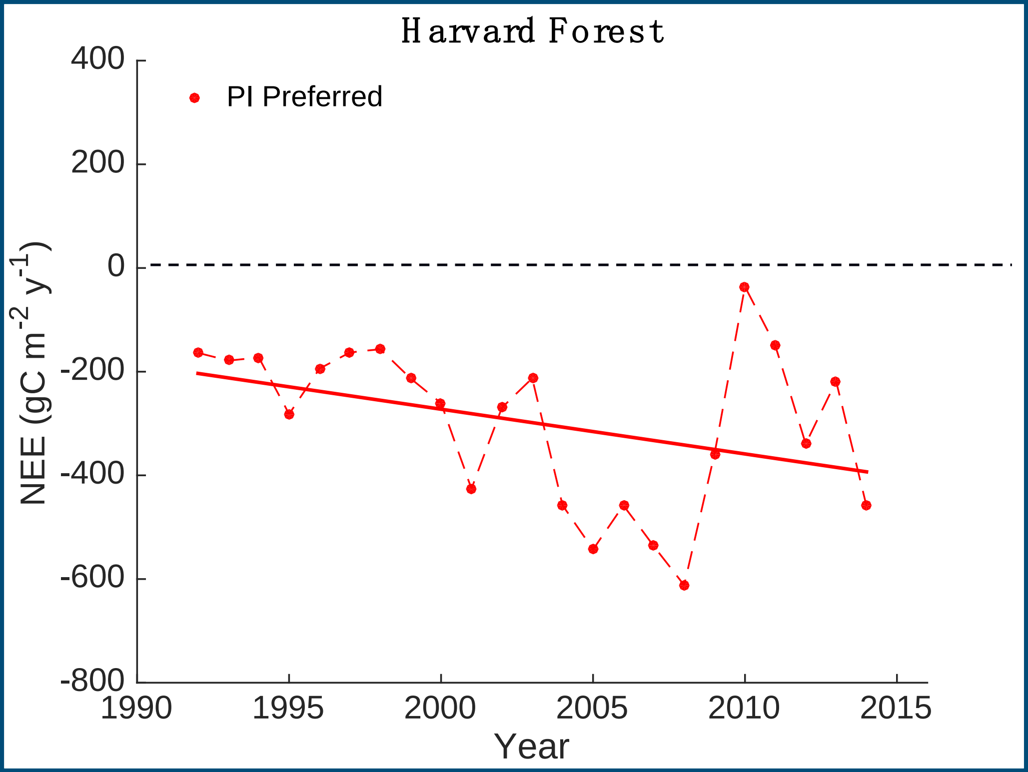


259 total sites registered ~= 2000 site years

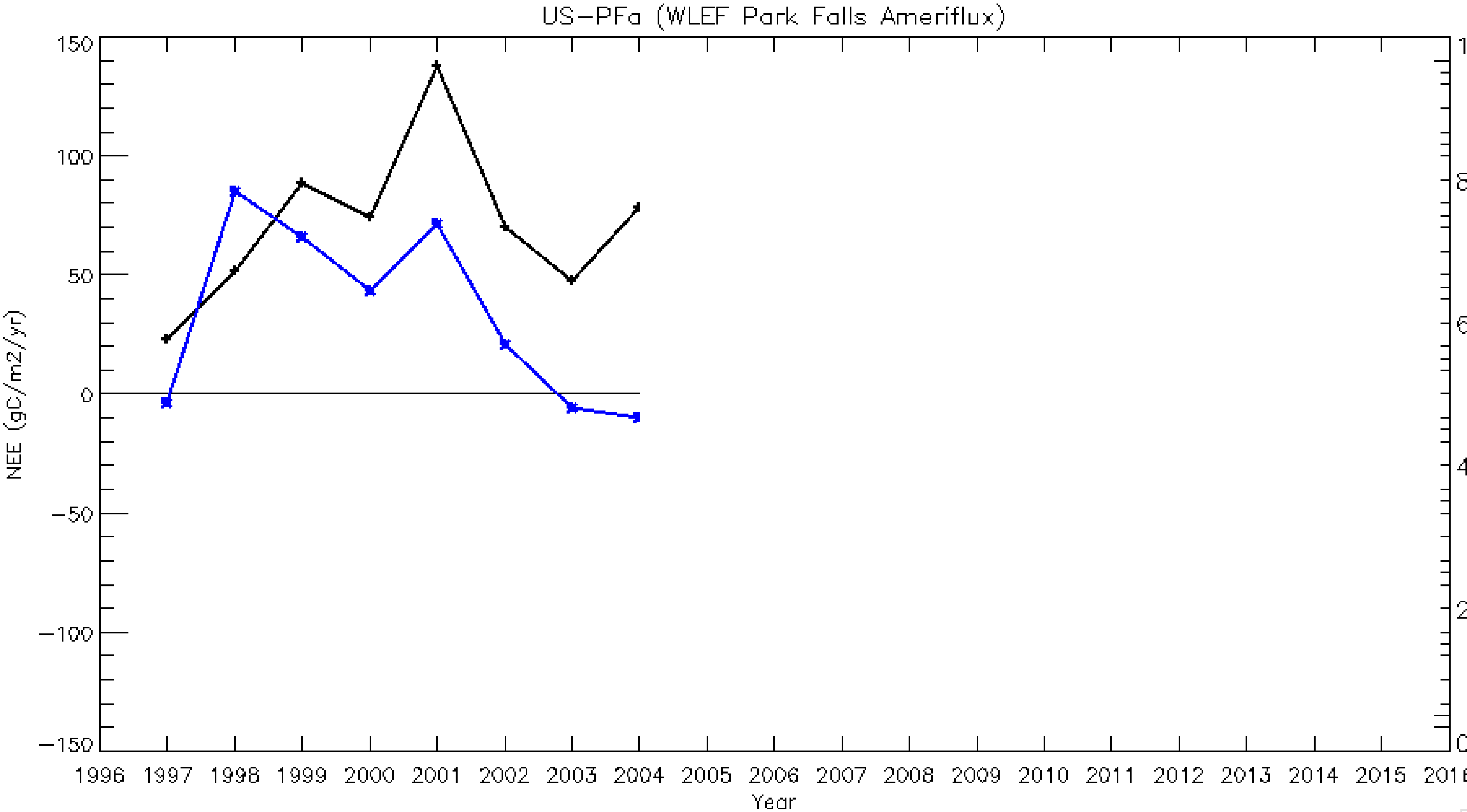


259 total sites registered ~= 2000 site years

The value of long-term observations

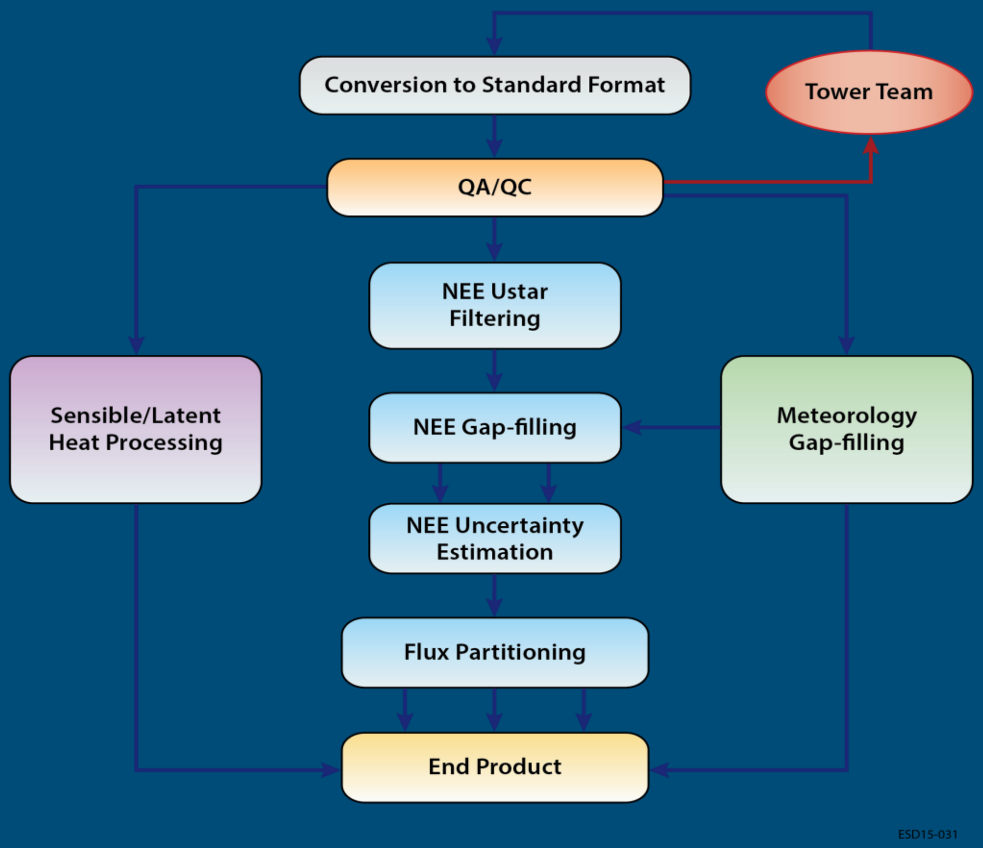


The value of long-term observations

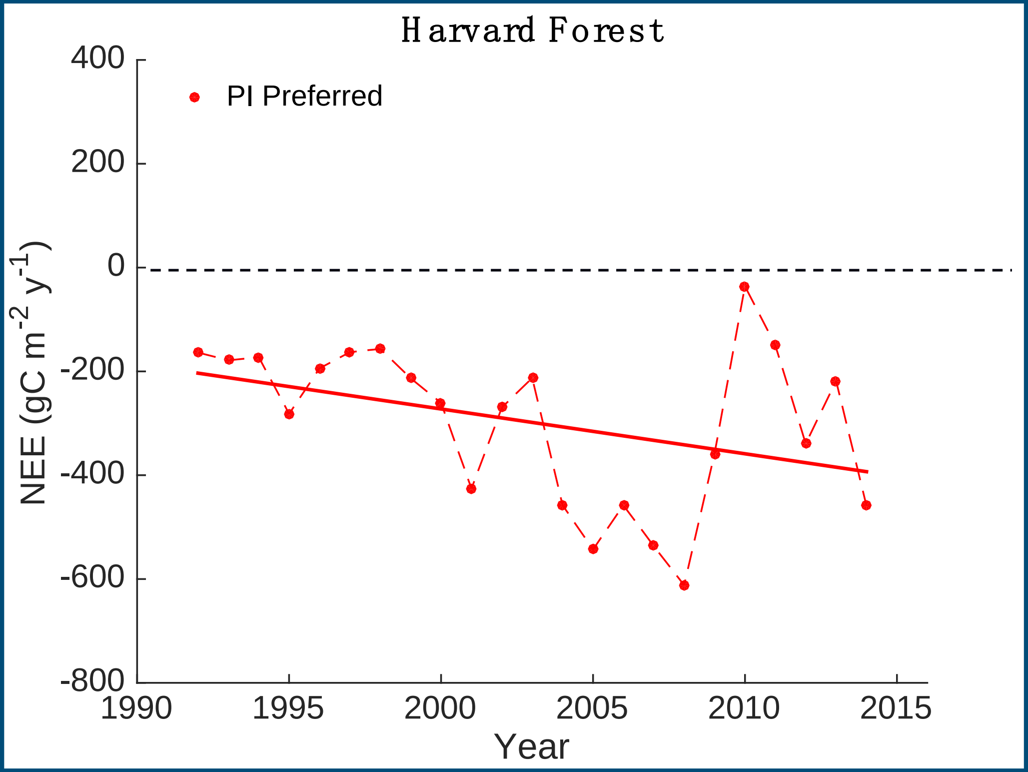


Courtesy of Ankur Desai

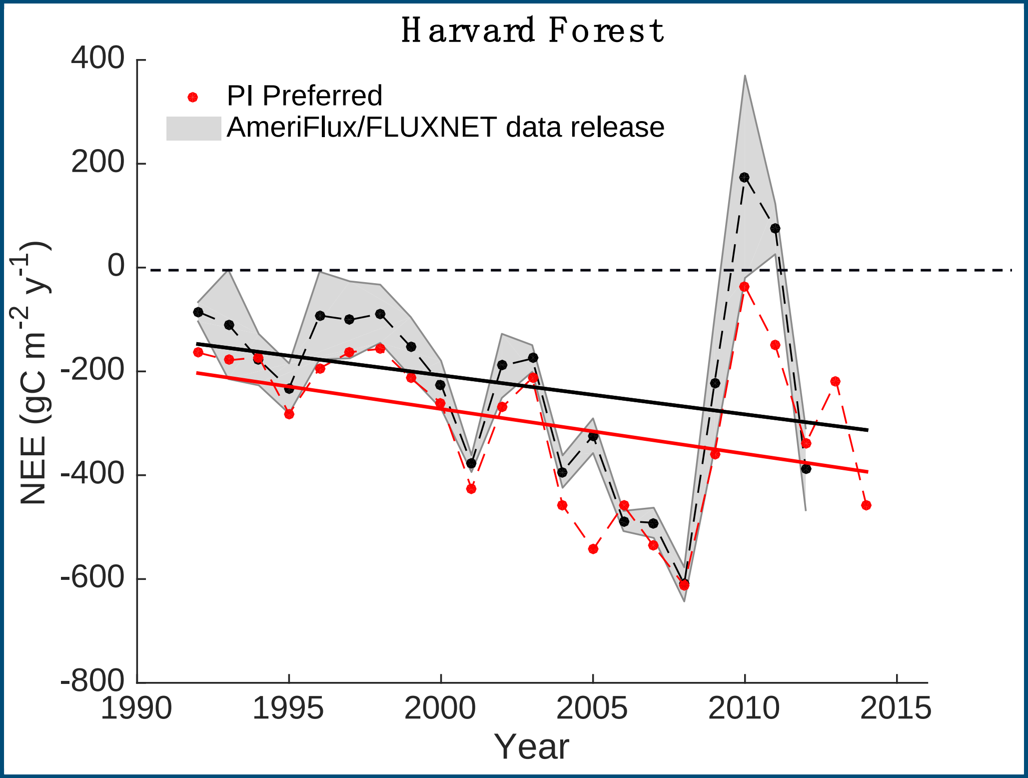
Advanced data processing



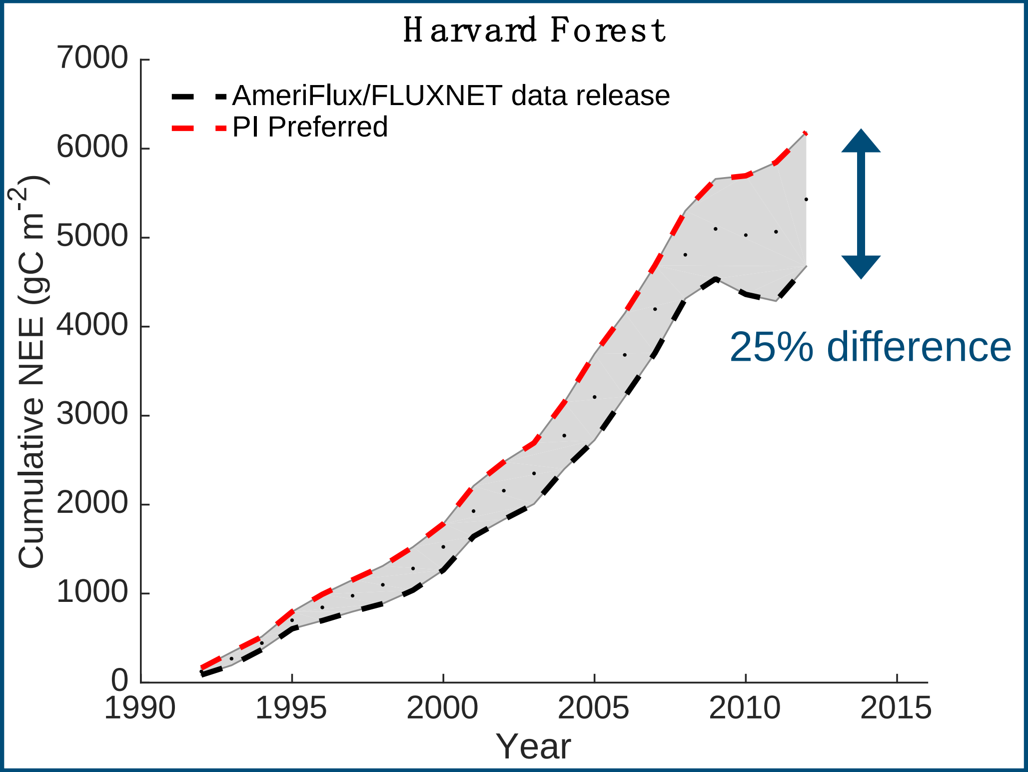
Advanced data processing



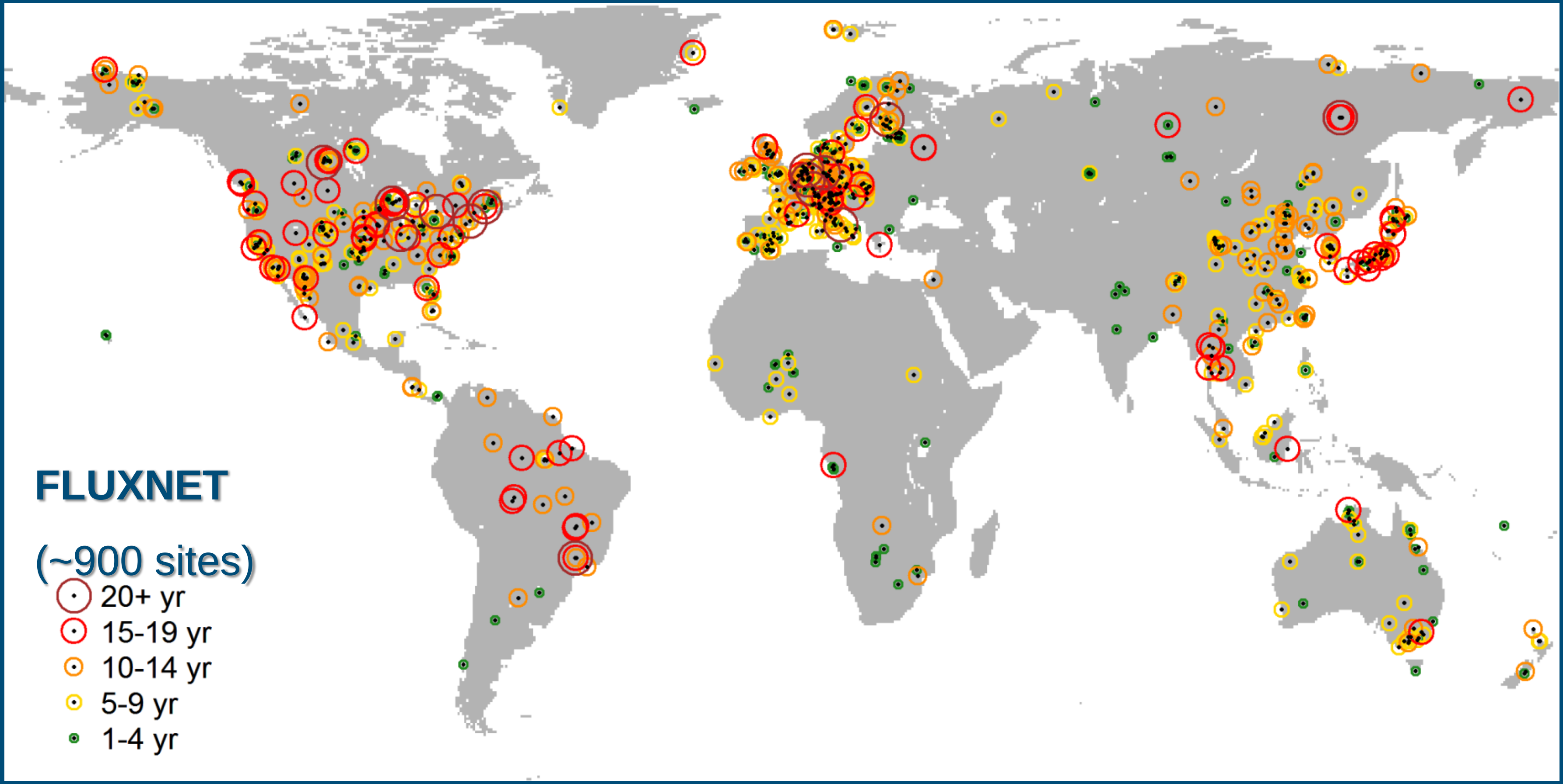
Advanced data processing



The value of long-term observations



FLUXNET: Global measurements of earth-atmosphere exchange



US: 48 sites; Canada: 16 sites; Australia: 16 sites;
Italy: 16 sites; Denmark: 10 sites; China: 9 sites

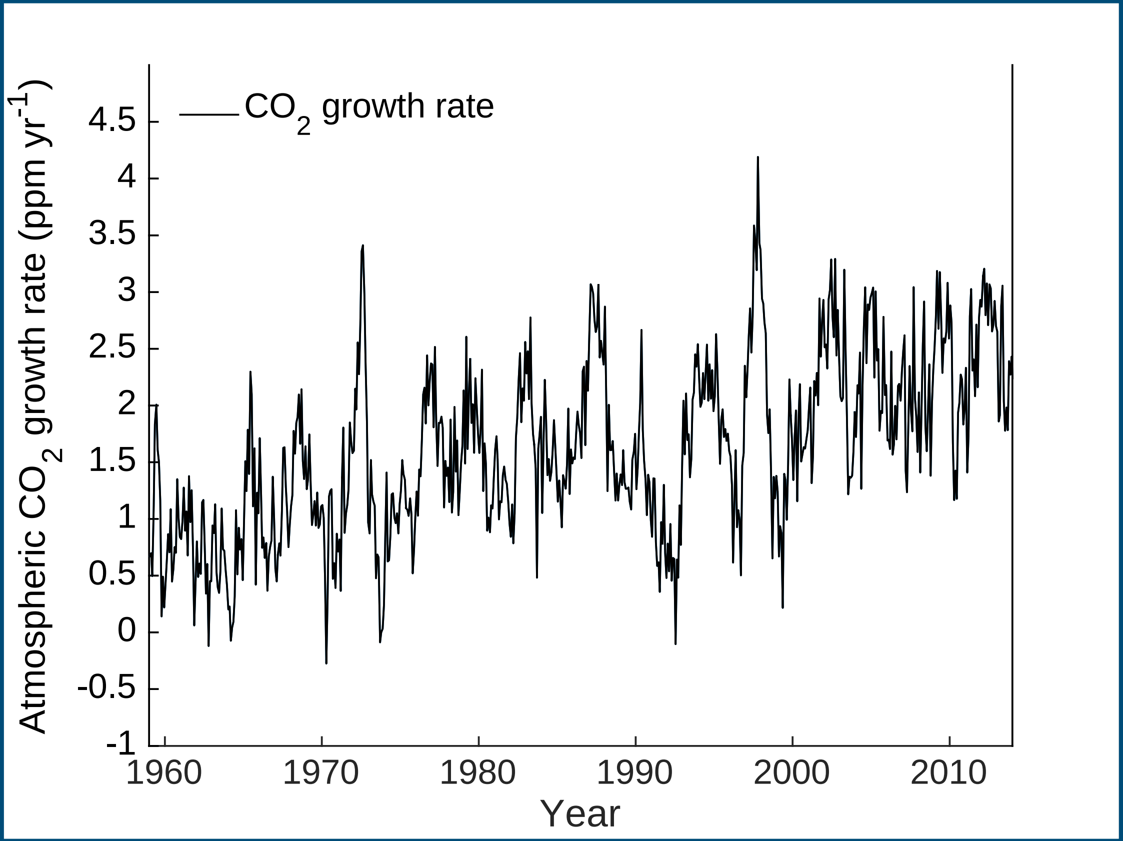
The growth rate of atmospheric CO_2

GR_{CO2} = emissions (fossil fuels, land use change, cement production)

- Terrestrial CO_2 sinks

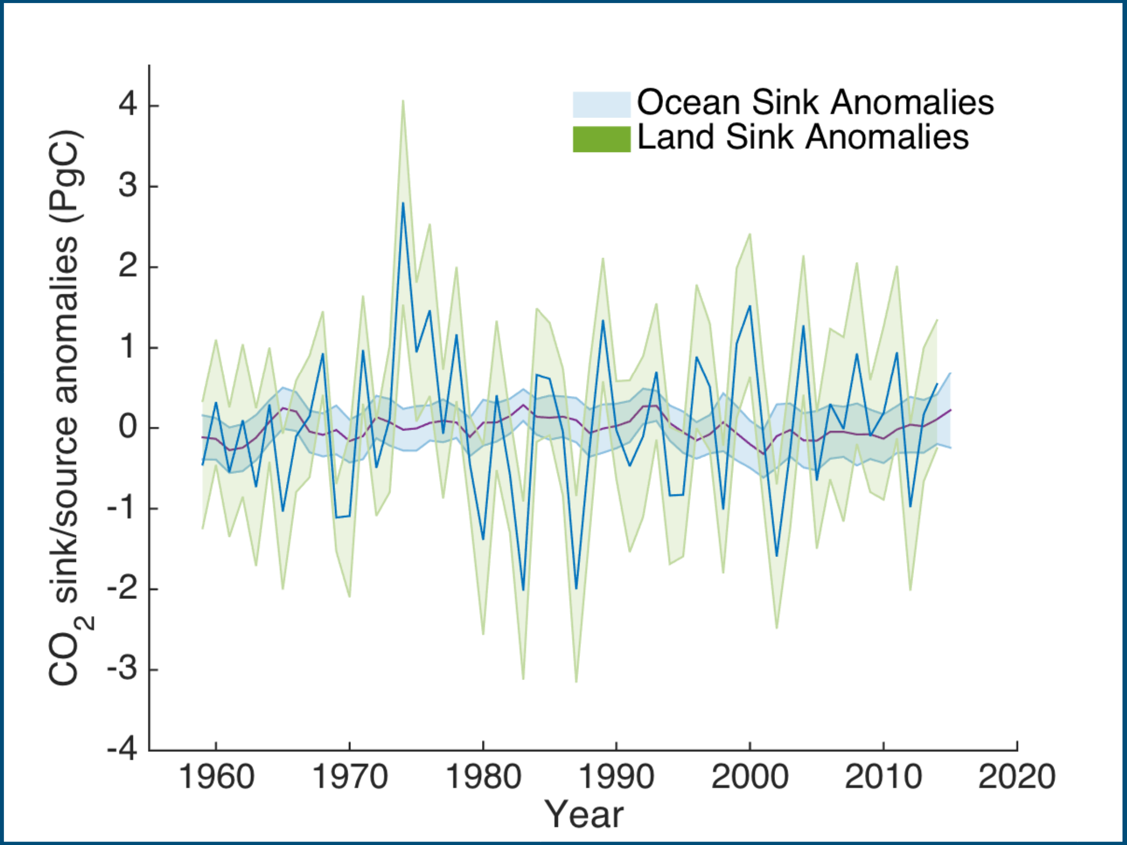
- Oceanic CO_2 sinks

The growth rate of atmospheric CO_2



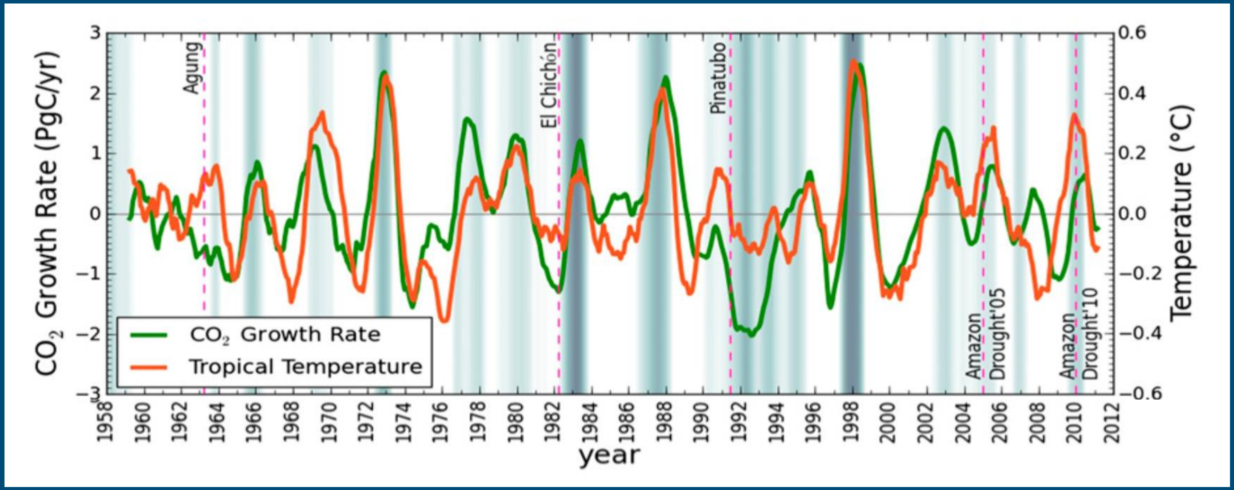
Data source: Scripps CO_2 program @ Mauna Loa

Land drives variability in the growth rate



Data source: Global Carbon Project

Linking the growth rate to the land

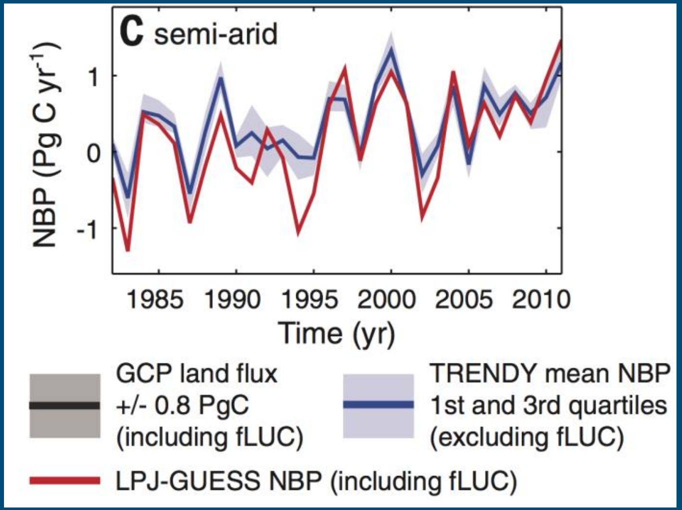


Weile Wang et al. (2013)

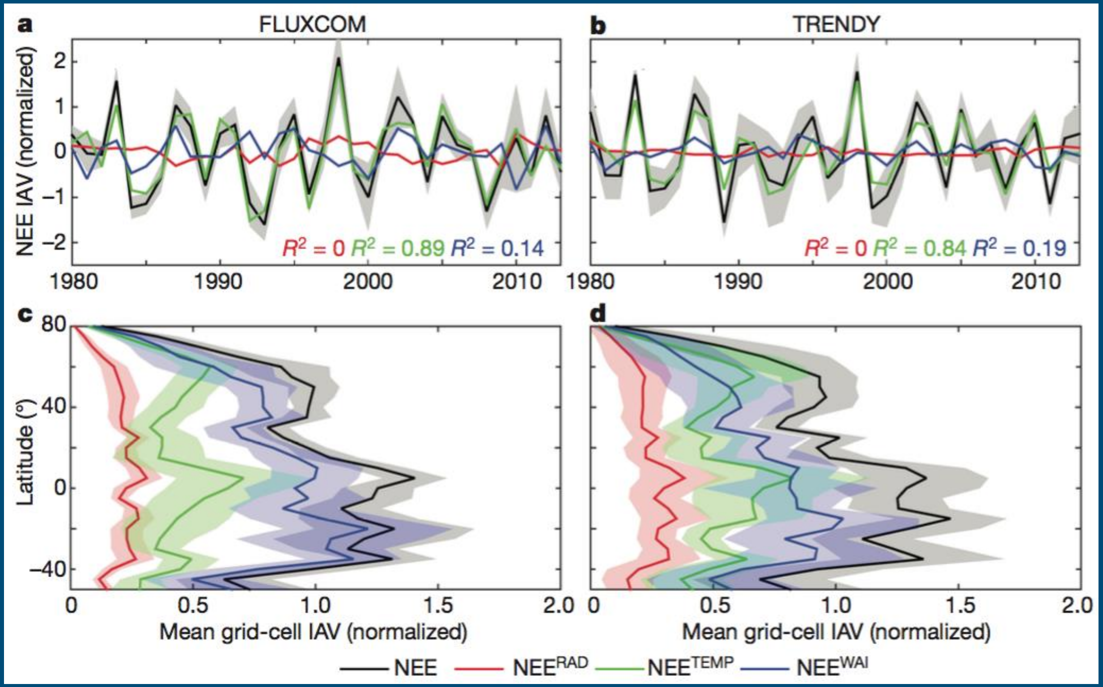
Ahlström et al. (2015); Poulter et al. (2015)

Variation in the growth rate tightly coupled to tropical temperatures.

Semi-arid regions also play an important role.



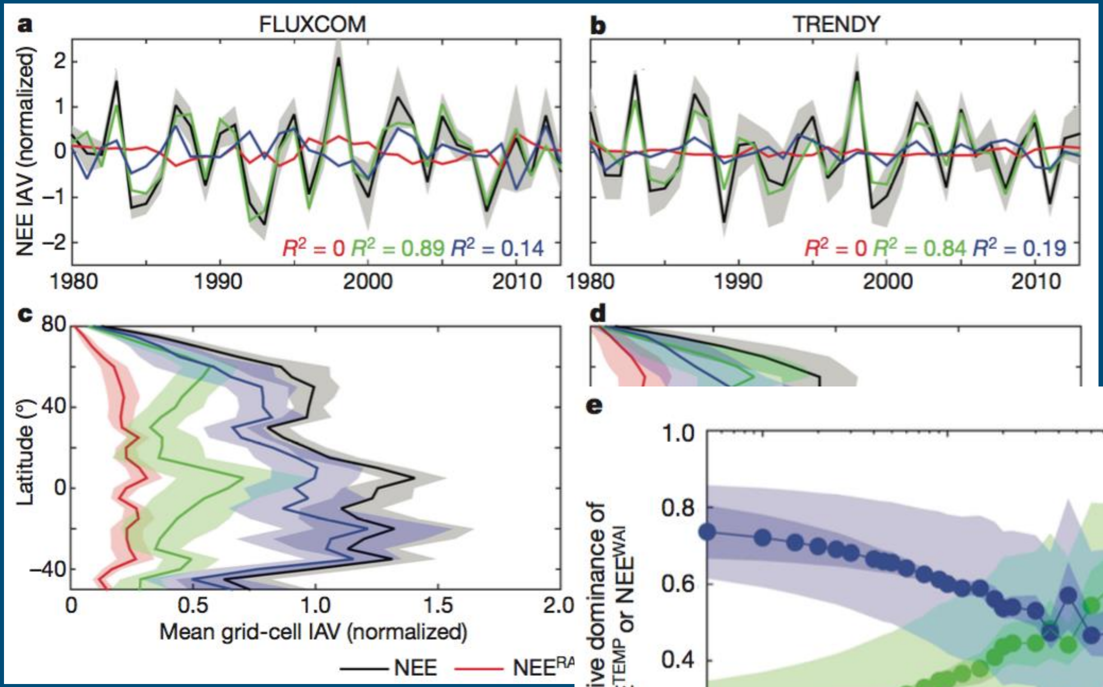
Linking the growth rate to the land

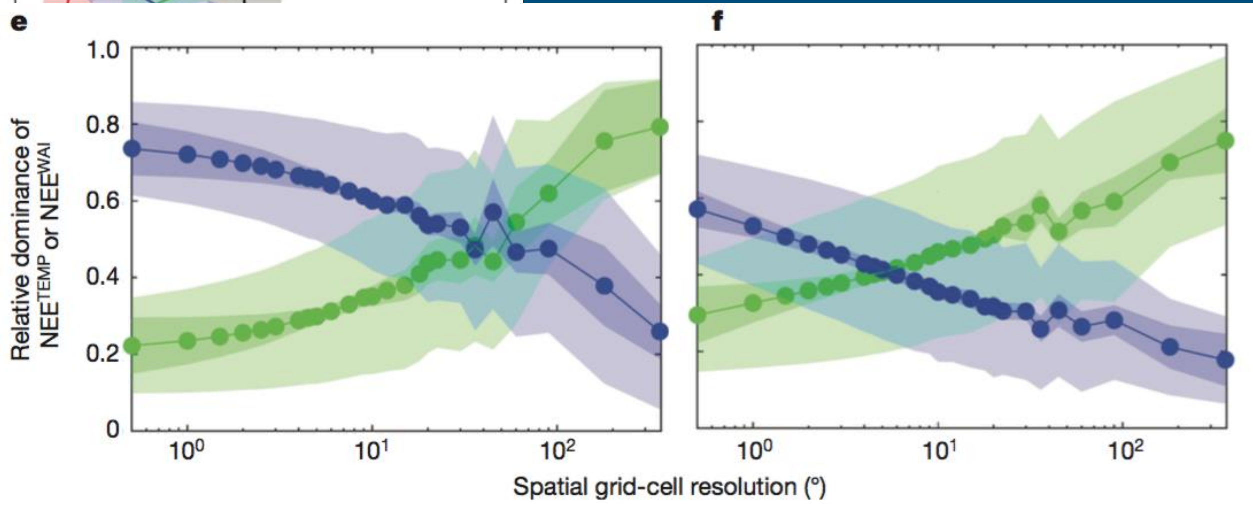


Jung et al. 2017

Water matters!

Linking the growth rate to the land



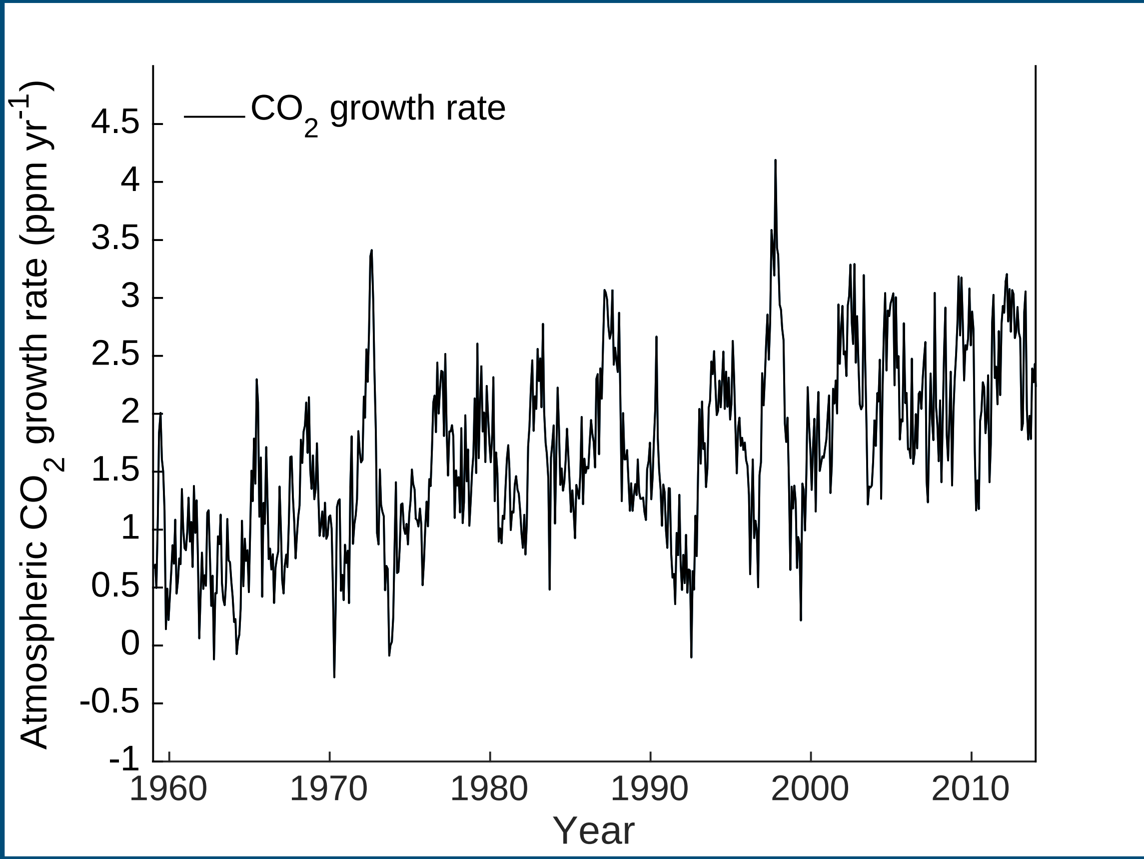


Jung et al. 2017

Water matters!

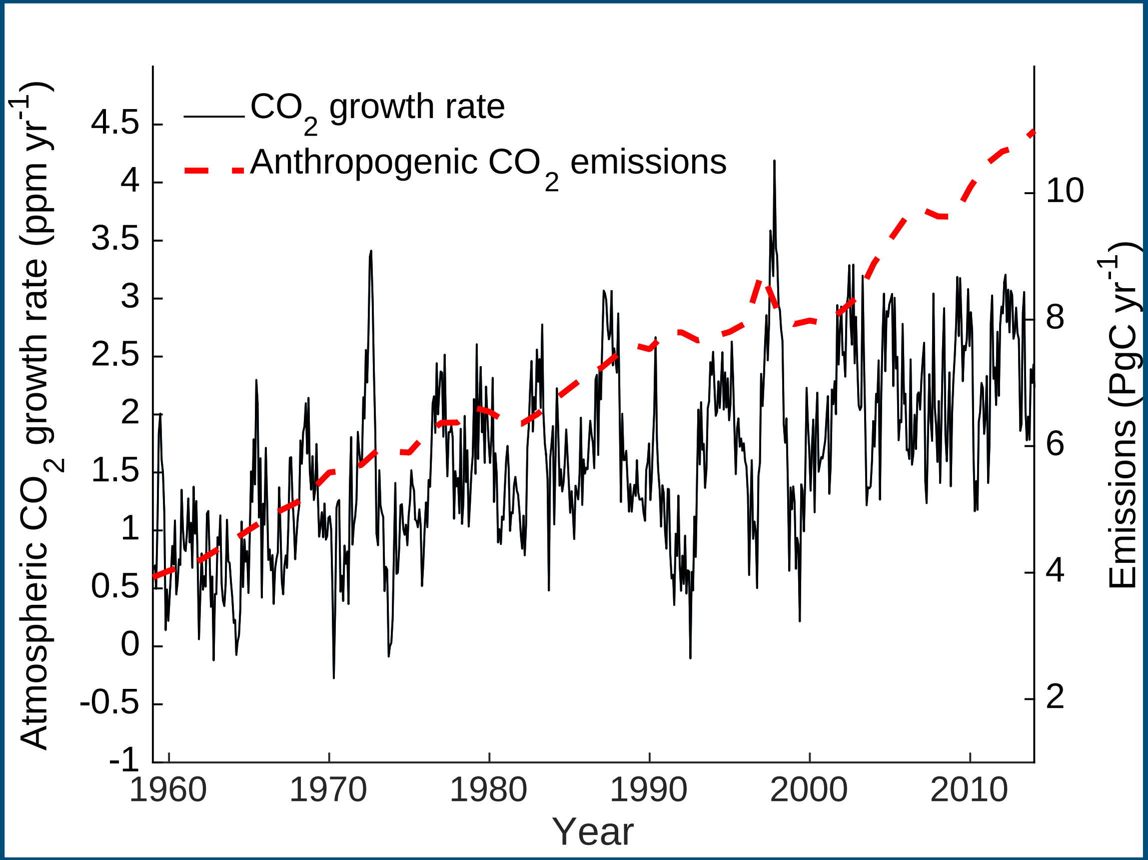
... at almost all scales but the globe!

The growth rate of atmospheric CO_2



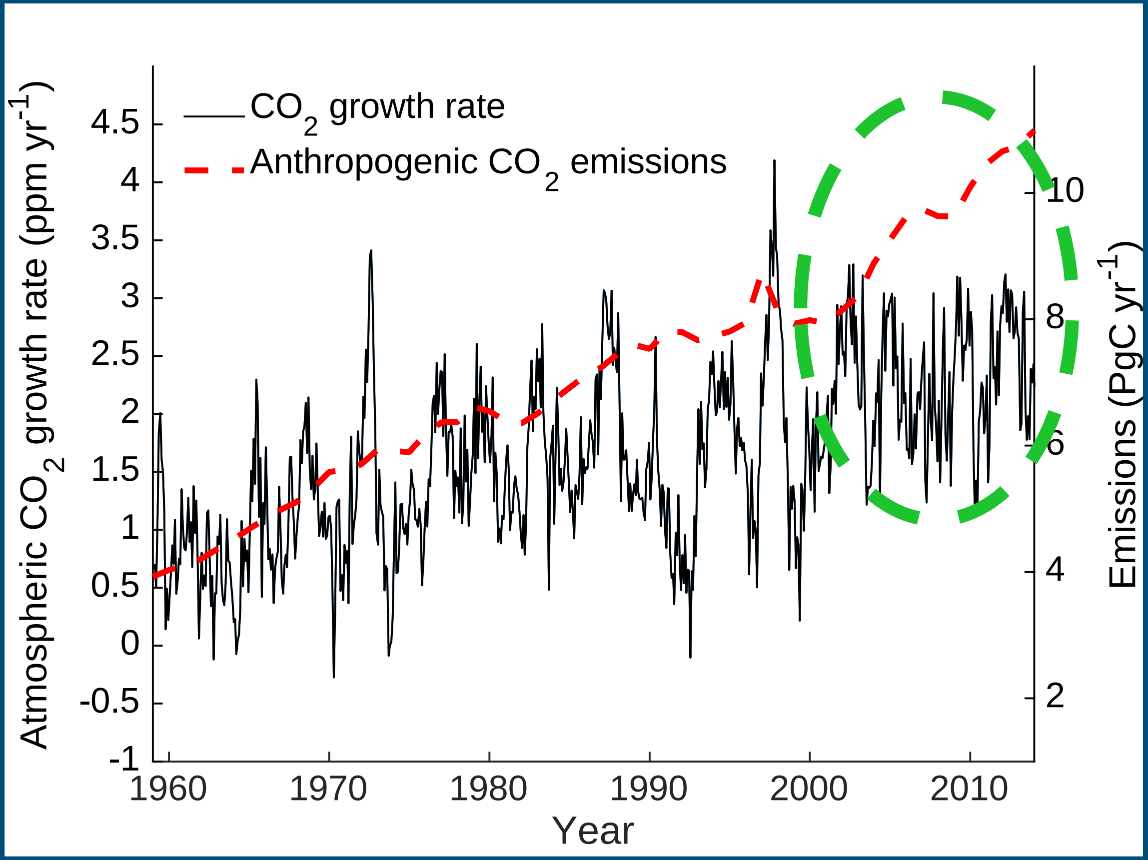
Data source: Scripps CO_2 program @ Mauna Loa

The growth rate of atmospheric CO_2



Data source: Scripps CO_2 program & GCP

The growth rate of atmospheric CO_2



Data source: Scripps CO_2 program & GCP

First-order diagnostics of the growth rate

Construct a linear model by assuming that the sink is a linear function of atmospheric CO_2 concentration:

$$F_{sink} = M + F_0$$

where β is the inverse residence time for excess carbon against the processes of land and ocean uptake.

$$GR_{CO2} = F_{fossil} + F_{LUC} - F_{SINK}$$

First-order diagnostics of the growth rate

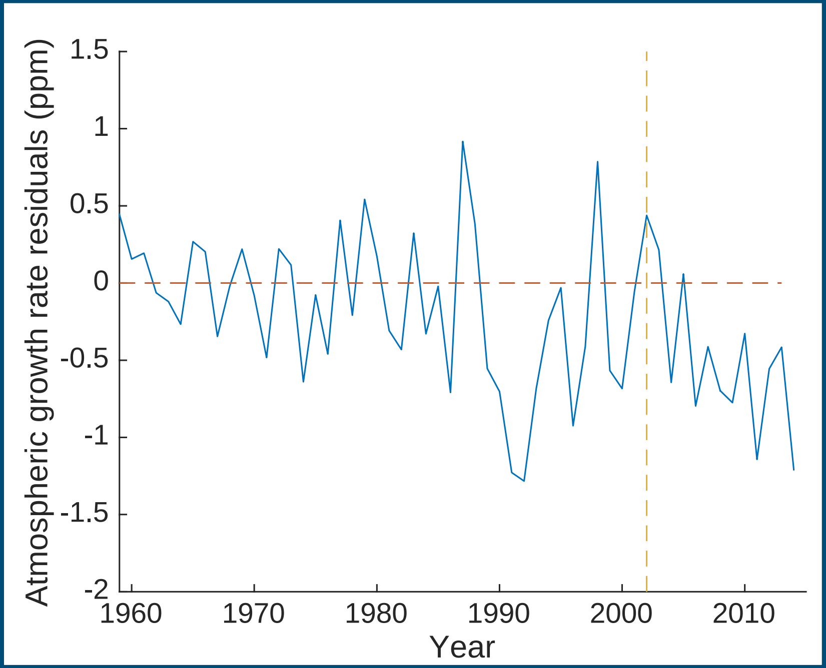
- Predict the growth rate using the linear model
- Examine dynamics of the residuals over time
- Any change in the residuals suggests a deviation of global sinks from the assumption of linearity.

Keenan et al. (2016)

First-order diagnostics of the growth rate

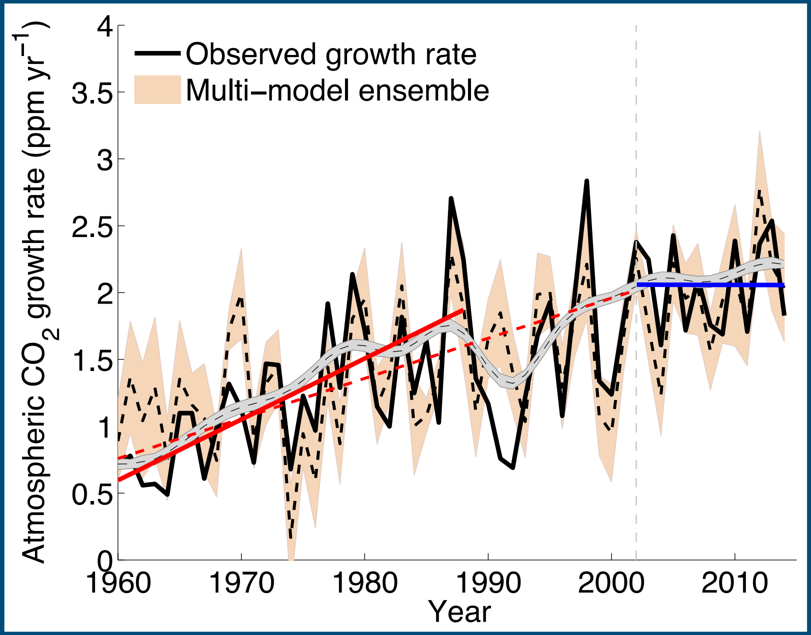
Residuals

- Predict the growth rate using the linear model
- Examine dynamics of the residuals over time
- Any change in the residuals suggests a deviation of global sinks from the assumption of linearity.



Keenan et al. (2016)

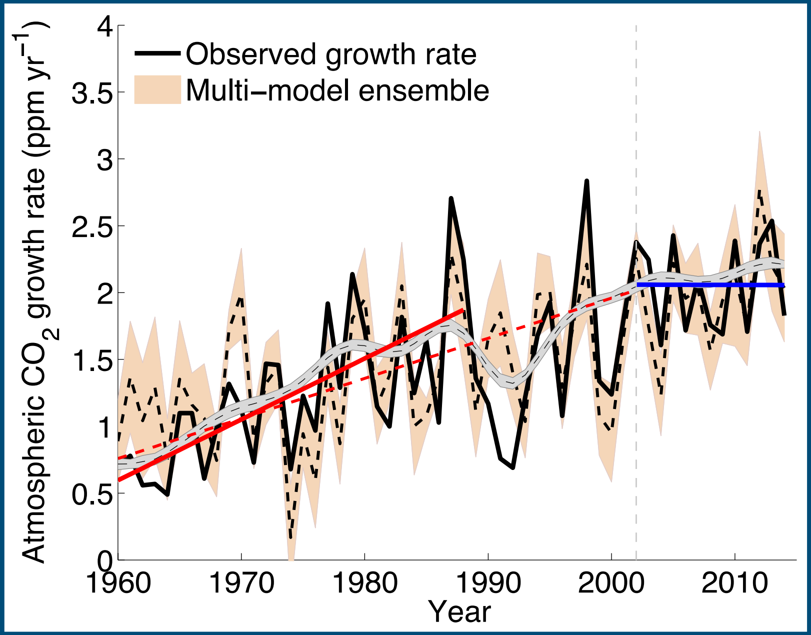
Growth Rate pause

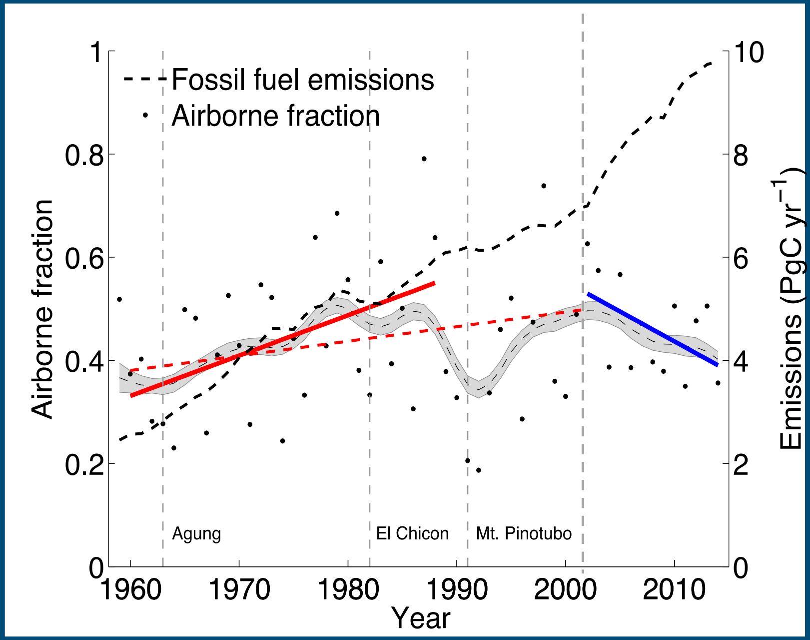


Keenan et al. (2016)

Growth Rate pause

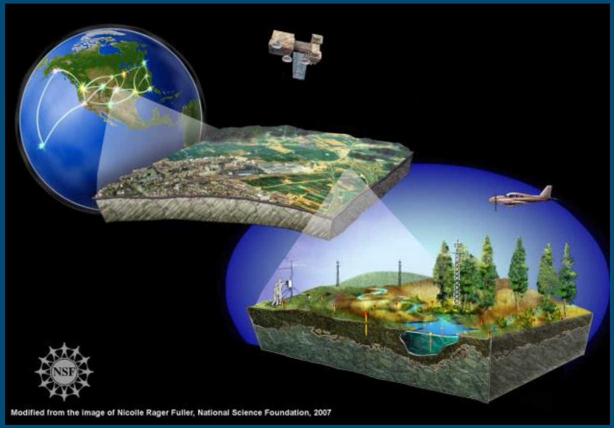
Airborne Fraction decline



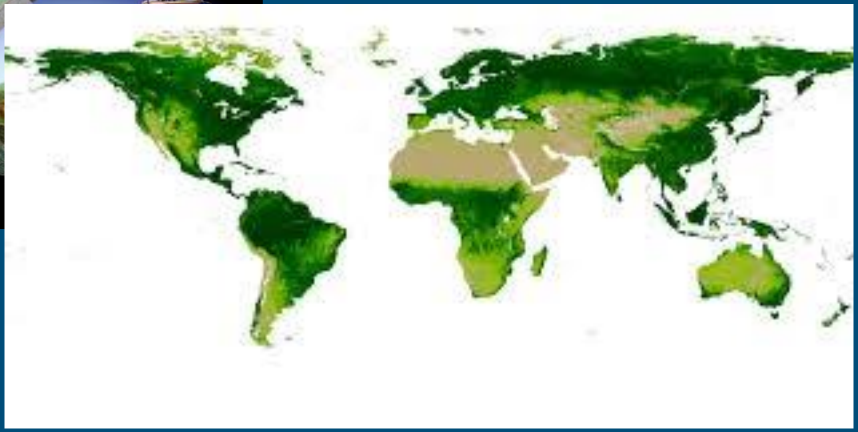


Keenan et al. (2016)

Design of a global diagnostic model



Design of a global diagnostic model



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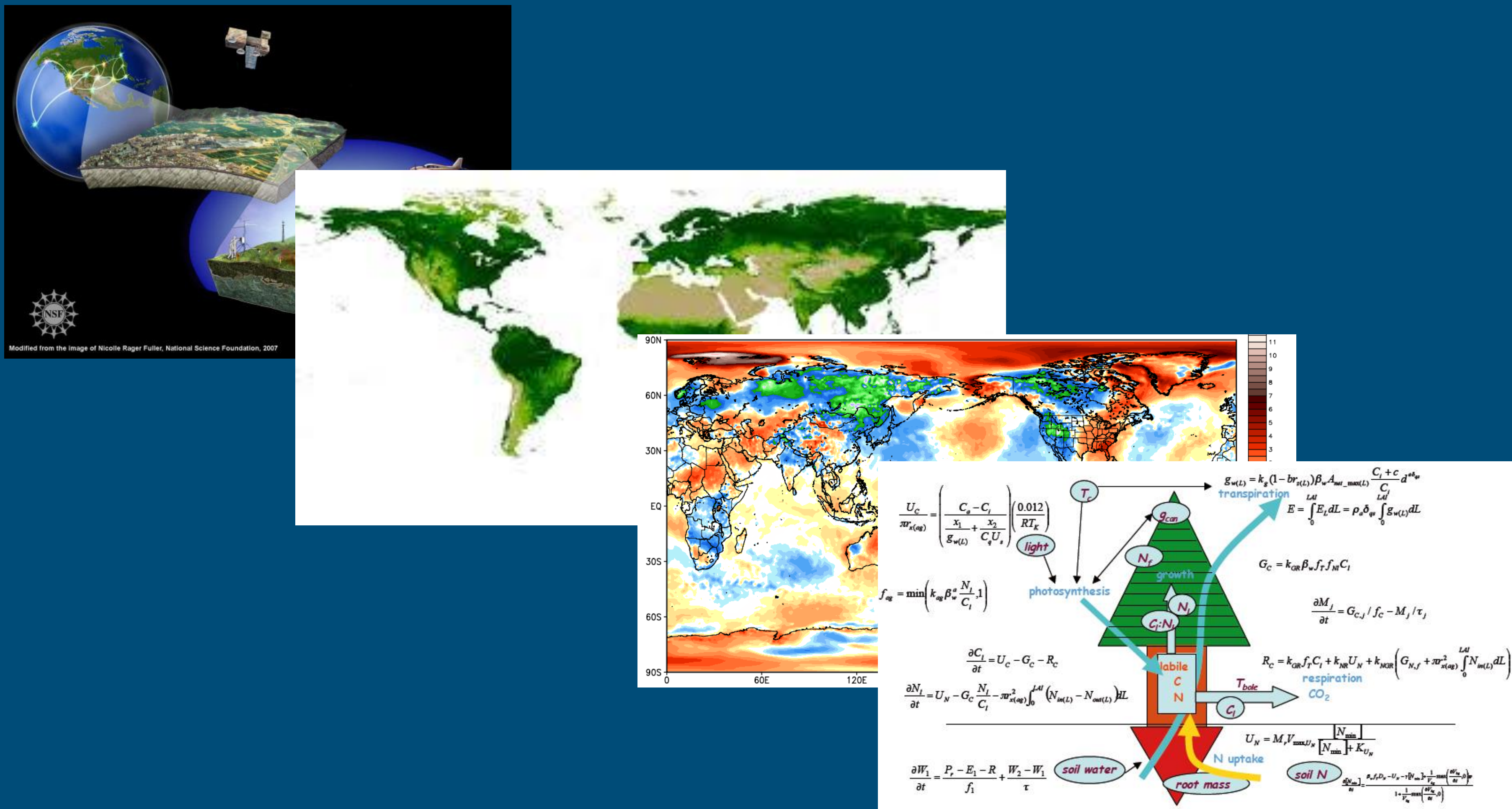


Design of a global diagnostic model

<u>The co-limitation hypothesis</u>:

"Plants allocate nitrogen to maintain a balance between two processes … each of which potentially limits photosynthesis"

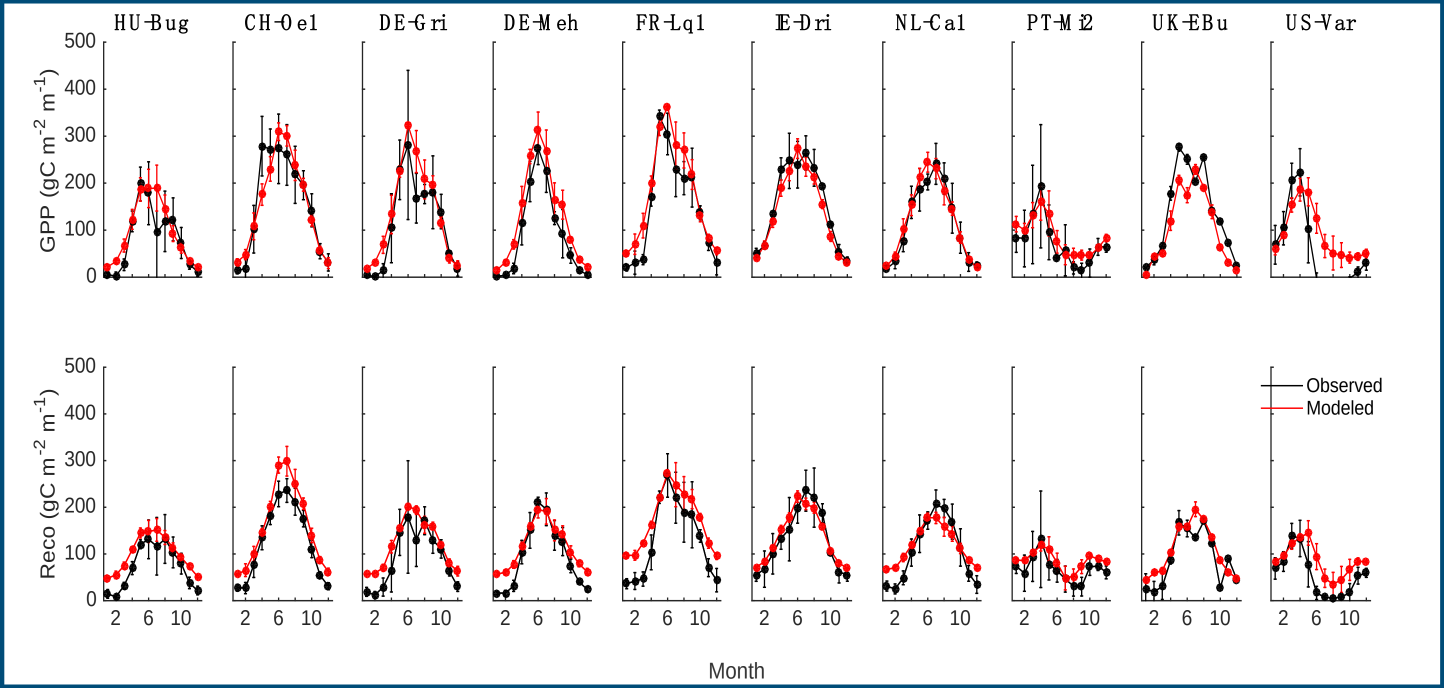
Chen et al. 1993

<u>The least cost hypothesis</u>:

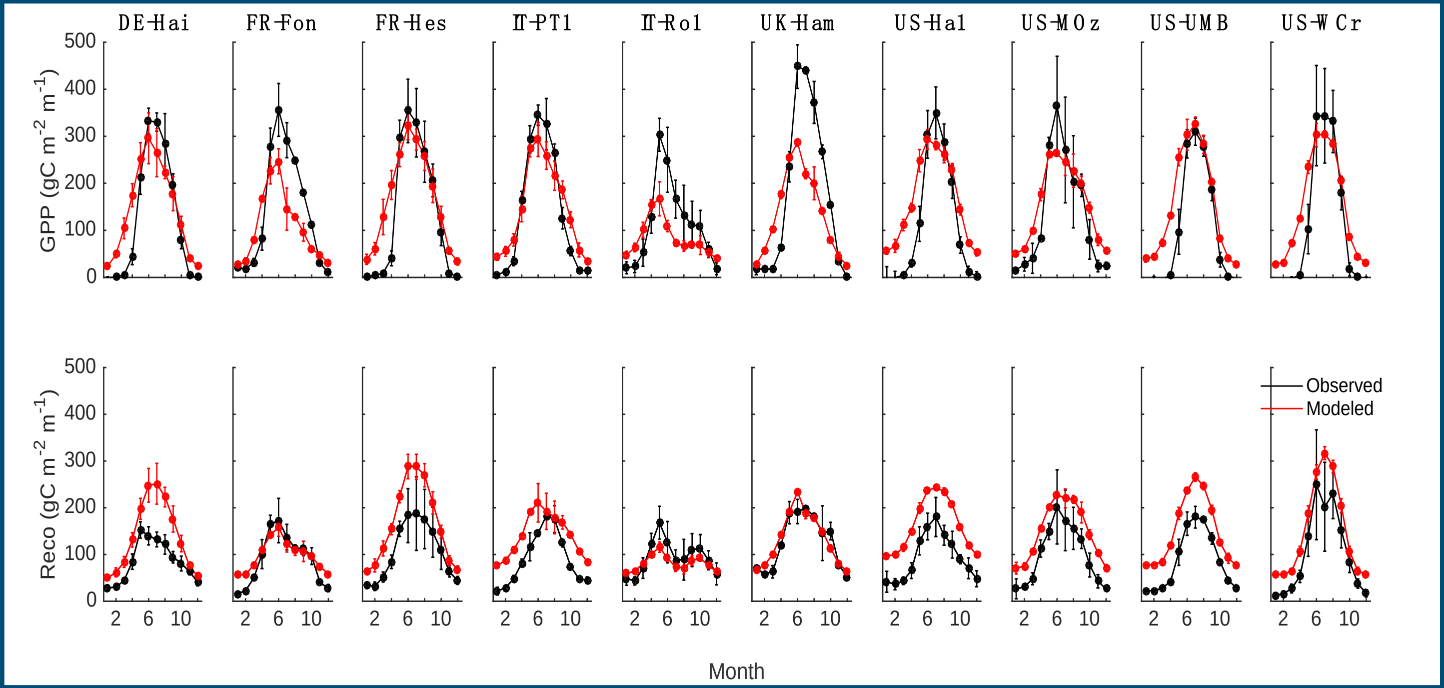
"the ratio of leaf-internal to ambient CO_2 partial pressure should minimize the combined costs of maintaining the capacities for carboxylation and transpiration. "

Prentice et al. 2014

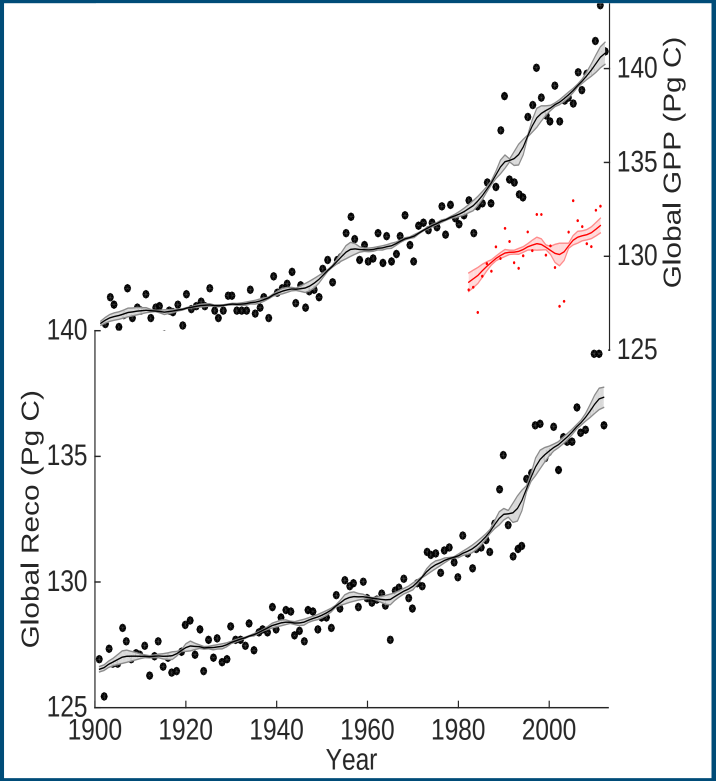
Testing at global grassland sites



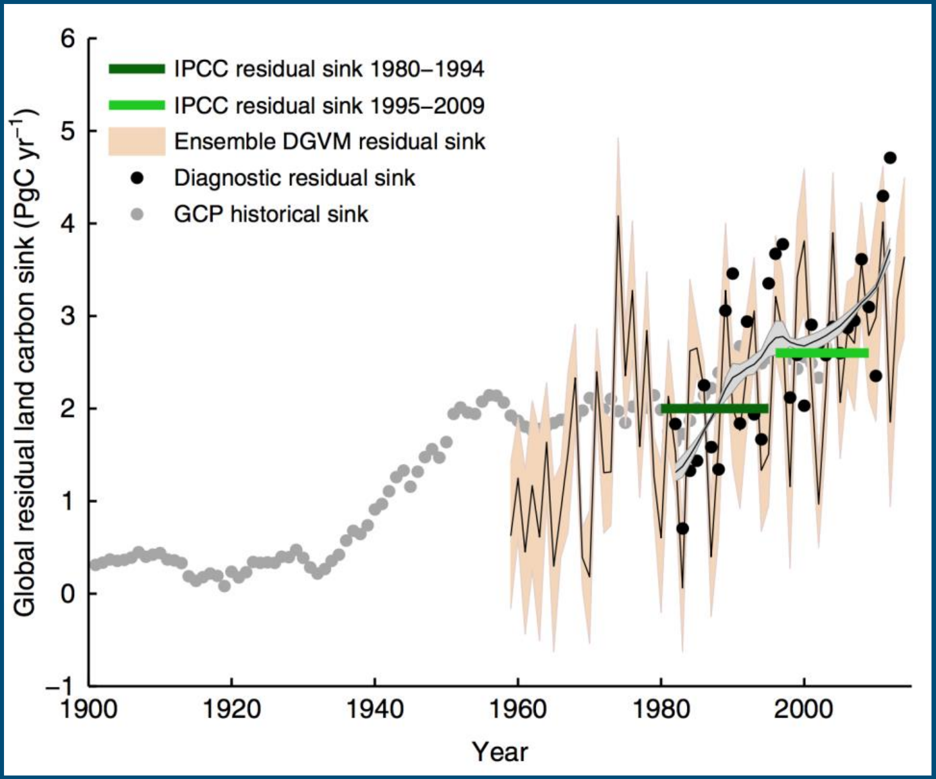
Testing at global DBF sites



Comparing to the MPI FLUXNET upscaling product

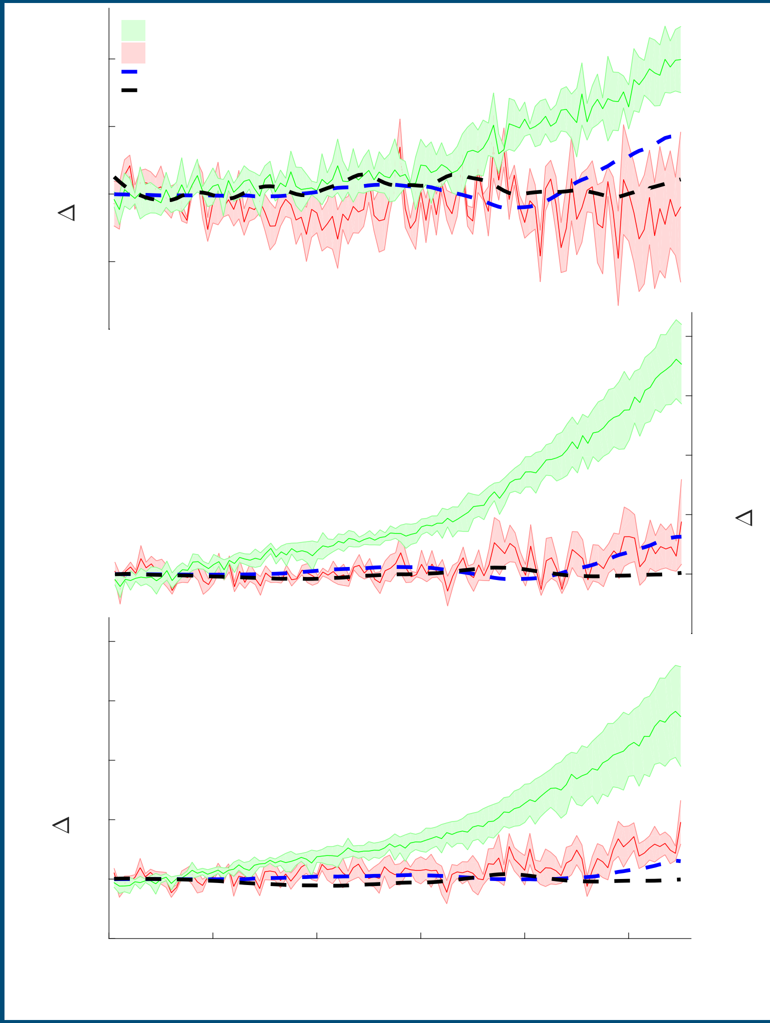


Enhanced land surface CO_2 uptake



Keenan et al. (2016)

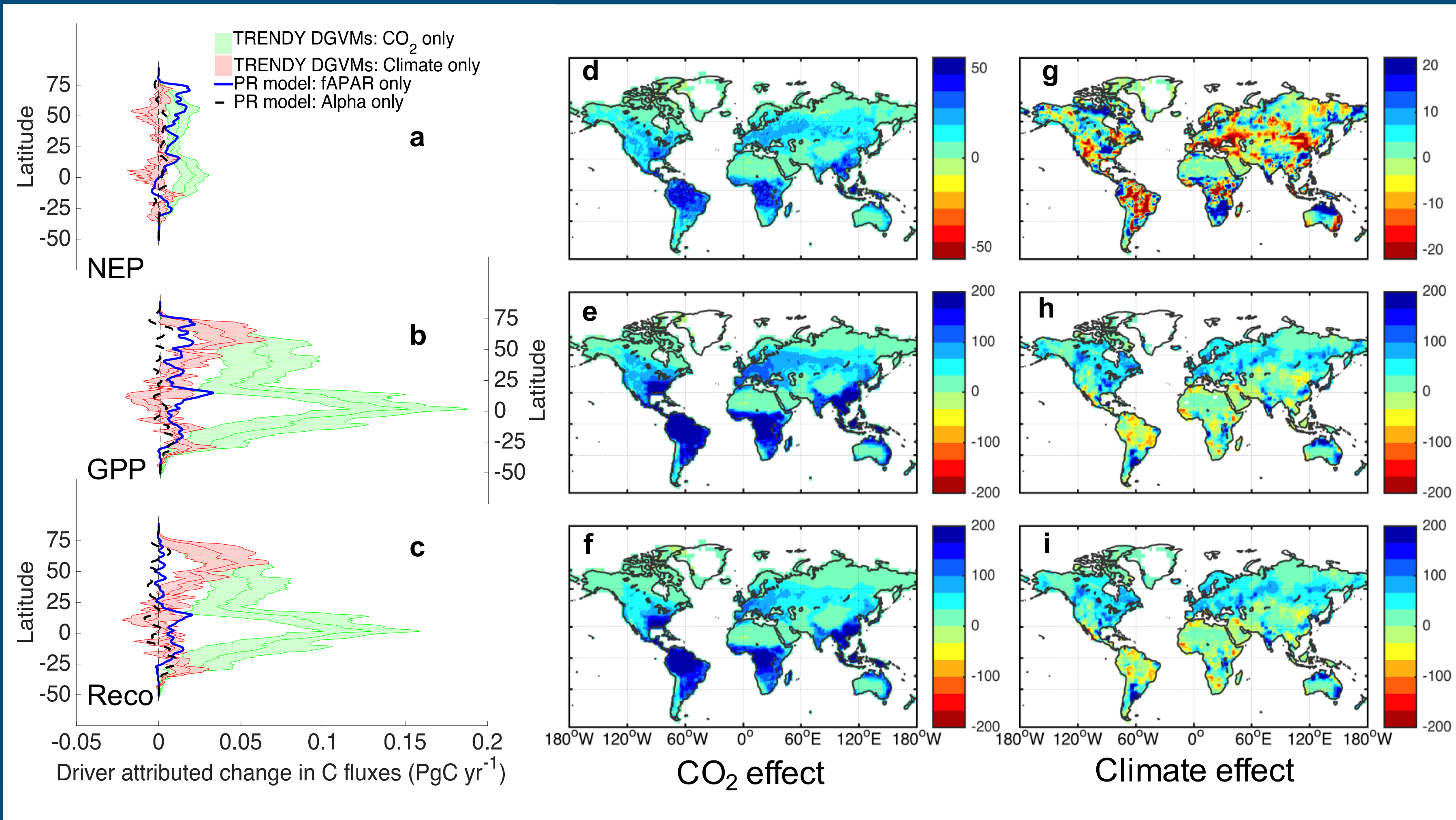
CO_2 Fertilization and Temperature



- CO_2 markedly increasing the net sink, photosynthesis and respiration.
- Vegetation greening a distant second.
- Warming increased both GPP and Respiration.
- No evidence for an increase in global water stress.

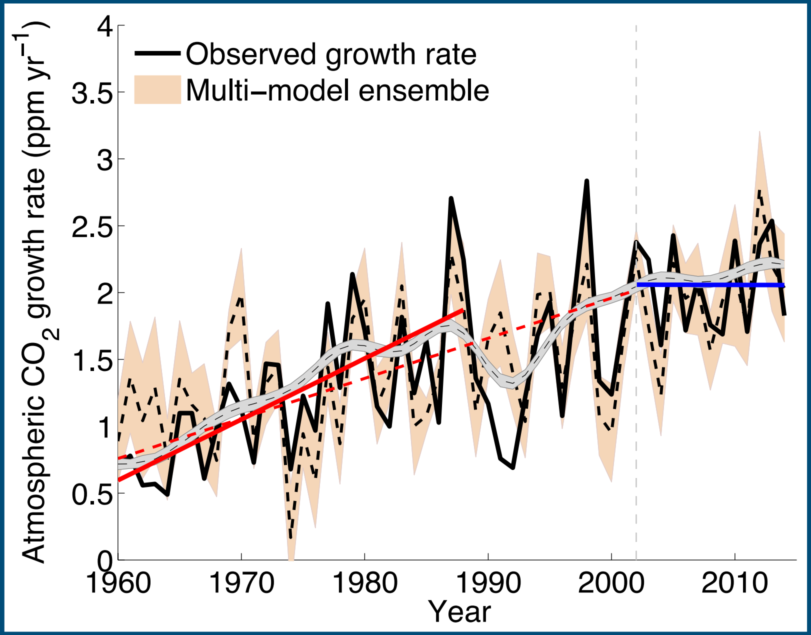
Keenan et al. (2016)

CO_2 Fertilization and Temperature

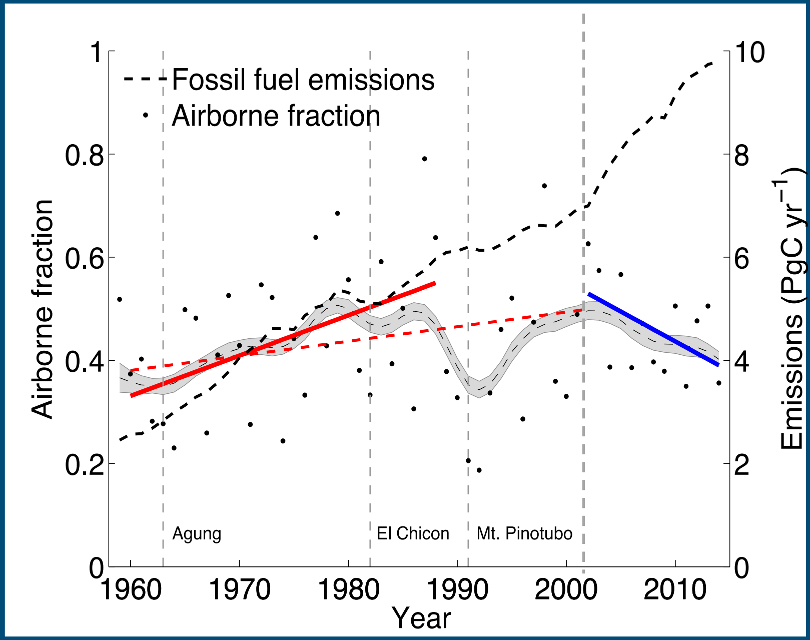


Keenan et al. (2016)

Growth Rate pause



Airborne Fraction decline

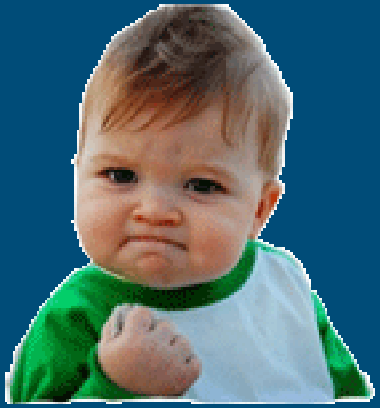


Keenan et al. (2016)

All good climate change stories must come to an end…

All good climate change stories must come to an end…

El Niño 2015



All good climate change stories must come to an end…

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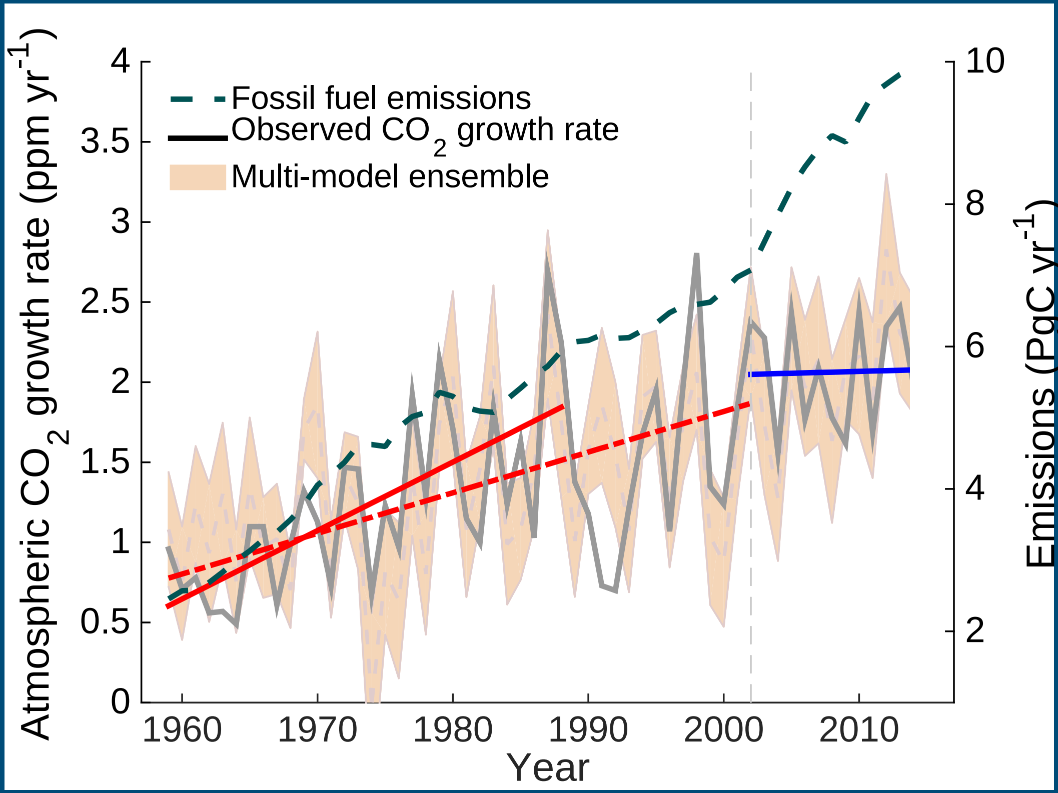

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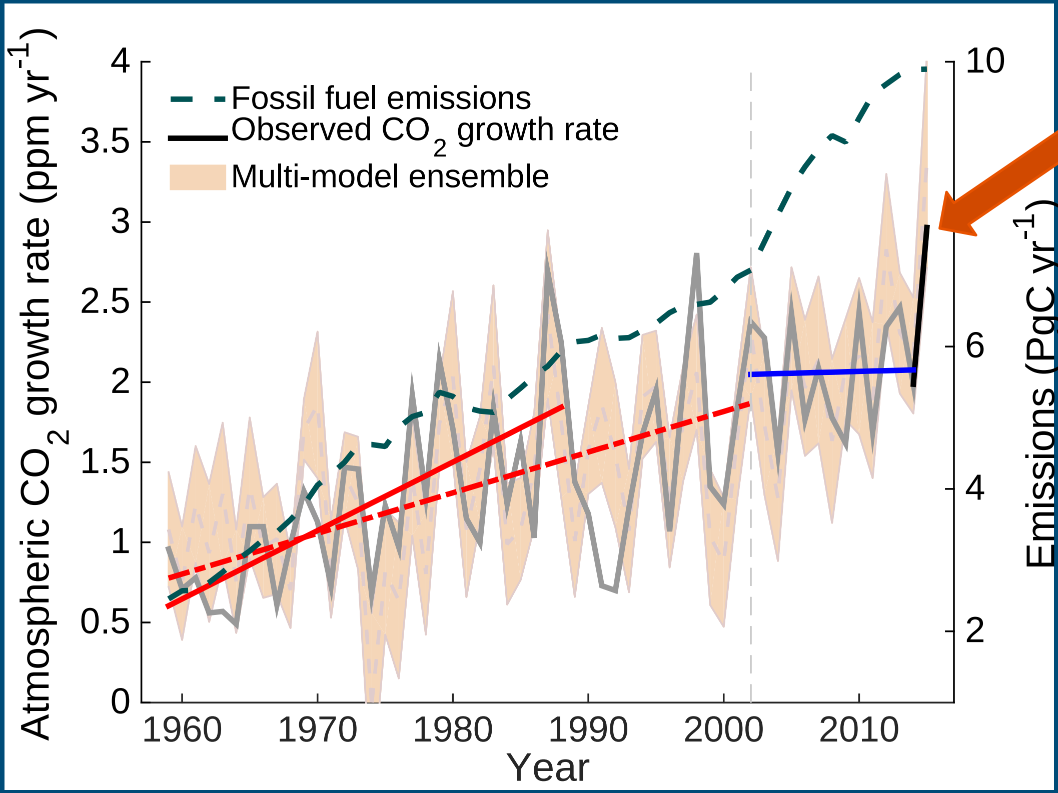
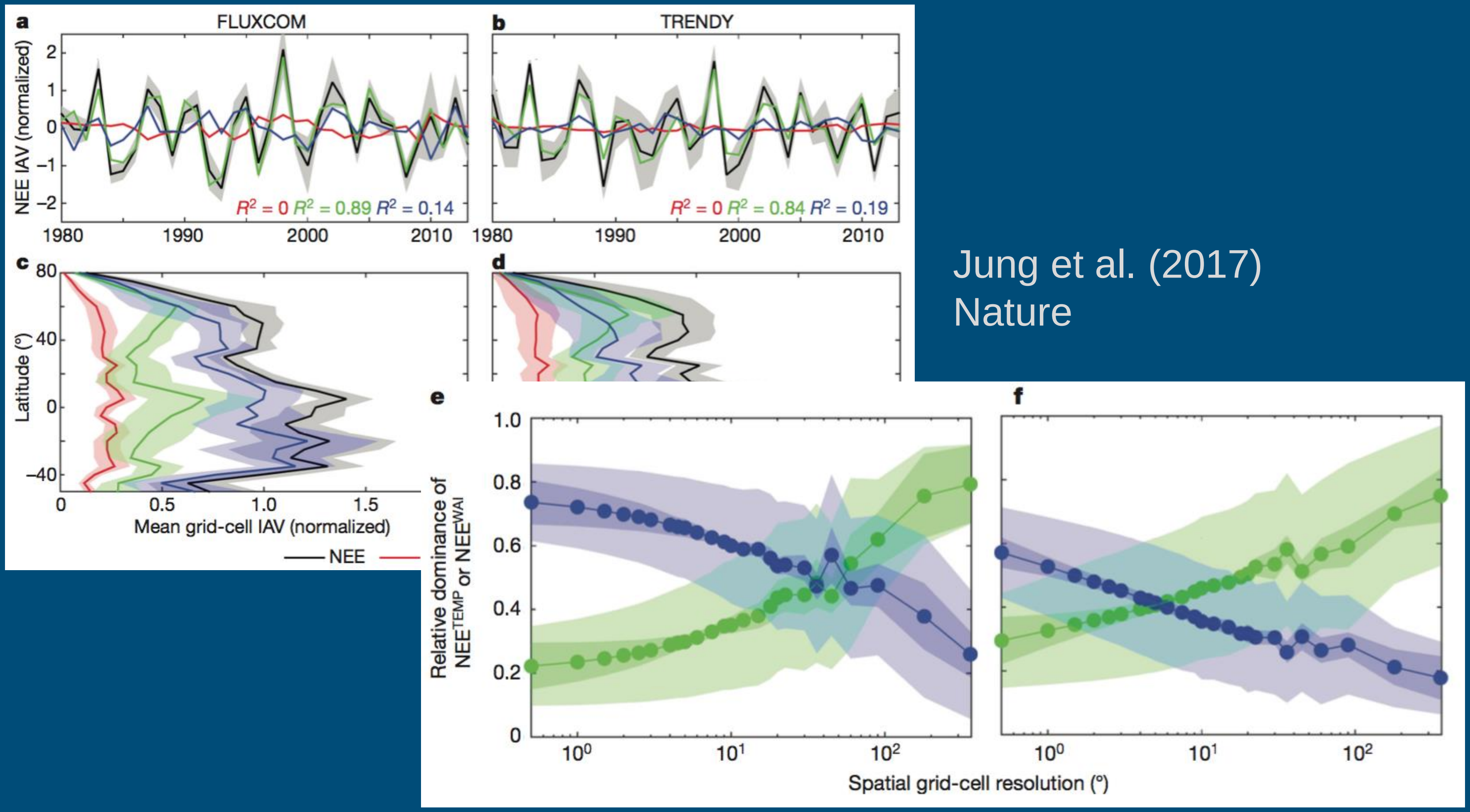


Largest growth recorded

A question of scale...



Jung et al. (2017) Nature

at the site scale...

Global Change Biology

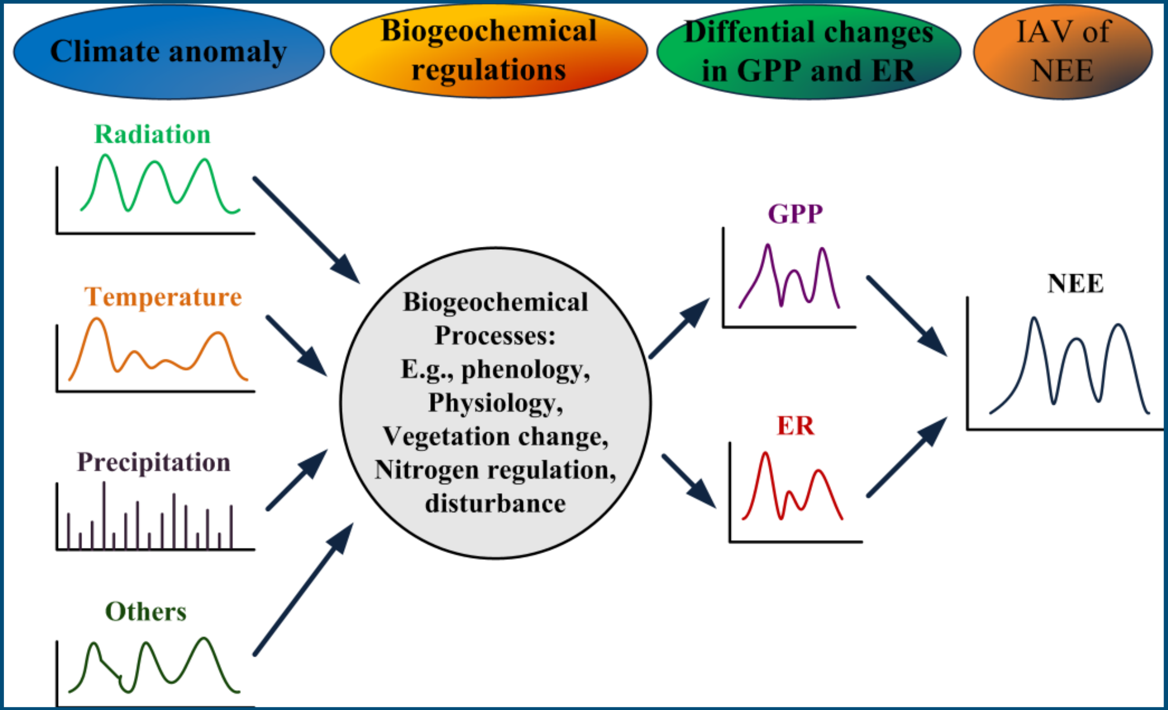
Global Change Biology (2012) **18**, 1971–1987, doi: 10.1111/j.1365-2486.2012.02678.x

Terrestrial biosphere model performance for inter-annual variability of land-atmosphere CO_2 exchange

Keenan et al. (2012)

- At the site level, models perform terribly
- 16 models and 3 satellite products, 11 forested sites
- None of the models fell within measurement uncertainty
- Systematic errors, common to all included models:
  - Underrepresentation of variability in soil thaw, snowpack melting, and canopy phenology
  - Difficulties in reproducing the lagged response to extreme climatic events

Biophysical Control

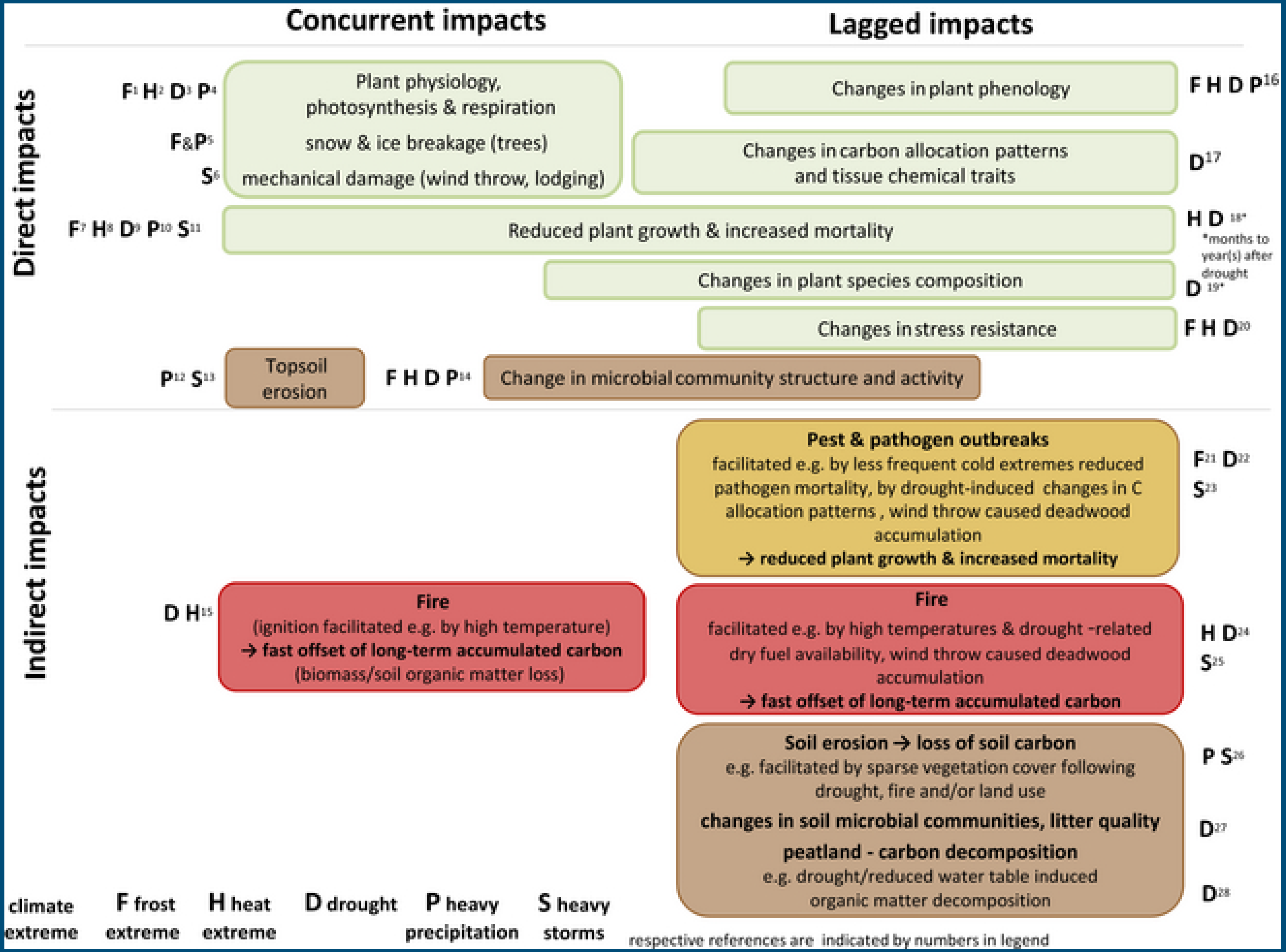


Niu et al. (in review)

Shao et al. 2015 AFM: 50/50 share between direct and indirect effects.

Bottom up

Direct and indirect pathways of influence



Frank et al. (2015)

Concurrent impacts

Lagged impacts

Concurrent impacts	
State Changes	
Changes in phenology from warming	
Changes in canopy structure from ice-storms/wind-throw	
Forest mortality due to drought	
Defoliation events (insect/wind/frost)	
Leaf/canopy temperature	
Trait Changes	
Acclimation	
Rate Changes	
Response of photosynthesis and respiration to environmental drivers	

Lagged impacts

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Lagged impacts	
State Changes	
Canopy development	
Regrowth from disturbance	
Litter layer dynamics	
Non-structural carbohydrate pool dynamics	
Hydrology	
Trait Changes	
Acclimation	
Rate Changes	
All of the above!	

Concurrent impacts	
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Acclimation	
Rate Changes	
All of the above!	

Expected response depends on the duration, intensity and co-variation of anomalous forcings.

Way forward?

Way forward?

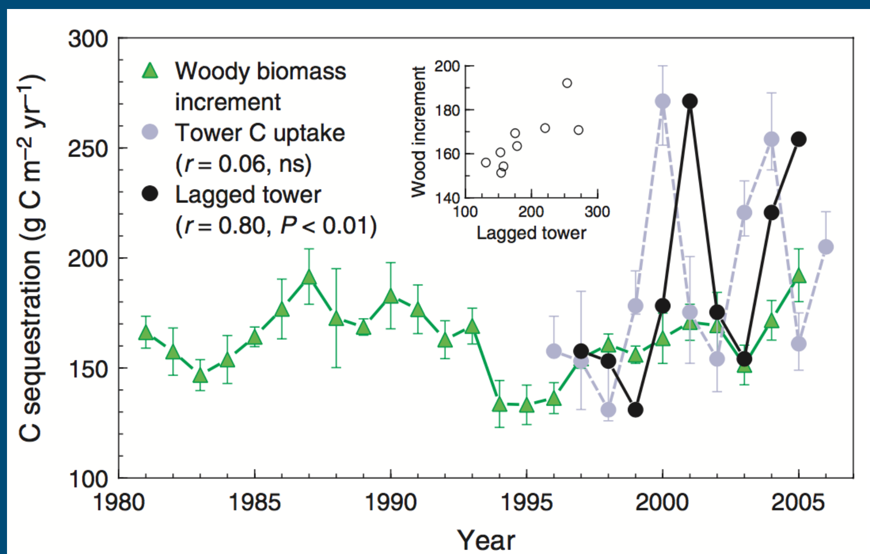
- Better data
  - with well characterized uncertainties
- Different data
  - BADM, remote sensing observations
- More sites
  - working on it!
- Longer datasets
  - F17 now has 10’s of sites with >7 years
- Better techniques
  - Model-data integration
  - Data mining/Machine learning (incl. deep learning)
  - Causal inference approaches (e.g., Granger analysis)

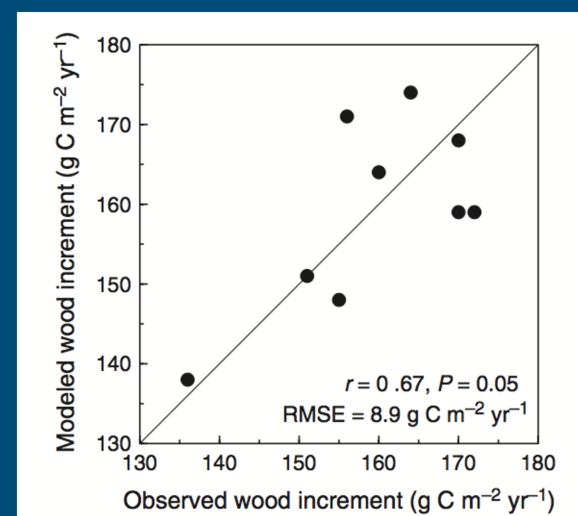
Model-data integration

Seasonal dynamics and age of stemwood nonstructural carbohydrates in temperate forest trees

Andrew D. Richardson[1], Mariah S. Carbone[2], Trevor F. Keenan[1], Claudia I. Czimczik[3], David Y. Hollinger[4], Paula Murakami[5], Paul G. Schaberg[5] and Xiaomei Xu[3]

New Phytologist (2013)



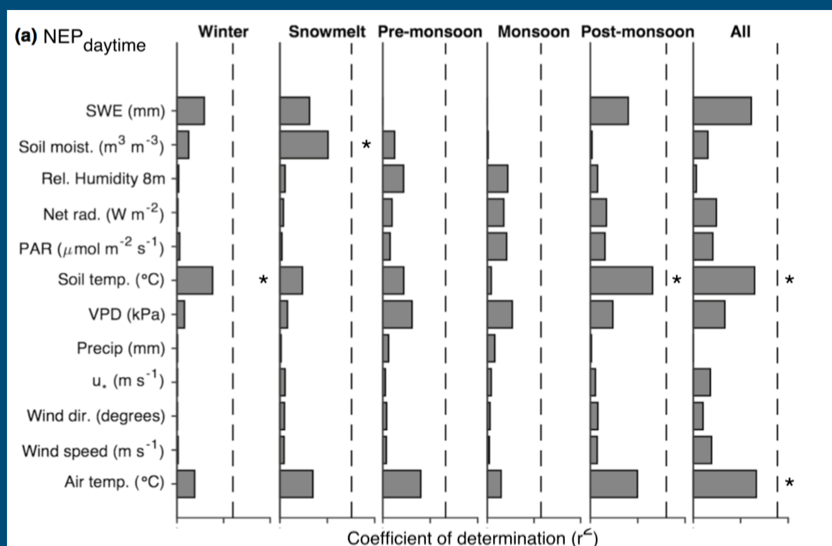


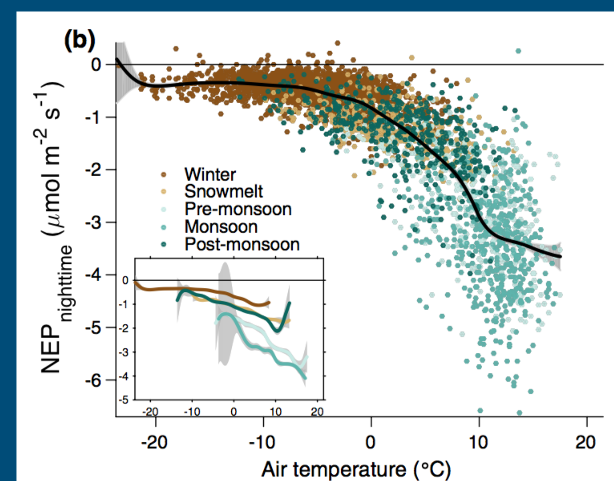
Machine Learning

Climate controls over ecosystem metabolism: insights from a fifteen-year inductive artificial neural network synthesis for a subalpine forest

Loren P. Albert[1] · Trevor F. Keenan[2] · Sean P. Burns[3,4] · Travis E. Huxman[5] · Russell K. Monson[1,6]

Oecologia (2017)





Take home messages:

1. Elevated CO_2 is stimulating increased plant C uptake
2. Warmer temperatures are leading to increased CO_2 release from ecosystems
3. The net effect is a large increase in terrestrial C uptake
4. We need to develop better techniques to merge the bottom-up and top-down

Implications:

1. Likely recent enhancement of terrestrial uptake
2. Large enough to result in a temporary pause in the growth rate of atmospheric CO_2
3. El Niño in 2015 caused a large increase in the growth rate

fin

. . .

Thank you!

Keenan, T. F. et al. 2016 Recent pause in the growth rate of atmospheric CO_2 due to enhanced terrestrial carbon uptake. Nat. Comm. 7, 13428.