Forest soil carbon dynamics under elevated CO_2

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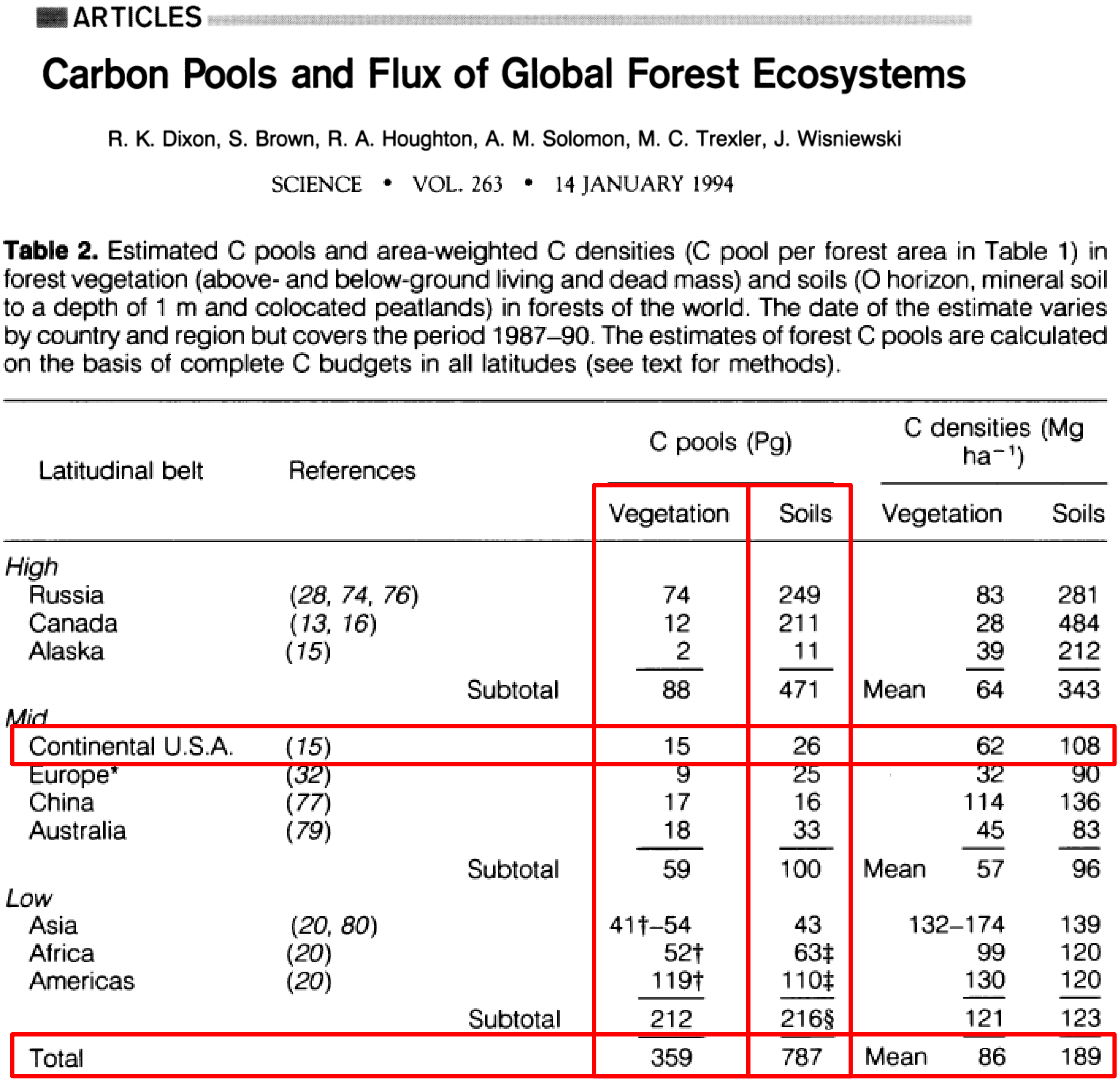
First Friday All Climate Change Talk
4/3/2015



Carbon Pools and Flux of Global Forest Ecosystems

R. K. Dixon, S. Brown, R. A. Houghton, A. M. Solomon, M. C. Trexler, J. Wisniewski

SCIENCE • VOL. 263 • 14 JANUARY 1994

Table 2. Estimated C pools and area-weighted C densities (C pool per forest area in Table 1) in forest vegetation (above- and below-ground living and dead mass) and soils (O horizon, mineral soil to a depth of 1 m and colocated peatlands) in forests of the world. The date of the estimate varies by country and region but covers the period 1987–90. The estimates of forest C pools are calculated on the basis of complete C budgets in all latitudes (see text for methods).

Latitudinal belt	References		C pools (Pg)			C densities (Mg ha^{-1})	
			Vegetation	Soils		Vegetation	Soils
High							
Russia	(*28, 74, 76*)		74	249		83	281
Canada	(*13, 16*)		12	211		28	484
Alaska	(*15*)		2	11		39	212
		Subtotal	88	471	Mean	64	343
Mid							
Continental U.S.A.	(*15*)		15	26		62	108
Europe*	(*32*)		9	25		32	90
China	(*77*)		17	16		114	136
Australia	(*79*)		18	33		45	83
		Subtotal	59	100	Mean	57	96
Low							
Asia	(*20, 80*)		41†–54	43		132–174	139
Africa	(*20*)		52†	63‡		99	120
Americas	(*20*)		119†	110‡		130	120
		Subtotal	212	216§		121	123
Total			359	787	Mean	86	189

Tellus (1992), *44B*, 81–99

The global carbon dioxide flux in soil respiration and its relationship to vegetation and climate

By J. W. RAICH, *Department of Botany, Iowa State University, Ames, Iowa, 50011-1020, USA,*
and W. H. SCHLESINGER, *Departments of Botany and Geology,*
Duke University, Durham, North Carolina, 27706, USA

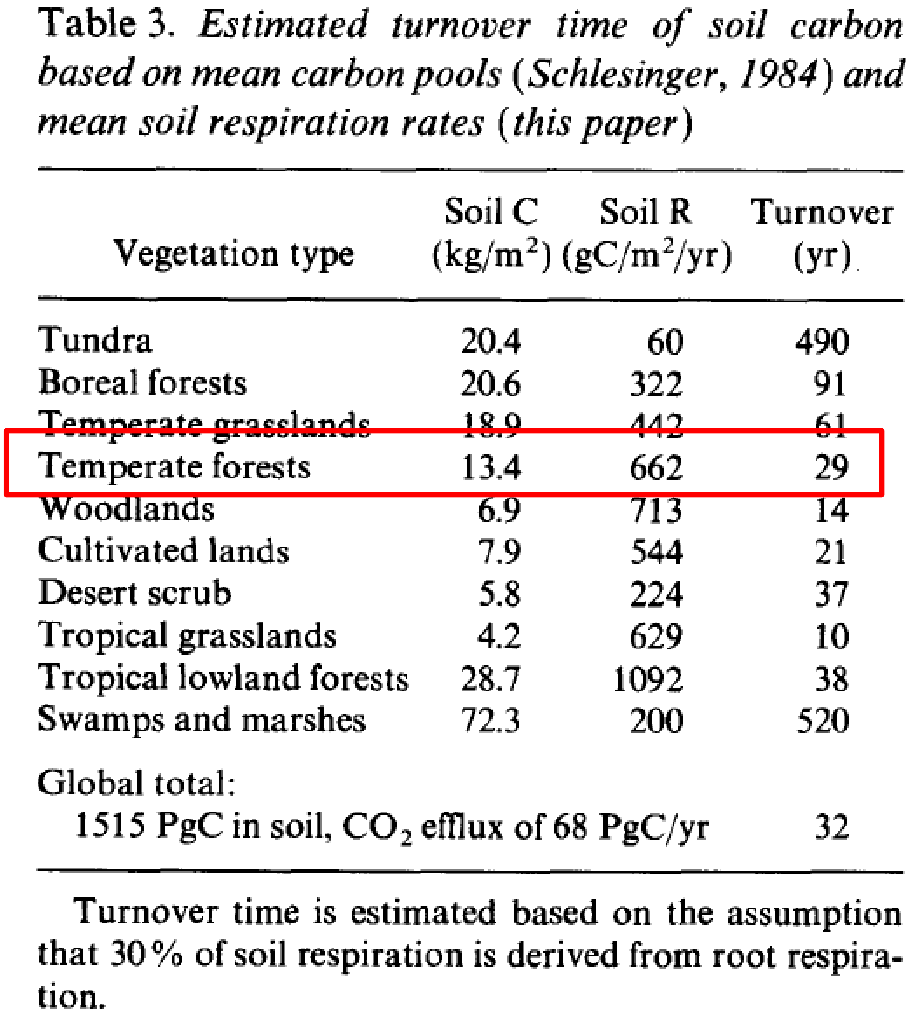
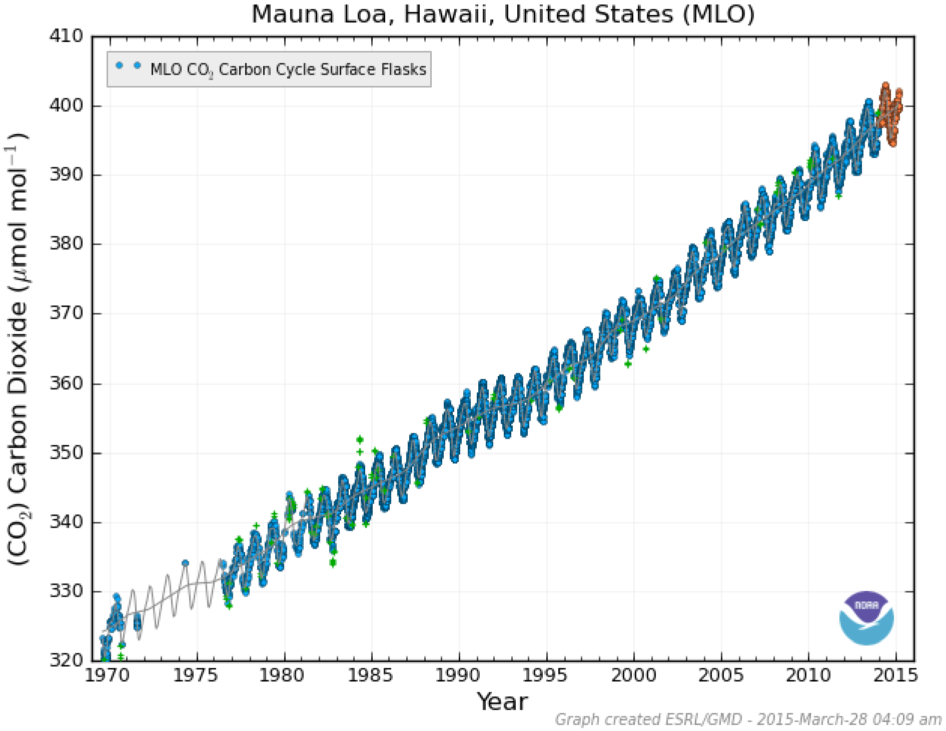
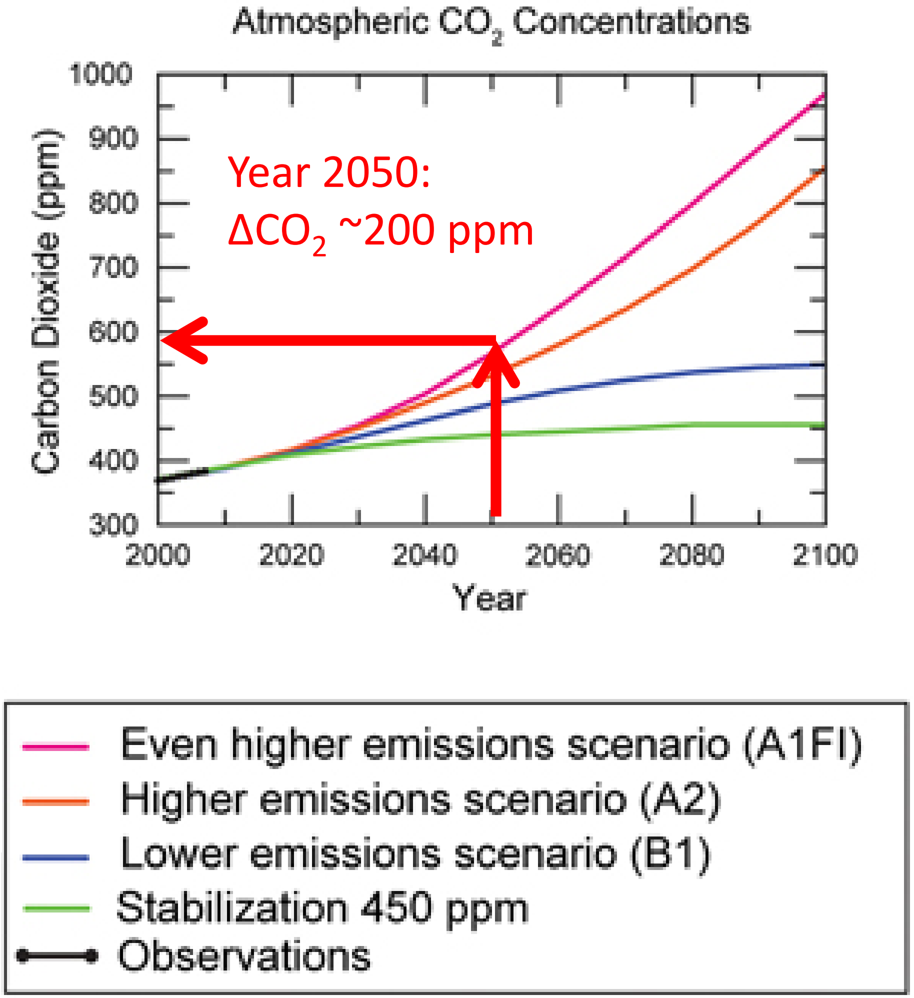


Table 3. *Estimated turnover time of soil carbon based on mean carbon pools (Schlesinger, 1984) and mean soil respiration rates (this paper)*

Vegetation type	Soil C (kg/m^2)	Soil R (gC/m^2/yr)	Turnover (yr)
Tundra	20.4	60	490
Boreal forests	20.6	322	91
Temperate grasslands	18.9	442	61
Temperate forests	13.4	662	29
Woodlands	6.9	713	14
Cultivated lands	7.9	544	21
Desert scrub	5.8	224	37
Tropical grasslands	4.2	629	10
Tropical lowland forests	28.7	1092	38
Swamps and marshes	72.3	200	520
Global total: 1515 PgC in soil, CO$_2$ efflux of 68 PgC/yr			32

Turnover time is estimated based on the assumption that 30% of soil respiration is derived from root respiration.





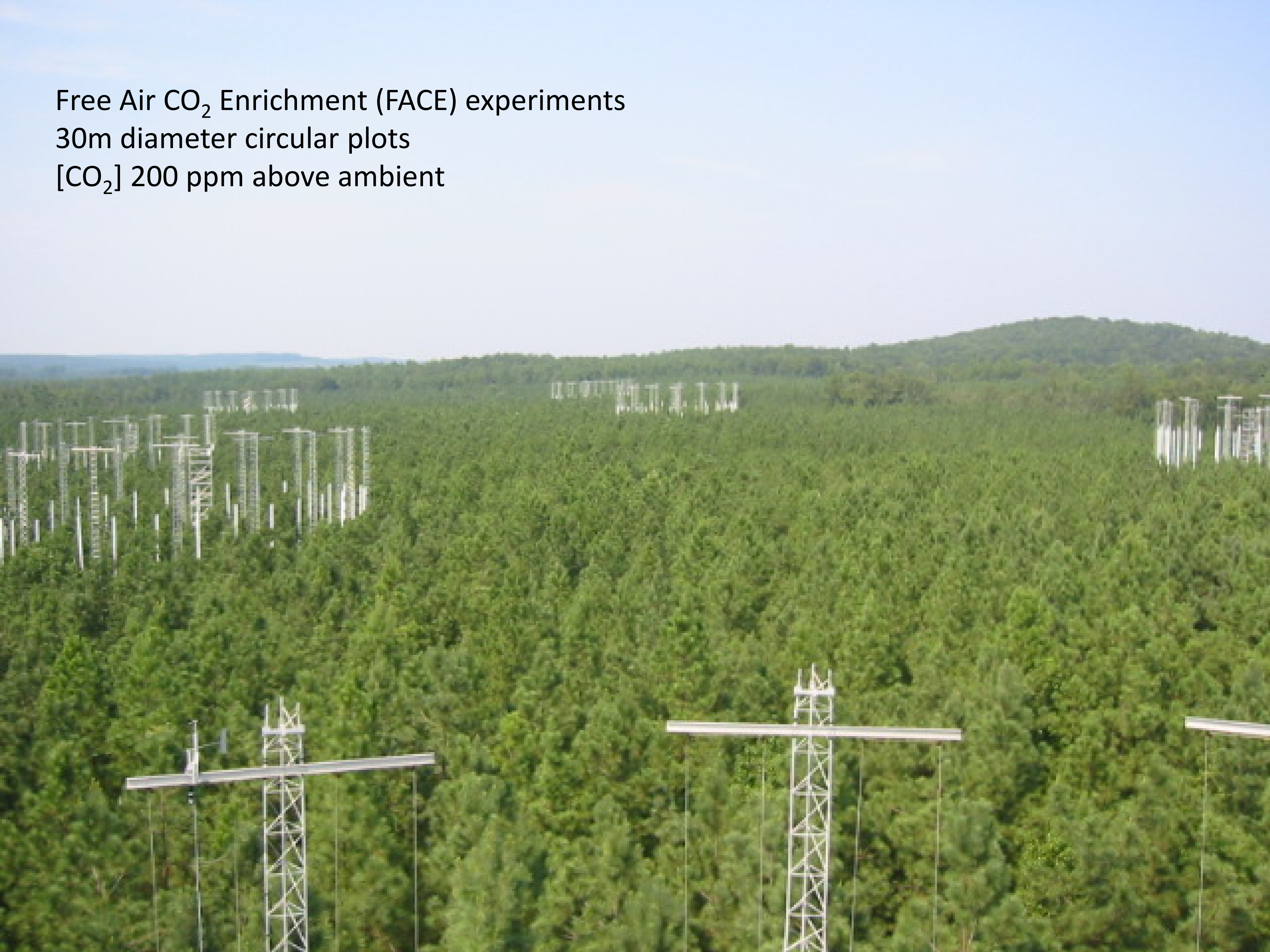
Year 2050:
ΔCO_2 ~200 ppm

http://www.esrl.noaa.gov/

http://www.epa.gov/climatechange/images/science/ScenarioCO2.jpg

How will increased atmospheric CO_2 affect forests?

- Expected fertilization effect on photosynthesis (carbon assimilation)
- Potential for added carbon sequestration if forest carbon pools are increased
- However, sequestration may be limited due to:
  - Allocation to labile carbon pools
  - Nutrient limitations
  - Photosynthetic downregulation
  - Other disturbance factors

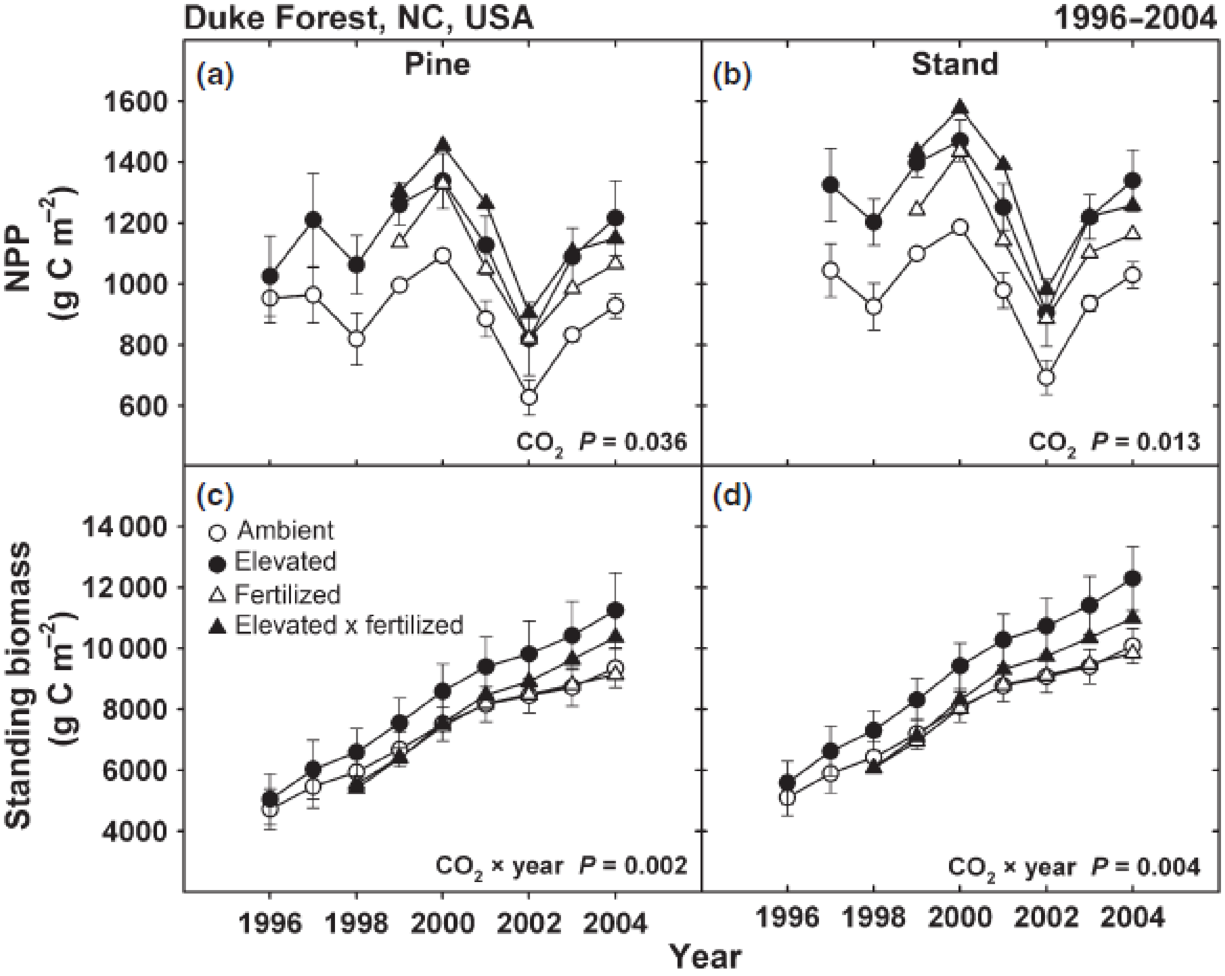


Free Air CO_2 Enrichment (FACE) experiments
30m diameter circular plots
$[CO_2]$ 200 ppm above ambient

Research
New Phytologist

Re-assessment of plant carbon dynamics at the Duke free-air CO_2 enrichment site: interactions of atmospheric [CO_2] with nitrogen and water availability over stand development

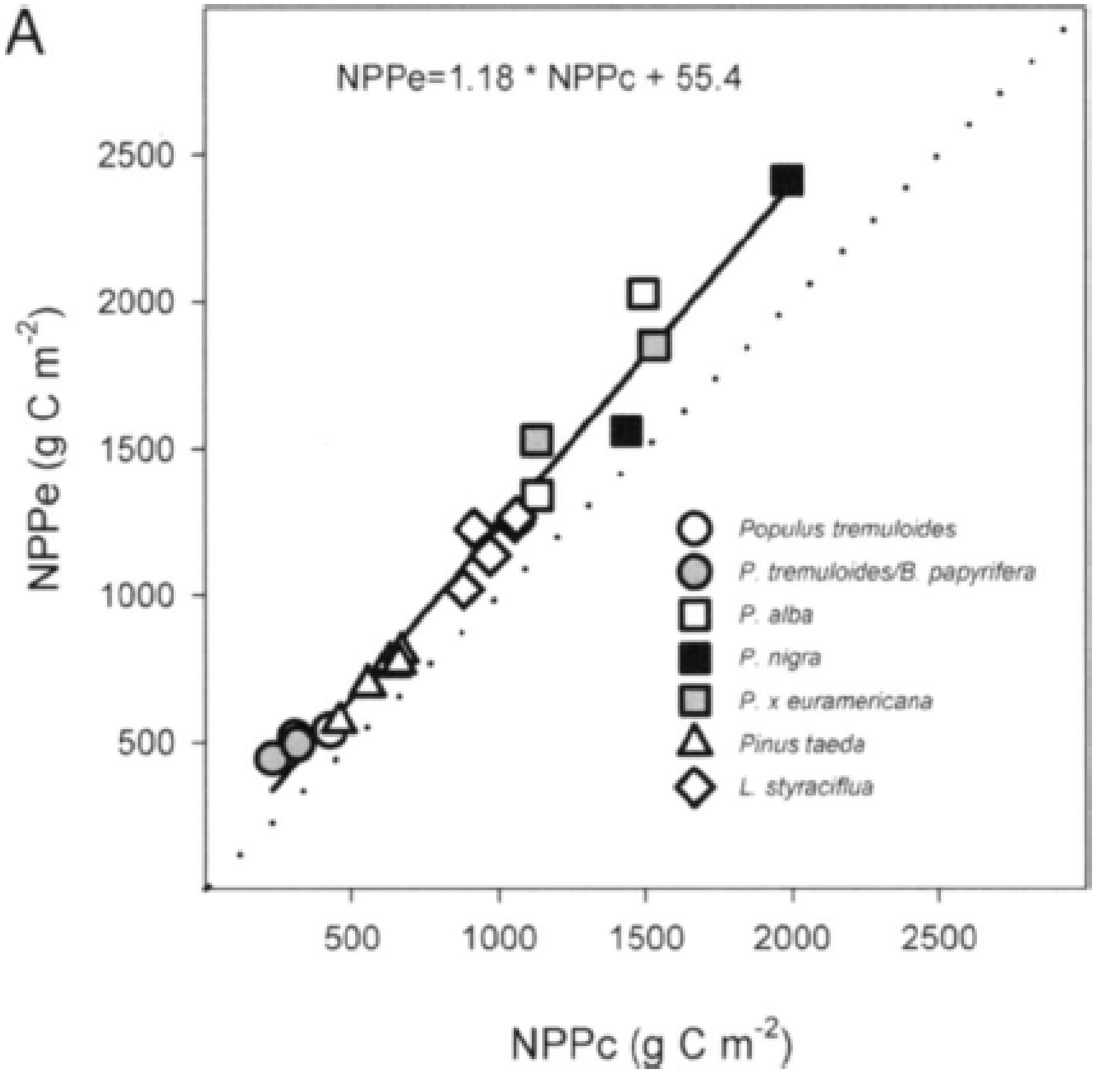
Heather R. McCarthy[1,6], Ram Oren[1], Kurt H. Johnsen[2], Anne Gallet-Budynek[3], Seth G. Pritchard[4], Charles W. Cook[5], Shannon L. LaDeau[5], Robert B. Jackson[5] and Adrien C. Finzi[3]



Forest response to elevated CO_2 is conserved across a broad range of productivity

Richard J. Norby[a,b], Evan H. DeLucia[c], Birgit Gielen[d], Carlo Calfapietra[e], Christian P. Giardina[f], John S. King[g], Joanne Ledford[a], Heather R. McCarthy[h], David J. P. Moore[i], Reinhart Ceulemans[d], Paolo De Angelis[e], Adrien C. Finzi[j], David F. Karnosky[k], Mark E. Kubiske[l], Martin Lukac[m], Kurt S. Pregitzer[k], Giuseppe E. Scarascia-Mugnozza[n], William H. Schlesinger[b,h], and Ram Oren[h]

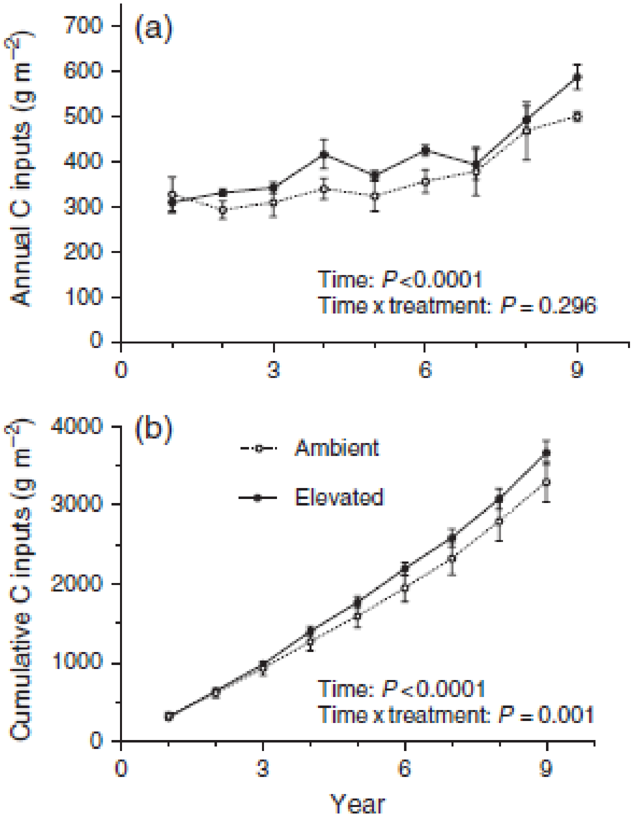
18052–18056 | PNAS | December 13, 2005 | vol. 102 | no. 50

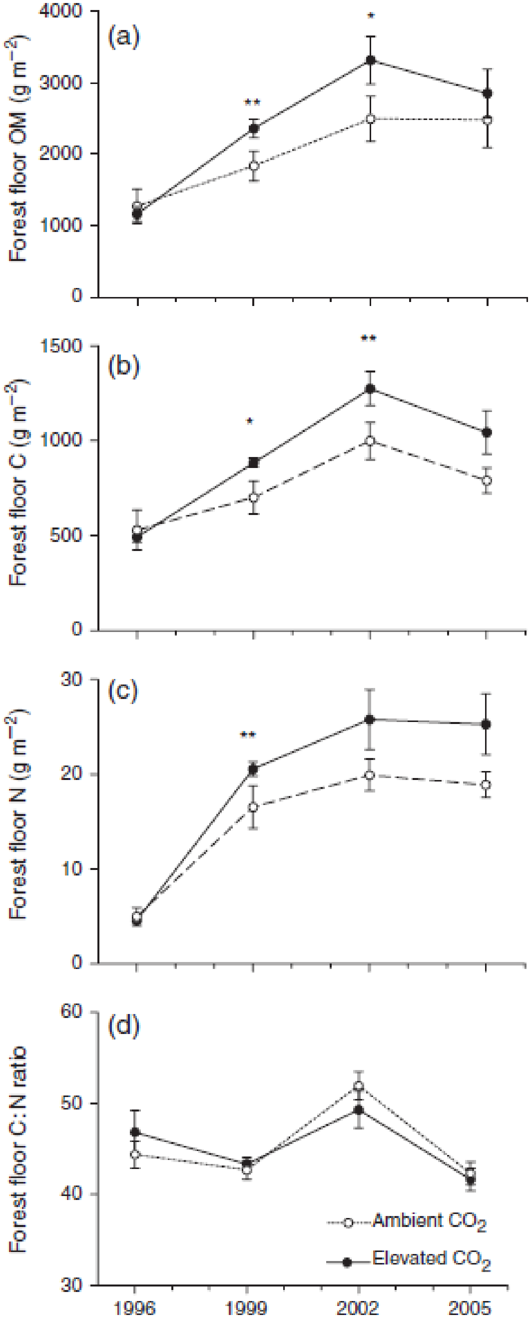


Global Change Biology (2008) **14**, 2910–2922, doi: 10.1111/j.1365-2486.2008.01701.x

Soil carbon sequestration in a pine forest after 9 years of atmospheric CO_2 enrichment

JOHN LICHTER*, SHARON A. BILLINGS†, SUSAN E. ZIEGLER‡, DEEYA GAINDH*,
REBECCA RYALS§, ADRIEN C. FINZI¶, ROBERT B. JACKSON‖,
ELIZABETH A. STEMMLER** and WILLIAM H. SCHLESINGER††



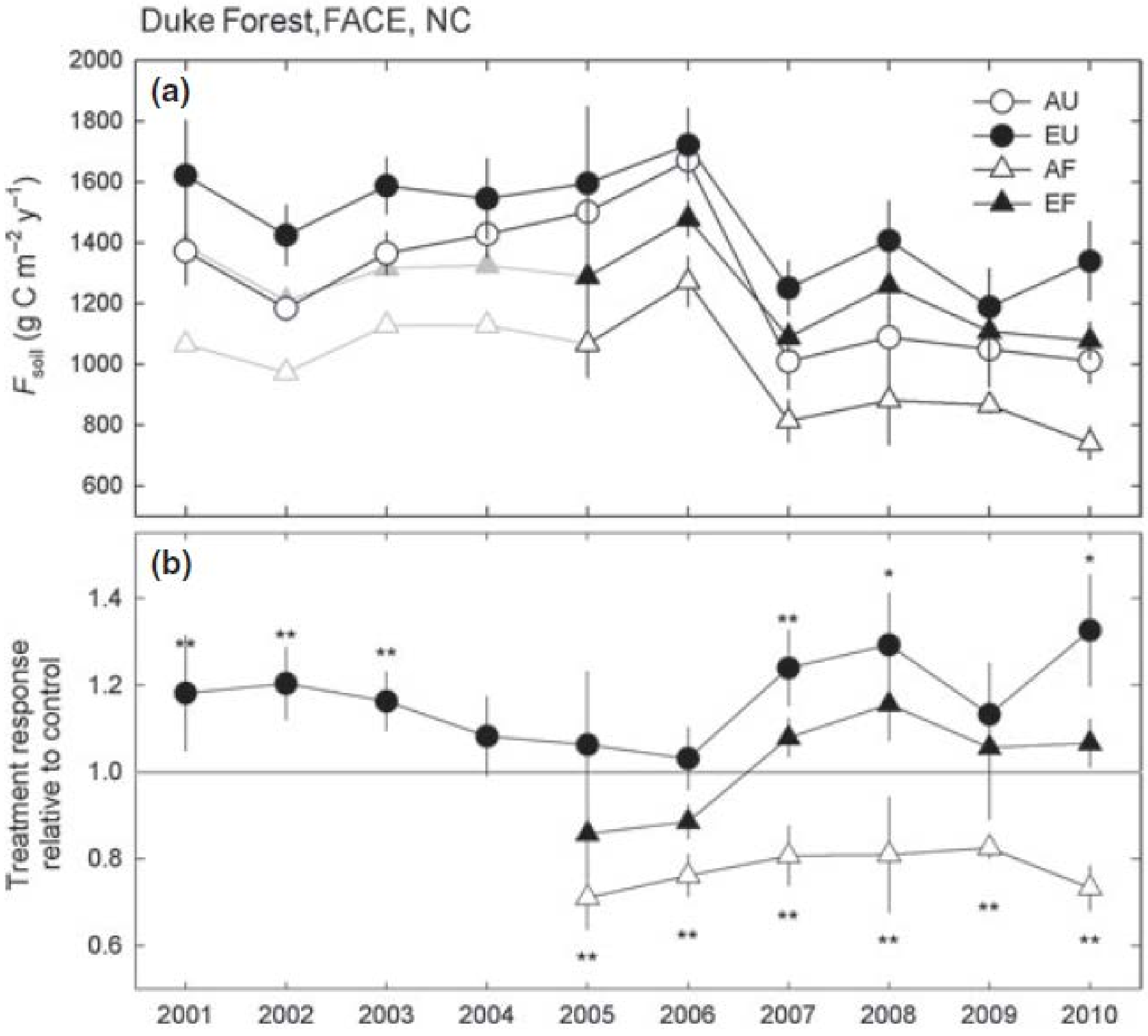


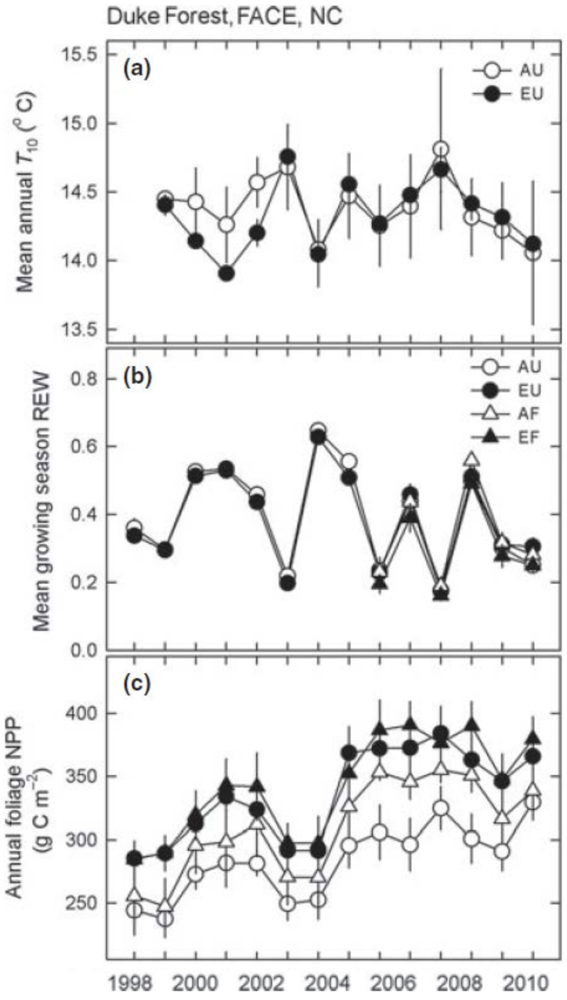
Global Change Biology
celebrating 20 years

Global Change Biology (2014) **20**, 1146–1160, doi: 10.1111/gcb.12414

Sustained effects of atmospheric [CO_2] and nitrogen availability on forest soil CO_2 efflux

A. CHRISTOPHER OISHI*†, SARI PALMROTH*‡, KURT H. JOHNSEN§, HEATHER R. MCCARTHY¶ and RAM OREN*‡||

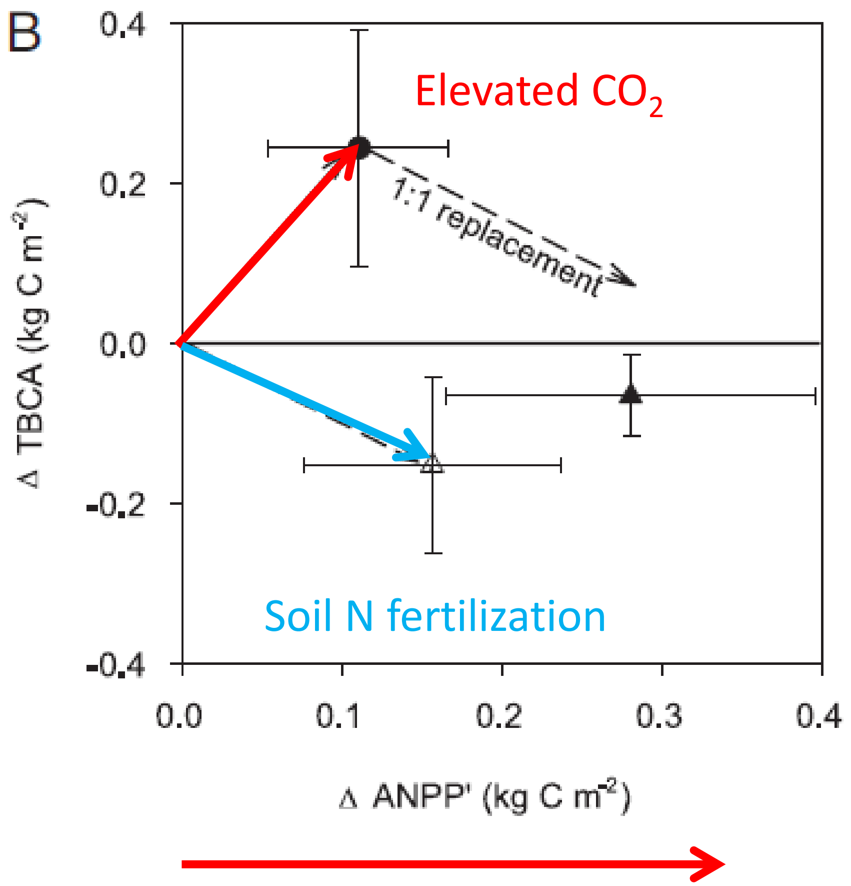




Aboveground sink strength in forests controls the allocation of carbon below ground and its [CO_2]-induced enhancement

Sari Palmroth*†, Ram Oren*, Heather R. McCarthy*, Kurt H. Johnsen‡, Adrien C. Finzi§, John R. Butnor‡,
Michael G. Ryan¶‖, and William H. Schlesinger*†

19362–19367 | PNAS | December 19, 2006 | vol. 103 | no. 51 www.pnas.org/cgi/doi/10.1073/pnas.0609492103



Enhanced aboveground productivity

Total Belowground Carbon Allocation

TBCA = Soil CO_2 efflux (respiration)
- leaf litterfall
+ Δ(root, litter, soil C)

General effects of increased atmospheric CO_2

- Increased aboveground biomass
  - Relatively stable
- Increased leaf production
  - Relatively labile
- Increased root production
  - Fine roots labile
  - Coarse roots stable
  - Source of respiration
- Increased root exudates
  - Very labile

- Increased supply of labile carbon to soil:
  - Induces soil priming
  - Changes in soil microbial communities

Modeling soil organic carbon

Carbon, **O**rganisms, **R**hizosphere, and **P**rotection in the **S**oil **E**nvironment (CORPSE; Sulman *et al*. 2014)

- Independent temperature & moisture sensitivities for different carbon classes
- Integrates rhizosphere processes and microbial influences on soil carbon stabilization
- Functions at stand-level or integrated into global land surface models

nature climate change

LETTERS

| DOI: 10.1038/NCLIMATE2436

Microbe-driven turnover offsets mineral-mediated storage of soil carbon under elevated CO_2

Benjamin N. Sulman[1,2,3]*, Richard P. Phillips[3], A. Christopher Oishi[4], Elena Shevliakova[1,5]
and Stephen W. Pacala[5]

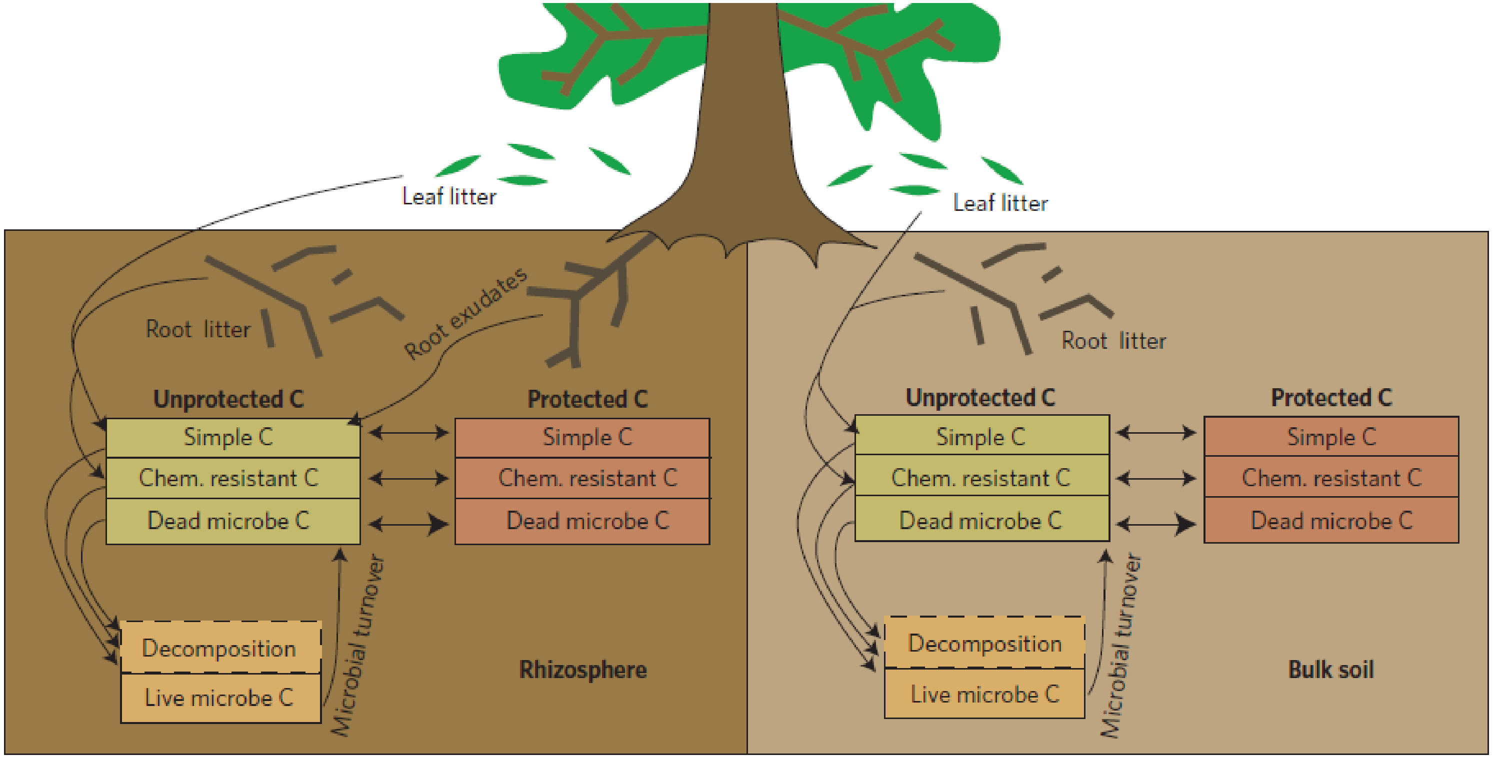


Figure 1 | Diagram of model structure. Soil carbon is divided into three chemical classes, which can be protected or unprotected. Decomposition is mediated by microbial biomass, which takes up a portion of decomposed carbon and loses carbon to CO_2 and the dead microbial C pool over time. Soil is separated into the rhizosphere, which receives root exudate inputs, and bulk soil, which does not.

Duke Forest FACE

Recalcitrant litter (pine)
Low clay content

Small increase in protected C
Large losses through priming

Oak Ridge FACE

Labile litter (broadleaf)
High clay content

Moderate increase in protected C
Small losses through priming

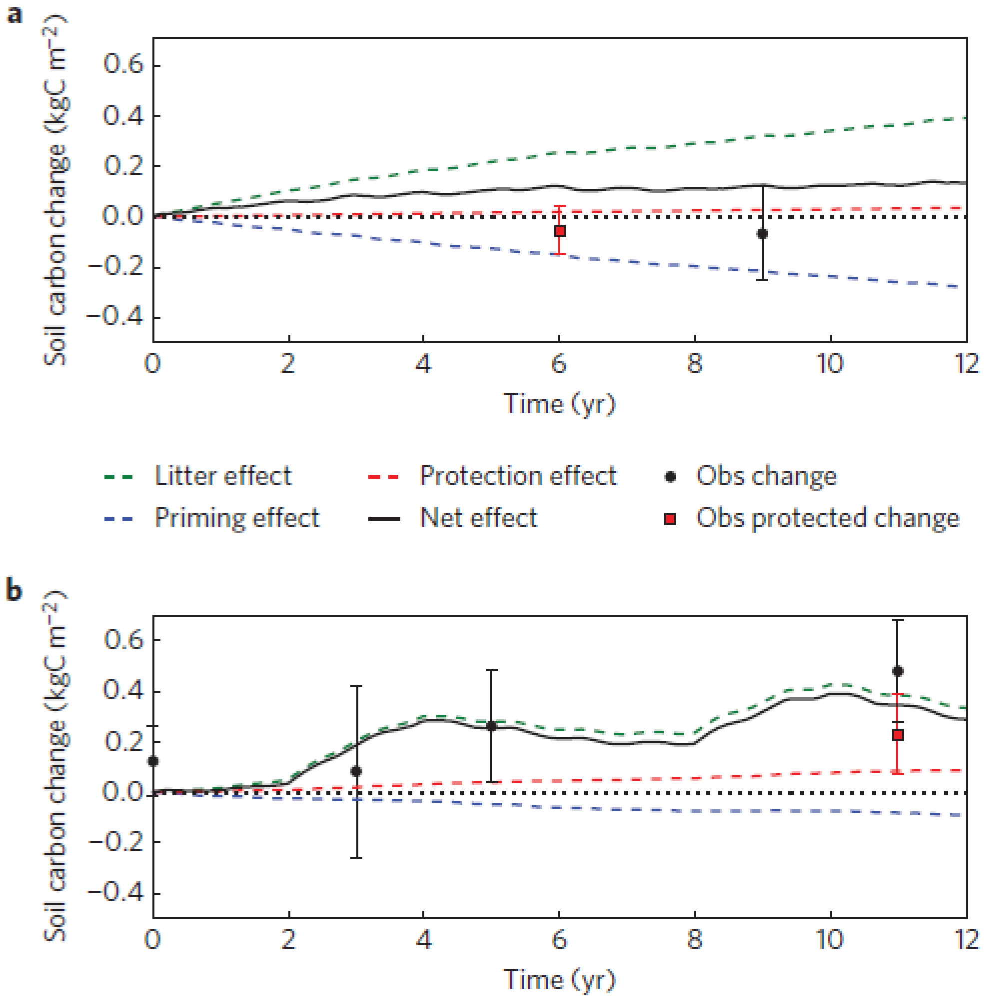
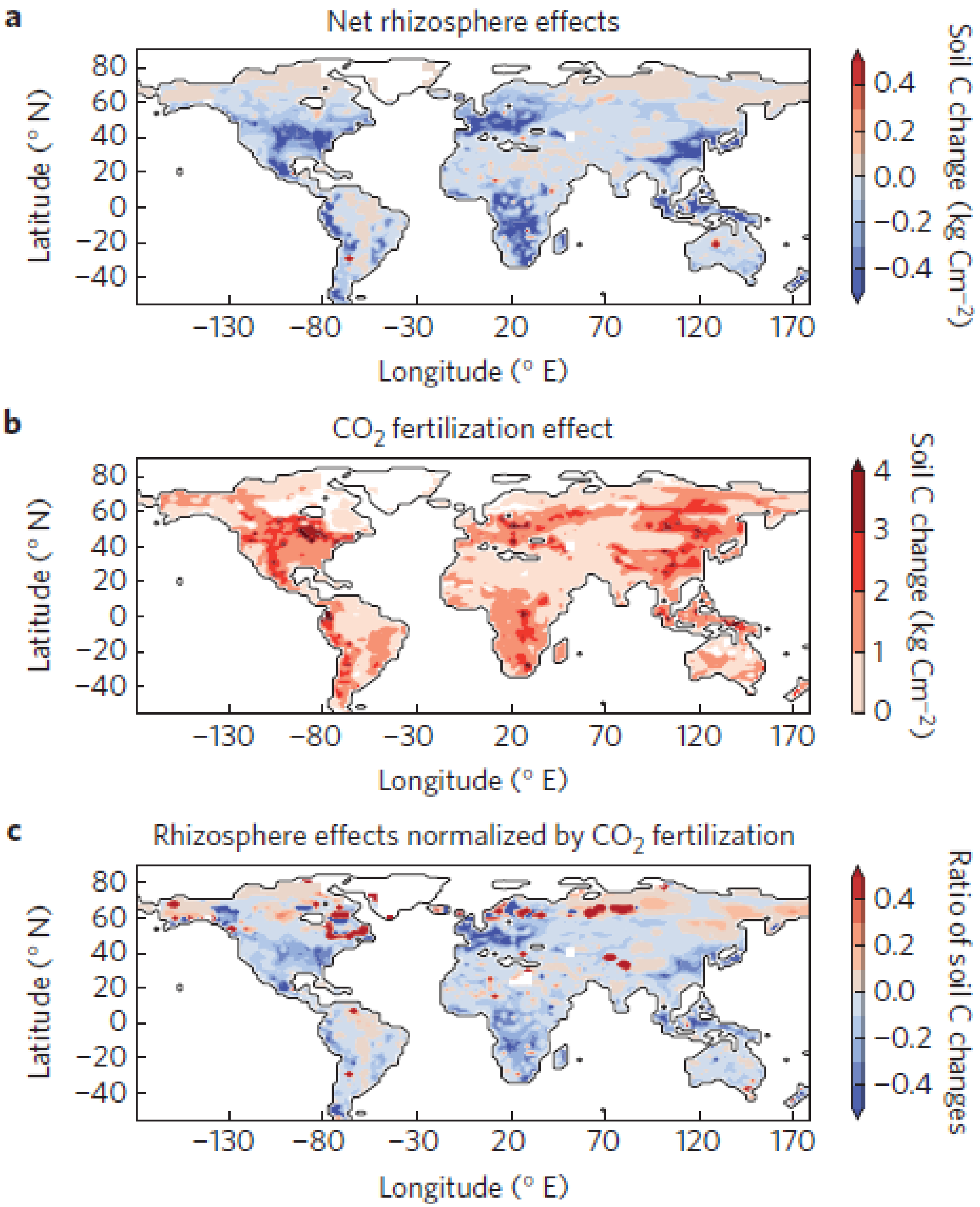


Figure 2 | Observed and modelled responses of soil carbon to elevated CO_2. Lines show modelled litter effects, priming effects, changes in protected carbon and the overall net change at Duke and ORNL FACE sites. Symbols with error bars show measured values and reported measurement standard error. **a**, Duke FACE. **b**, ORNL FACE.

30-year simulated soil carbon dynamics

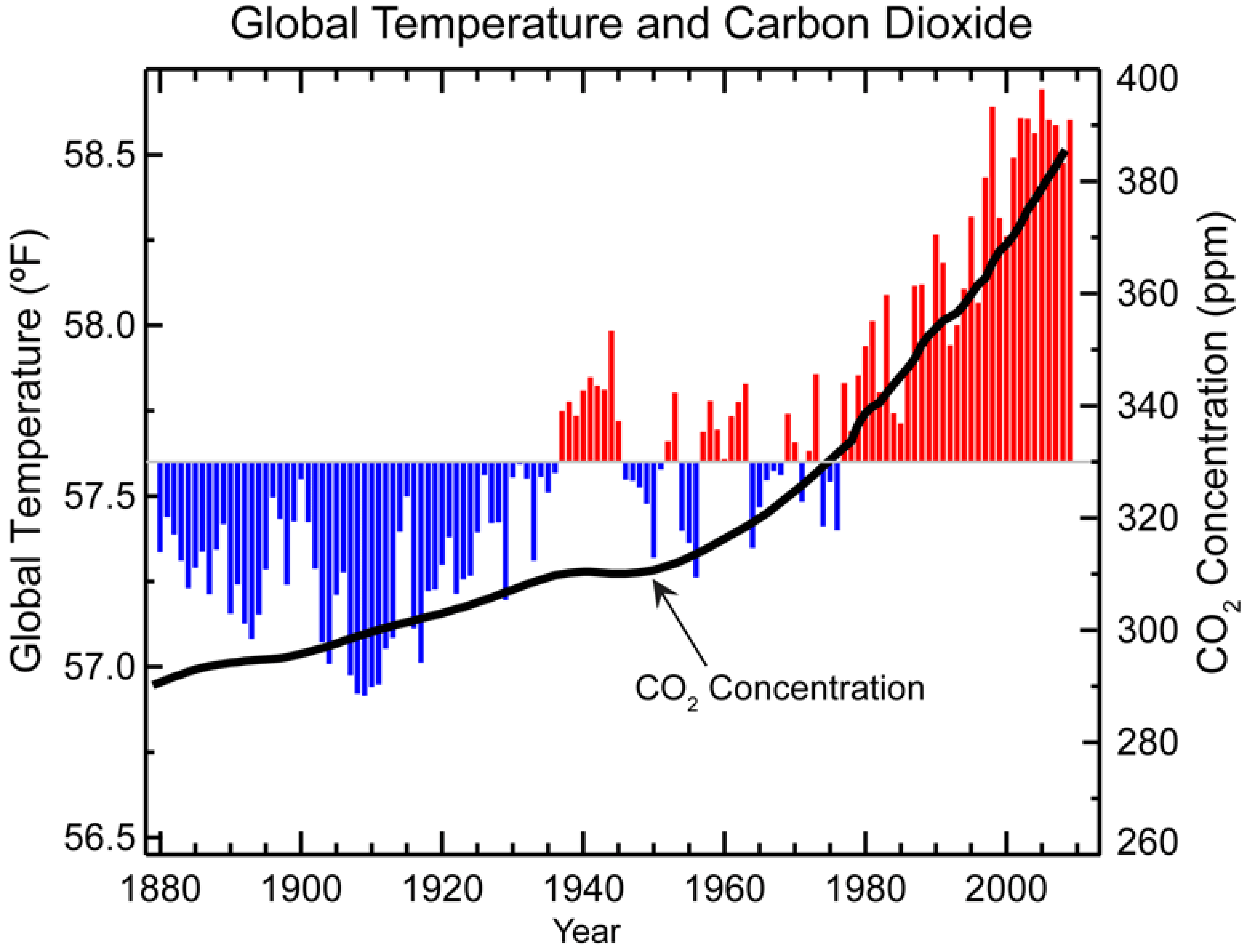


Changes in soil C stocks due to enhanced rhizosphere C supply

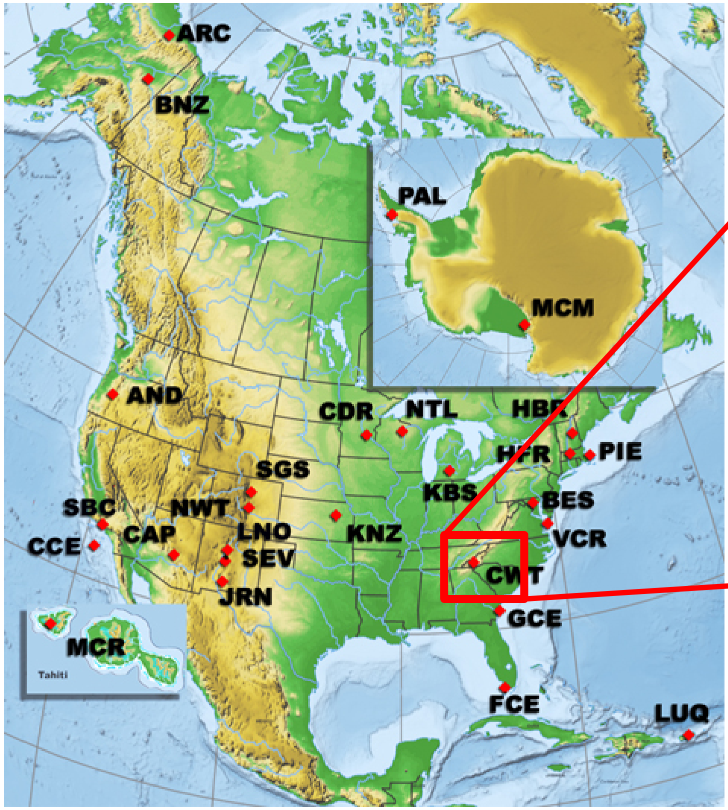
Priming effects lead to C losses in many areas

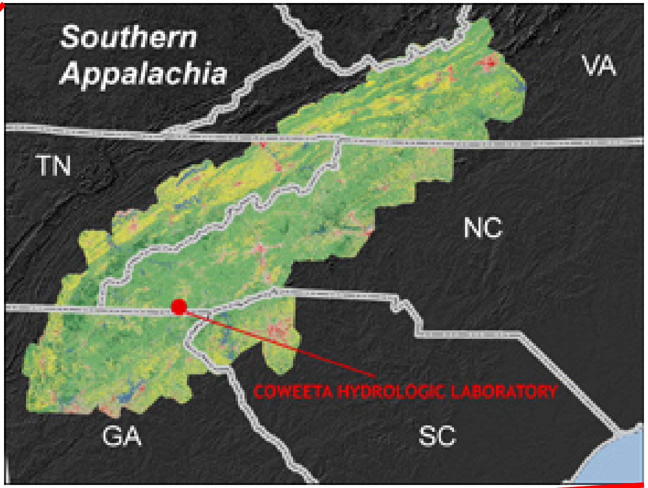
Increases in soil C stocks due to enhanced NPP

Relative effect of rhizosphere Activity as a proportion of CO$_2$ effect



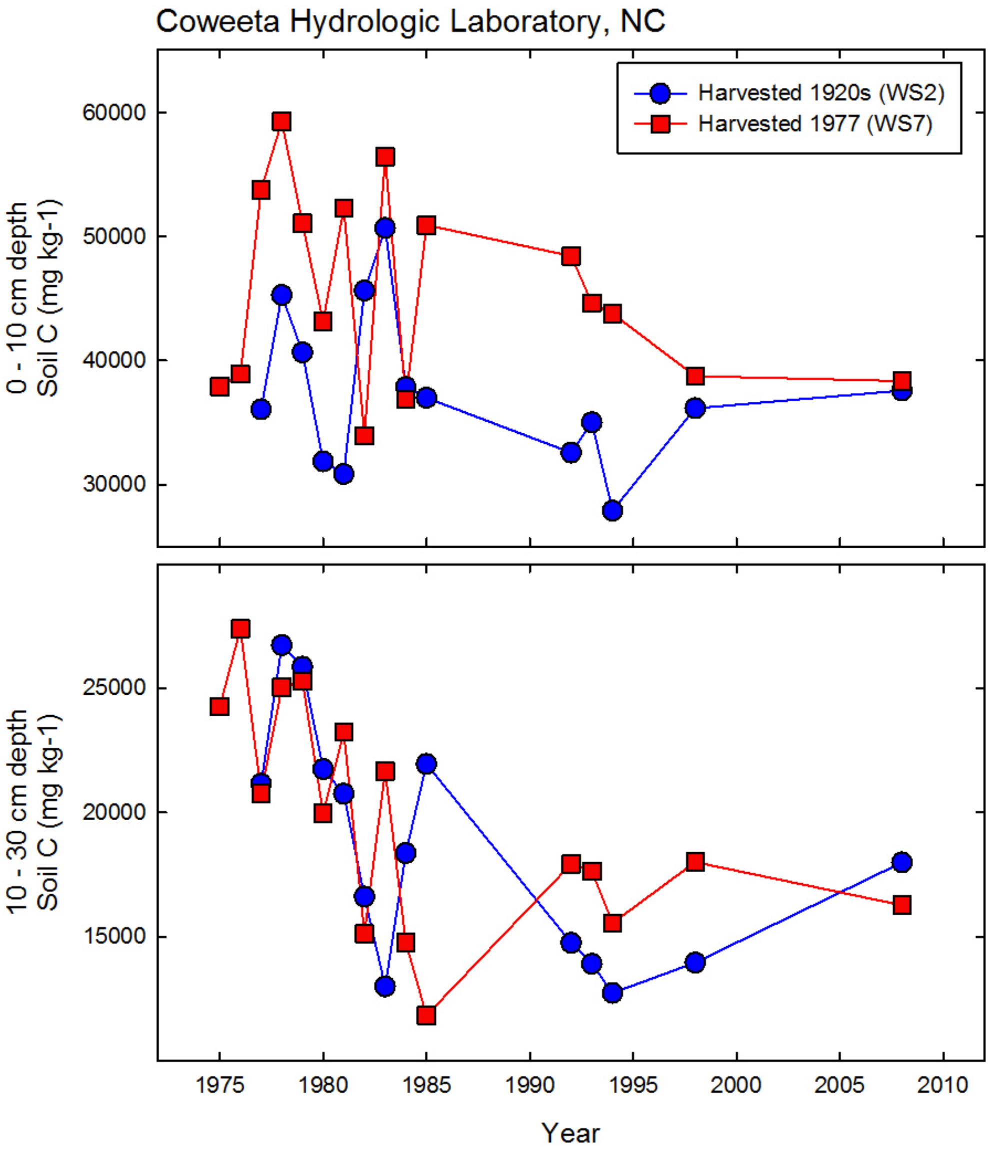
http://www1.ncdc.noaa.gov/pub/data/cmb/images/indicators/global-temp-and-co2-1880-2009.gif





Coweeta Hydrologic Lab (LTER: CWT)
Established 1934
(when ambient CO_2 ~ 310 ppm)

MAP: 1800 mm
MAT: 12.7
January: 2.7
July: 21.4
http://www.lternet.edu/lter-sites



Possible loss of shallow soil C since 1980s

Loss of deeper soil C through mid-1980s in different aged plots

Possible stabilization of total soil C

Data courtesy of Jennifer Knoepp

Ecological Applications, 21(6), 2011, pp. 2049–2067

Can forest management be used to sustain water-based ecosystem services in the face of climate change?

Chelcy R. Ford,[1] Stephanie H. Laseter, Wayne T. Swank, and James M. Vose

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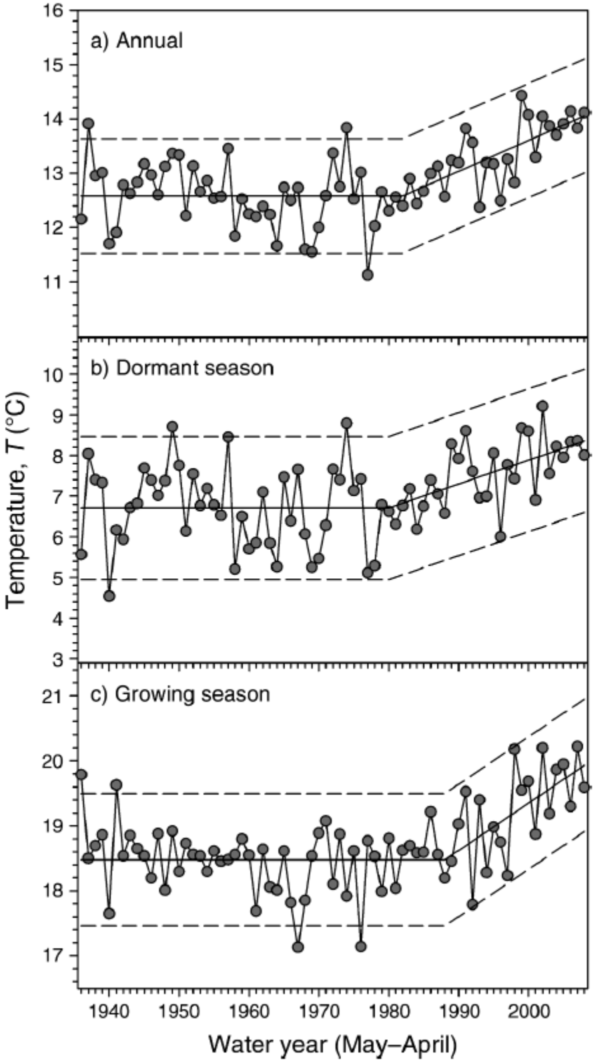
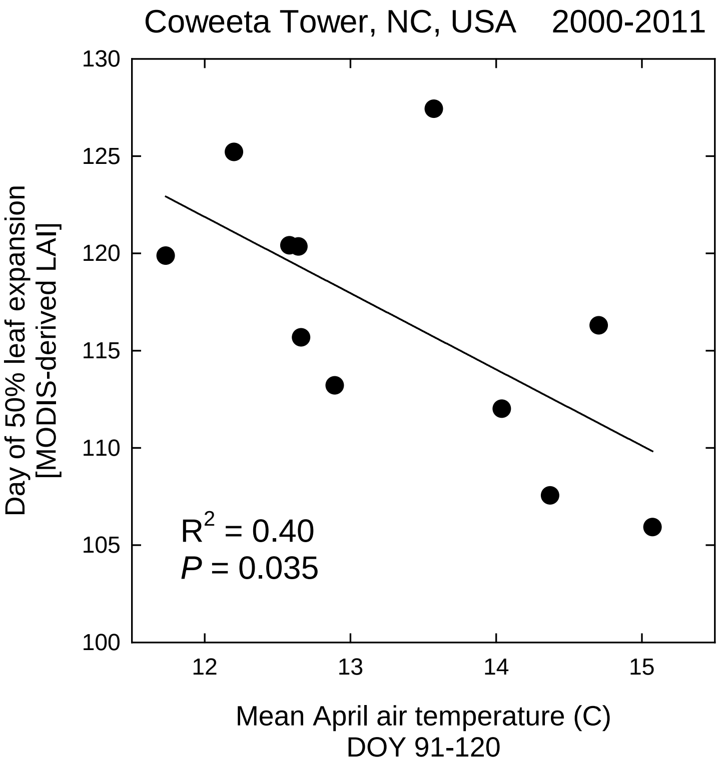
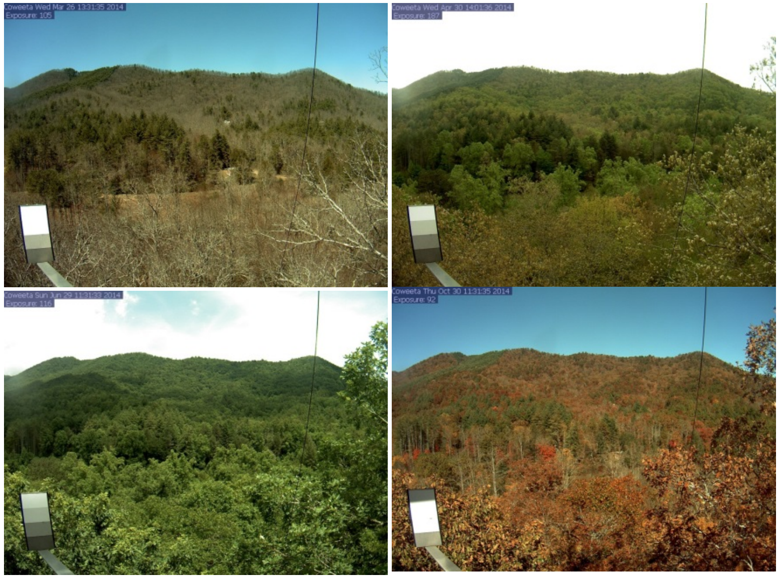
Otto, North Carolina 28763 USA*

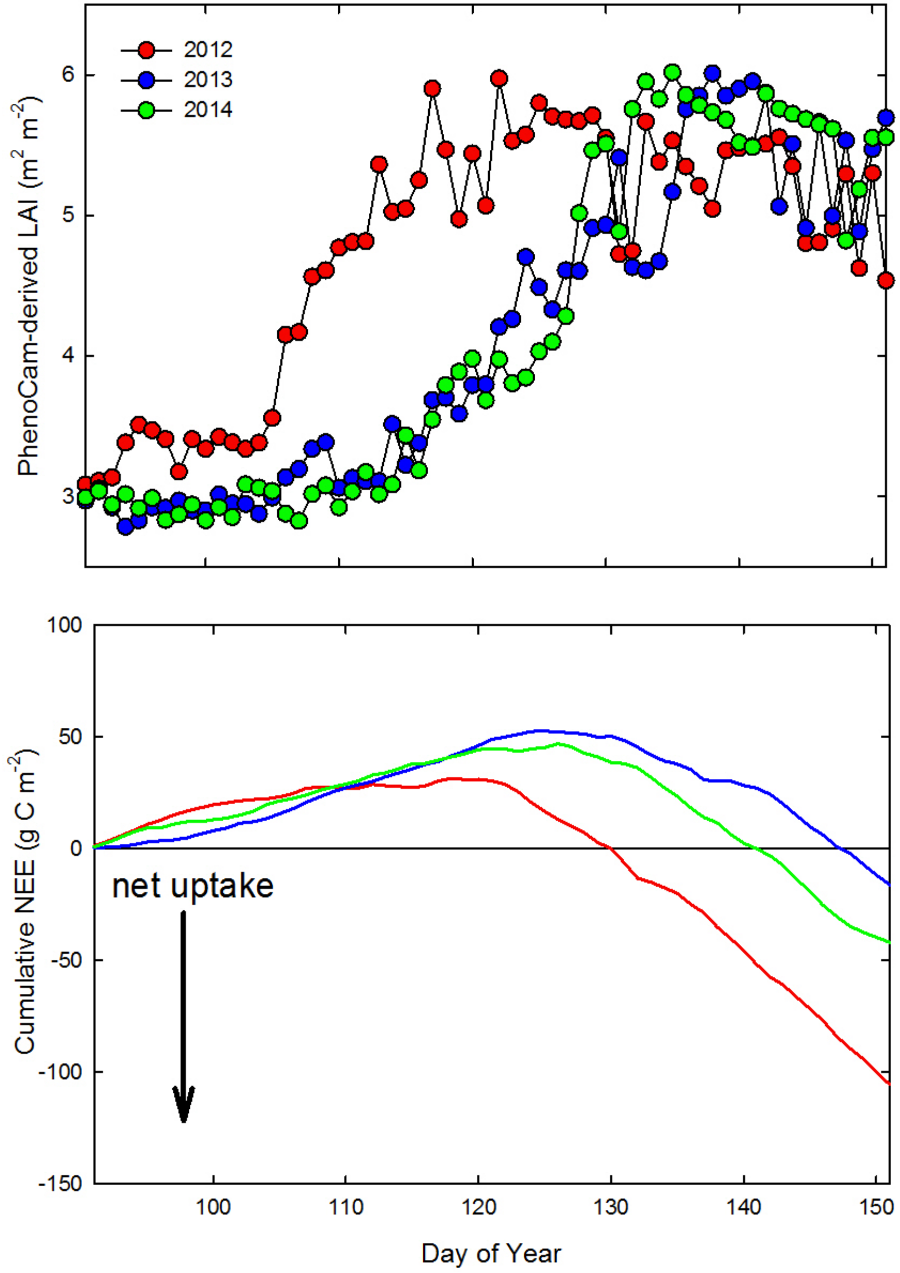




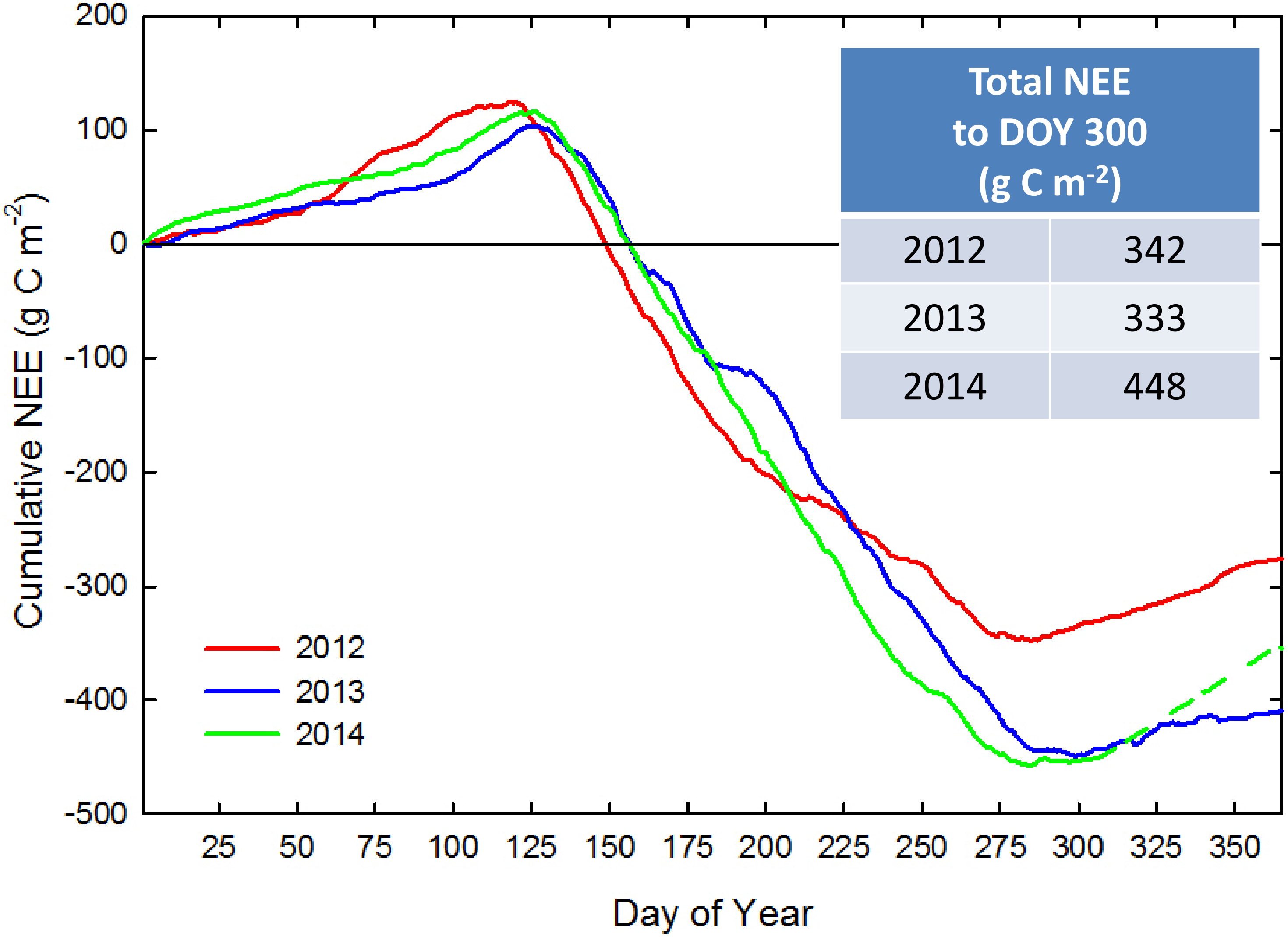
MODIS data from Hwang et al., Global Change Biol. 2014 http://phenocam.sr.unh.edu/webcam/sites/coweeta/



Coweeta Tower, NC, USA



Coweeta Tower, NC, USA



Total NEE to DOY 300 (g C m^{-2})	
2012	342
2013	333
2014	448

Summary

- Aboveground biomass gains expected under elevated CO_2
- Belowground carbon dynamics will vary
  - Added carbon supply may be stabilized in protected forms
  - Added carbon supply may stimulate turnover of soil carbon
- Overall effects of climate change on soil carbon will depend on:
  - Climatic drivers (CO_2, temperature, water)
  - Soil properties and vegetation
  - Land use history
  - Disturbance (pests, storms, etc.)

Acknowledgements

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- Oklahoma University: Heather McCarthy
- Indiana University: Benjamin Sulman, Kimberly Novick, Taehee Hwang
- US EPA: John Walker
- PhenoCam project: Thomas Milliman (UNH) & Andrew Richardson (Harvard)

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  - USDA Agriculture and Food Research Initiative Foundational Program (AFRI)
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