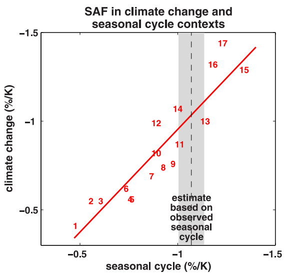
Reducing Uncertainties Using Observations

To reduce feedback uncertainties using contemporary observations,

1. there must be a relationship between contemporary variability and future trends on longer time scales within the model, and
2. it must be possible to constrain contemporary variability in the model using observations.

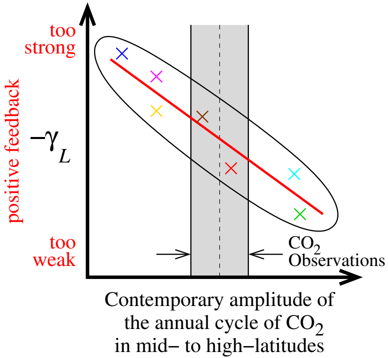
Example

Hall and Qu (2006) evaluated the strength of the springtime snow albedo feedback (SAF; $\Delta\alpha_s/\Delta T_s$) from 17 models used for the IPCC AR4 and compared them with the observed springtime SAF from ISCCP and ERA-40 reanalysis.



Hypothesis 1 – *Seasonal to Annual Time Scale*

A stronger climate-carbon cycle feedback will be exhibited by models with weak contemporary annual cycles of atmospheric CO_2 in the Northern Hemisphere extratropics.



CO_2 observations from GLOBALVIEW-CO2 and TCCON

Feedback may be too strong because

- R_h too sensitive to temperature, releasing too much carbon in winter and mid-summer and canceling out uptake from NPP; or
- *GPP* not sensitive enough to temperature, limiting response to spring warming and reducing mid-summer maximum.

Contemporary measurements can narrow the range of model spread and reduce the uncertainty of $\gamma_L = \Delta C_L / \Delta T_s$.

Temperature Dependence of Heterotrophic Respiration

$$R_h = C_{bg} k_0 Q_{10}^{\left(\frac{T-T_0}{10}\right)}$$

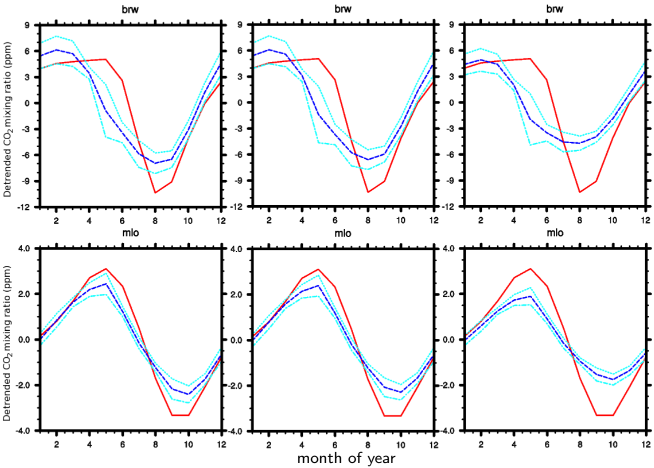
$Q_{10} = 1.5$ $Q_{10} = 2.0$ $Q_{10} = 3.0$

Barrow (BRW)

71.32° N, -156.61° E

Mauna Loa (MLO)

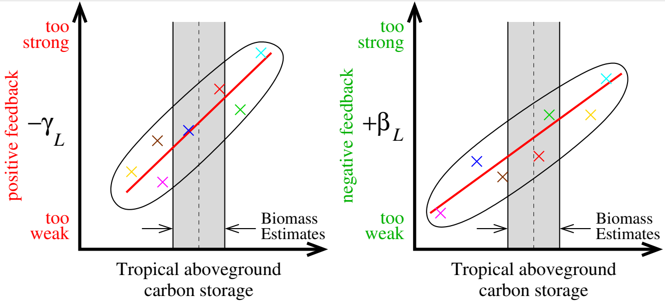
19.54° N, -155.58° E



GLOBALVIEW-CO2/TRANSCOM impulse response function (TIRF), CLM4/Mean TIRF, CLM4/TIRF bounds

Hypothesis 2 – *Interannual to Decadal Time Scale*

Models with excess biomass in the tropics have larger effective carbon losses due to temperature and larger effective sensitivities of carbon storage to CO_2.

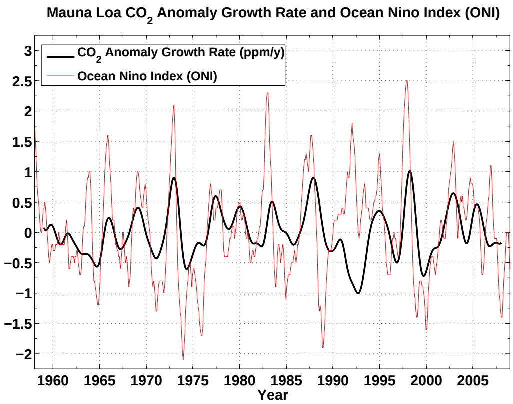


Biomass estimates from Saatchi et al. (2007) and LBA-RAINFOR Project

Over-estimates of biomass could lead to large releases of carbon during droughts and may indicate too strong an effective response to temperature (a negative feedback), possibly resulting from too strong a response to CO_2 increases (a positive feedback).

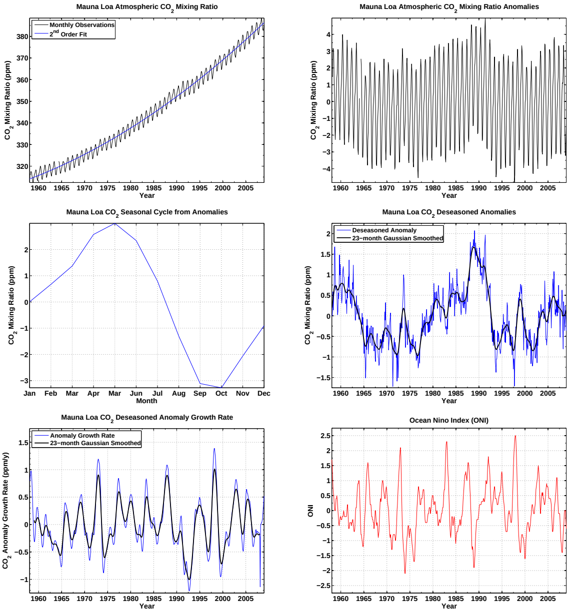
Hypothesis 3 – *Interannual to Decadal Time Scale*

The relationship between El Niño-Southern Oscillation (ENSO) and observed CO_2 anomalies at Mauna Loa may be exploited to evaluate ocean and terrestrial model responses.

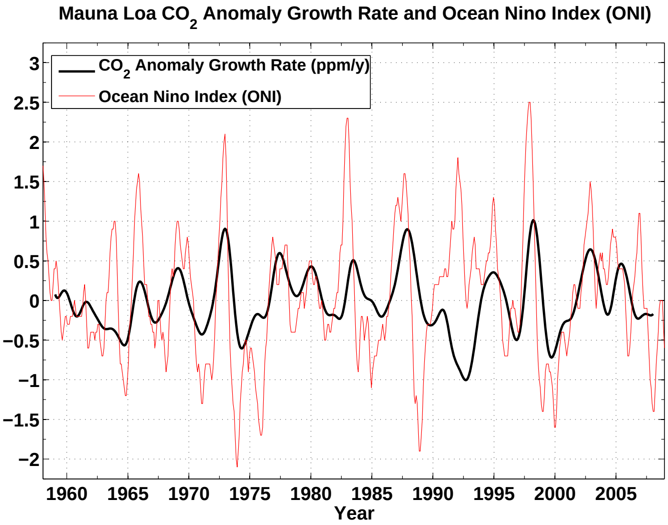


CO_2 Dependence on El Niño-Southern Oscillation (ENSO)

- Keeling and Revelle (1985) described a shutdown in upwelling and biological activity during El Niño years, resulting in a shutdown of CO_2 out-gassing.
- Many others have confirmed this response, including Rayner et al., Feeley et al., Baker et al., and others.
- They suggested the deficiency in CO_2 flux is more than compensated for by widespread forest fires and plant deaths due to drought.
- While the net effect of *natural* processes may once have been a sink, the opposite effect is observed today.
- Opportunistic burning for forest clearing is likely to strengthen the sensitivity of CO_2 to El Niño.


Mauna Loa Atmospheric CO2 Mixing Ratio
Monthly Observations
2nd Order Fit
CO2 Mixing Ratio (ppm)
Year
Mauna Loa Atmospheric CO2 Mixing Ratio Anomalies
CO2 Mixing Ratio (ppm)
Year
Mauna Loa CO2 Seasonal Cycle from Anomalies
CO2 Mixing Ratio (ppm)
Jan Feb Mar Apr Mar Jun Jul Aug Sep Oct Nov Dec
Month
Mauna Loa CO2 Deseasoned Anomalies
Deseasoned Anomaly
23−month Gaussian Smoothed
CO2 Mixing Ratio (ppm)
Year
Mauna Loa CO2 Deseasoned Anomaly Growth Rate
Anomaly Growth Rate
23−month Gaussian Smoothed
CO2 Anomaly Growth Rate (ppm/y)
Year
Ocean Nino Index (ONI)
ONI
Year

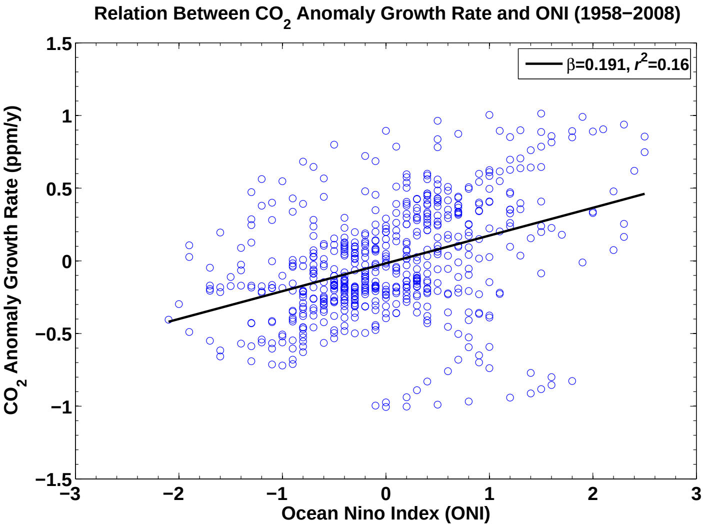
CO_2 Anomaly Growth Rate and Ocean Niño Index



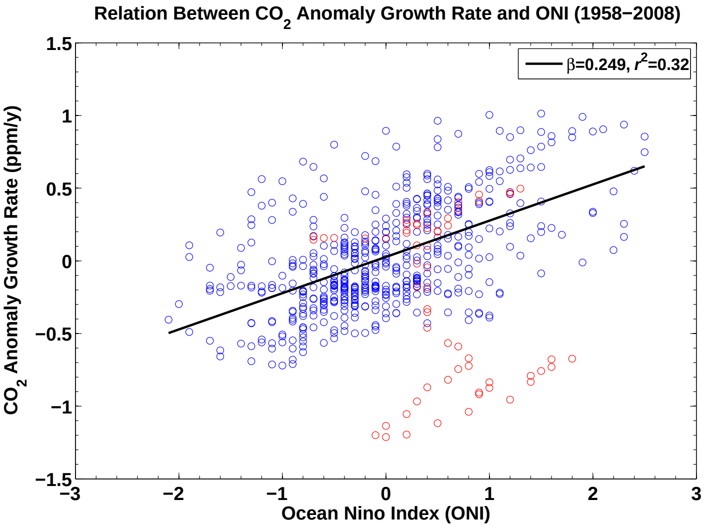
Mount Pinatubo Eruption

- June 1991 on island of Luzon in the Philippines
- Second largest volcanic eruption of 20th century
- Millions of tons of sulfur dioxide discharged into atmosphere
- Gases and ash reached 34 km high and over 400 km wide
- Largest disturbance of stratosphere since Krakatau in 1883

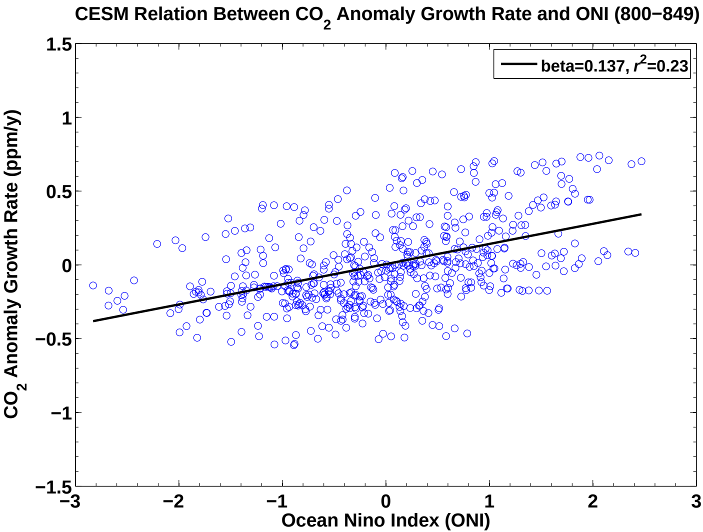
Relation Between CO_2 Anomaly Growth Rate and ONI



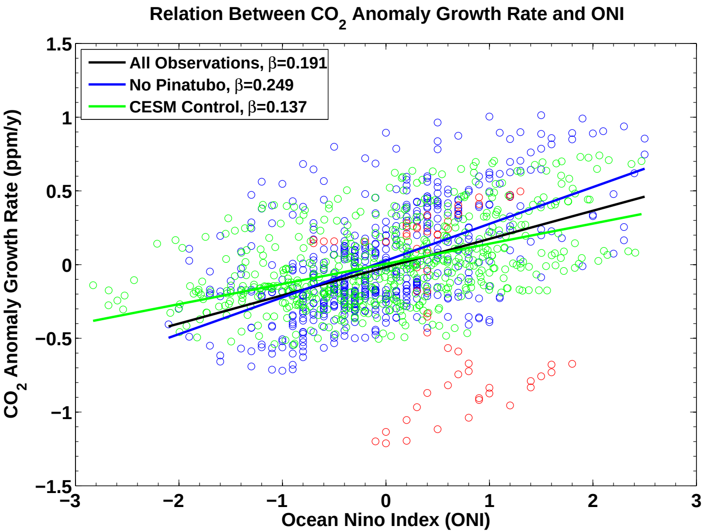
Relation Without 1991–1995 (Pinatubo Period)



Community Earth System Model (CESM) Control Run



CESM vs. Observations



References

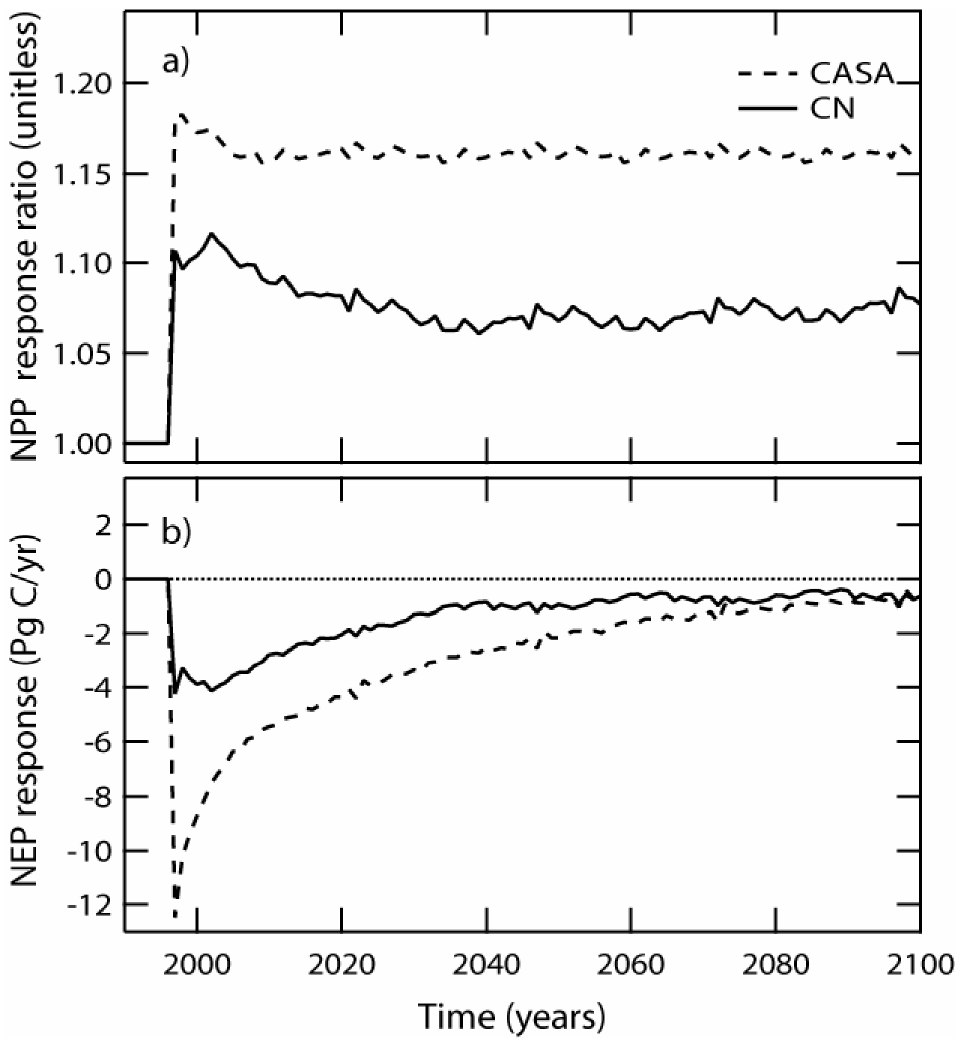
A. Hall and X. Qu. Using the current seasonal cycle to constrain snow albedo feedback in future climate change. *Geophys. Res. Lett.*, 33(3): L03502, Feb. 2006. doi:10.1029/2005GL025127.

S. S. Saatchi, R. A. Houghton, R. C. D. S. Alvalá, J. V. Soares, and Y. Yu. Distribution of aboveground live biomass in the Amazon basin. *Global Change Biology*, 13(4):816–837, Apr. 2007. doi:10.1111/j.1365-2486.2007.01323.x.

It may be possible to separate β_L into more easily digestible (testable) components:

- β_L is the carbon uptake (NECB) sensitivity to elevated levels of atmospheric CO_2
- $$\beta_L = C \cdot \beta_{fert} \cdot NPP_0 \cdot \tau_0 \qquad (4)$$
- Where C is a constant (units of 1/ppm)
- $$\beta_{fert} = \frac{\left(NPP_f - NPP_i\right)/ NPP_f}{\ln(CO_{2f} / CO_{2i})}$$
- NPP_0 is initial or steady state NPP (~ contemporary NPP)
- τ_0 is the initial or steady state turnover time of carbon in the system

Example application:
Explaining model responses to FACE simulations

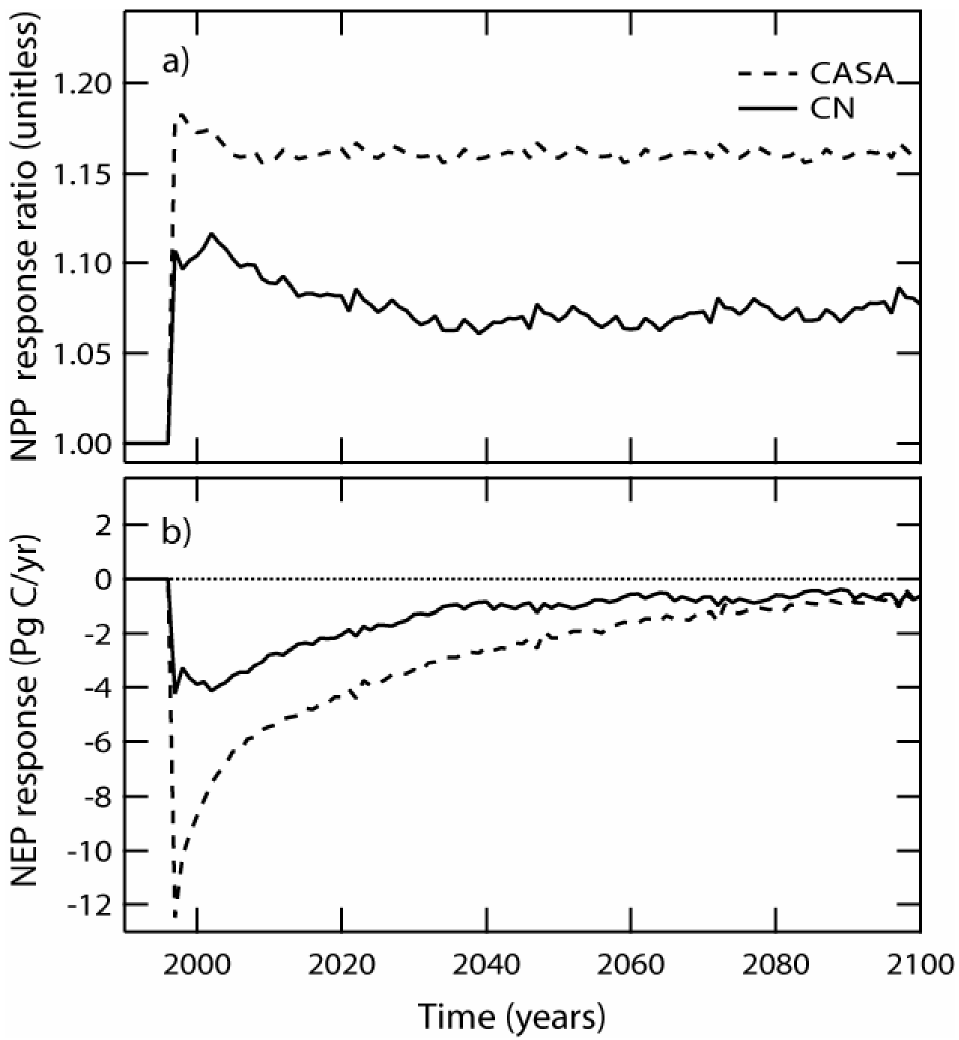


CASA' and CN NPP responses to elevated CO_2 were different by ~ a factor of 2 or less

Yet initial model carbon storage responses to CO_2 (β_L) were different by more than a factor of 3

Why?

Example application: Explaining model responses to FACE simulations



CASA' and CN NPP responses to elevated CO_2 were different by ~ a factor of 2 or less

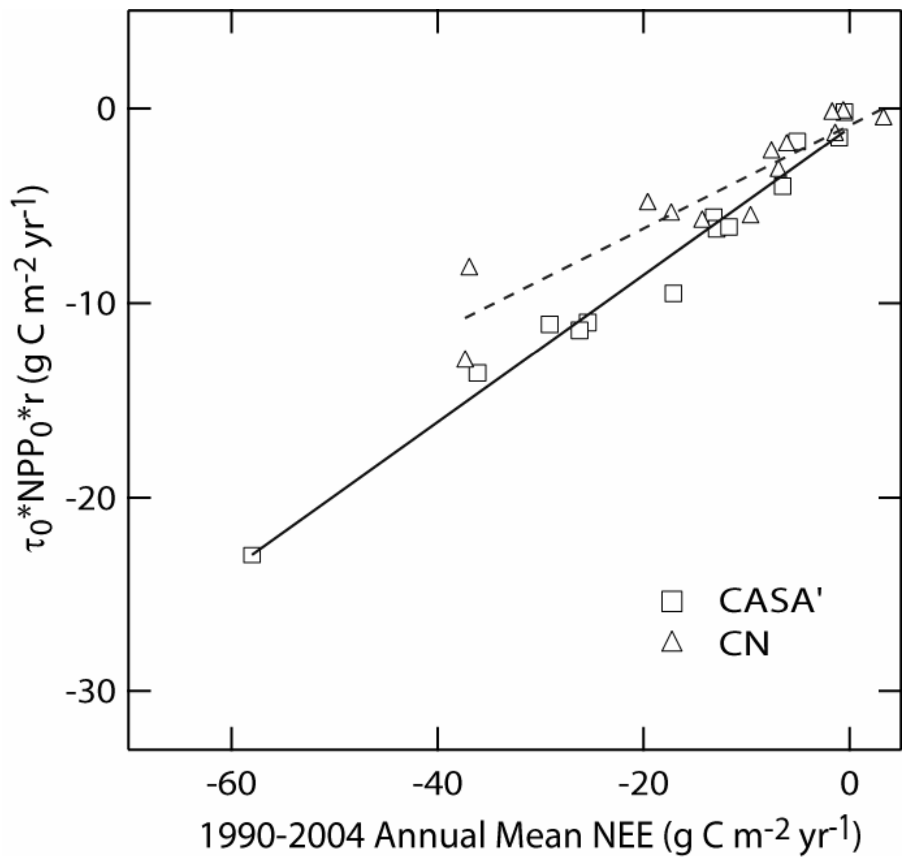
Yet initial model carbon storage responses to CO_2 (β_L) were different by more than a factor of 3

Why?

NPP in CN was considerably smaller than in CASA' modifying rates of storage in plant biomass

Example application:
Explaining differences in model responses to historical changes in atmospheric CO_2 and N deposition

The Y axis is a prediction of β_L based on initial NPP, residence times, and relative changes in NPP



(*same as β_L*)

- Transient historical runs from 1800-2004
- Each point is a biome mean
- The predictive equation explains intra- and inter model variability in β_L
- May work well for models in which allocation is not strongly modified by elevated CO_2 or N deposition

Using this framework for CMIP5 analysis: proposed approach for analyzing β_L