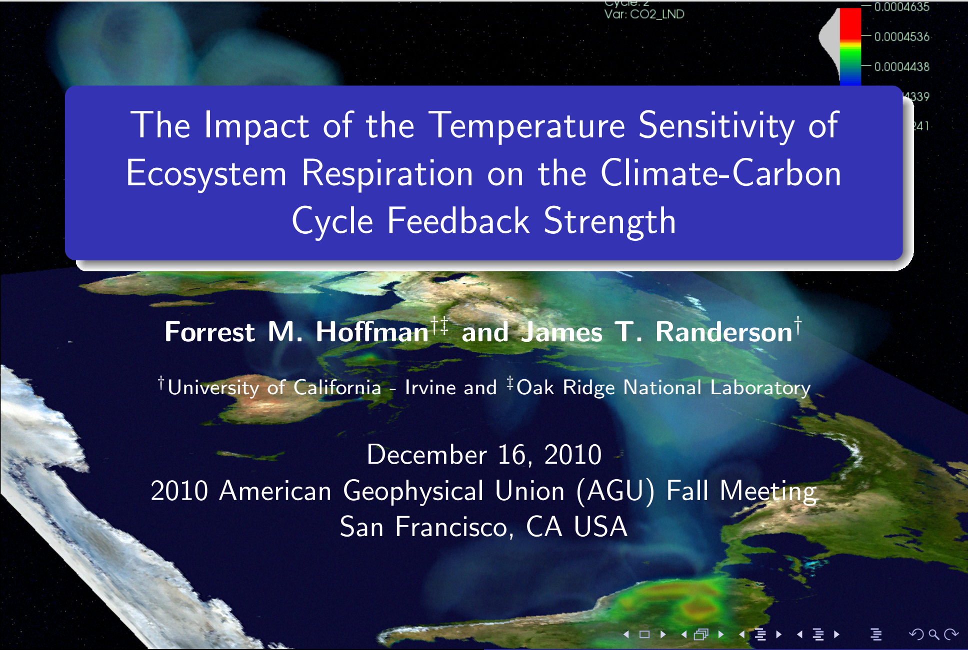

The Impact of the Temperature Sensitivity of Ecosystem Respiration on the Climate-Carbon Cycle Feedback Strength

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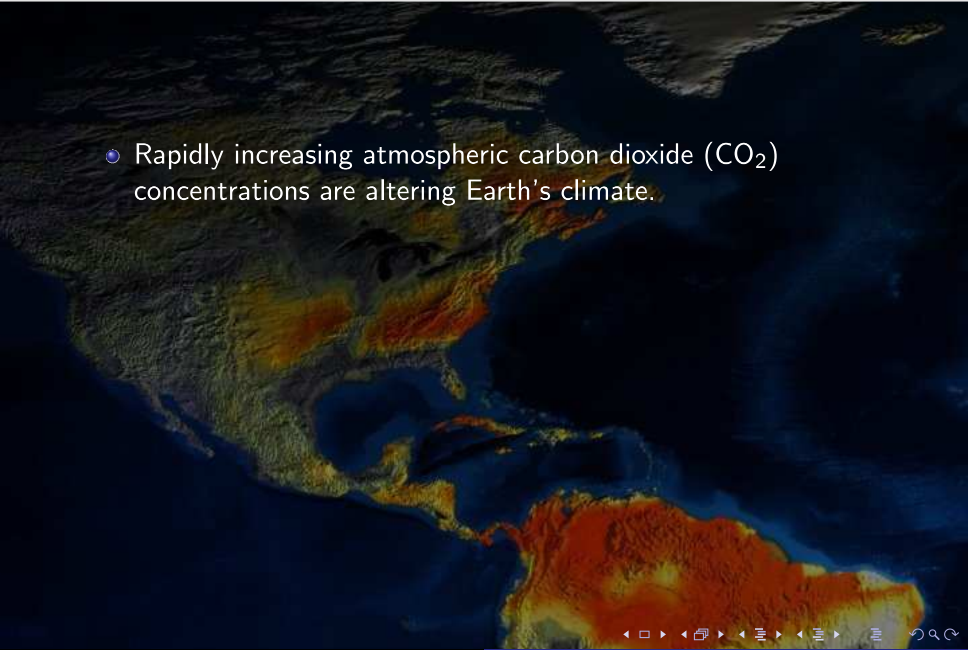

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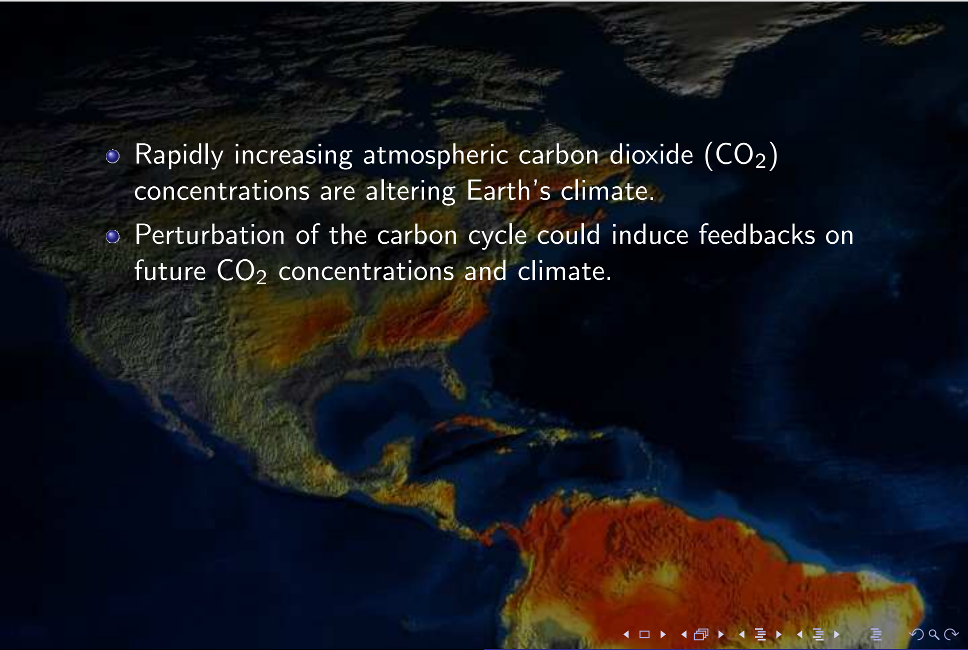

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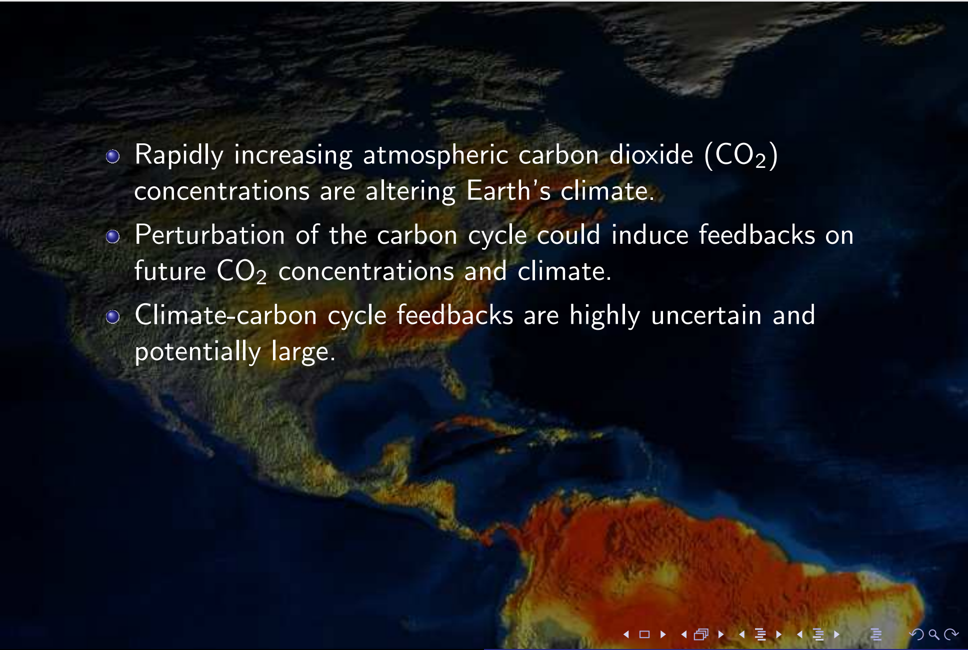

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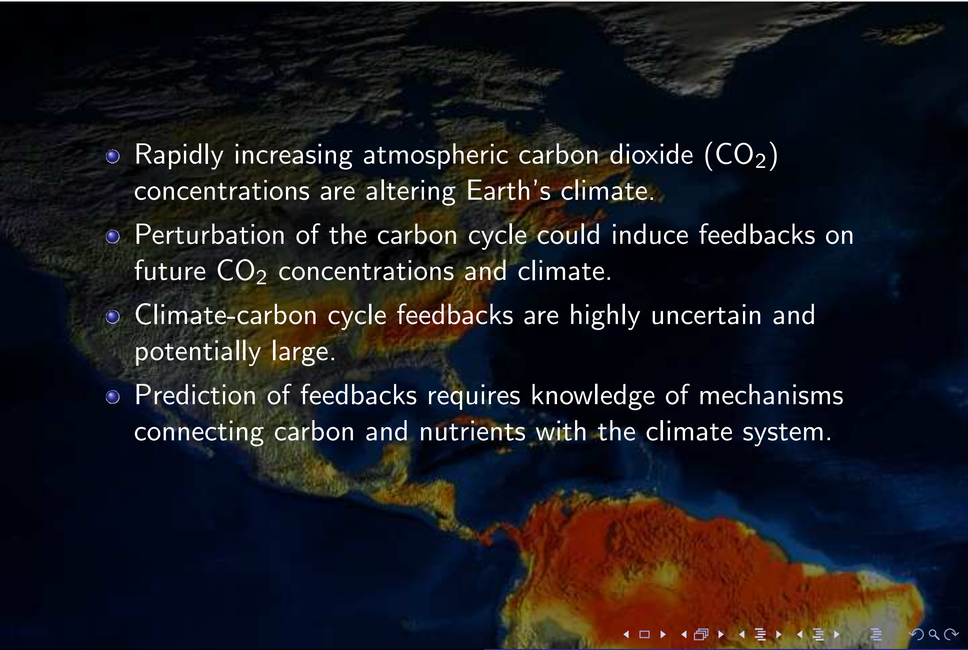

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- Perturbation of the carbon cycle could induce feedbacks on future CO_2 concentrations and climate.
- Climate-carbon cycle feedbacks are highly uncertain and potentially large.
- Prediction of feedbacks requires knowledge of mechanisms connecting carbon and nutrients with the climate system.

Objectives

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Reduce the range of uncertainty in climate predictions by improving the model representation of feedbacks through comparisons with contemporary observations.

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Objective 2

Develop a freely available, user extensible climate-carbon cycle benchmarking system based upon evaluation criteria and metrics agreed upon by the international modeling community.

Feedback Analysis

- Friedlingstein et al. (2003, 2006) defined the climate-induced change in atmospheric CO$_2$ in terms of the change due to direct addition of CO$_2$,

  $$\Delta C_A^c = \frac{1}{1-g}\Delta C_A^u, \tag{1}$$

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where α is the climate sensitivity to CO_2 in K ppm^{-1}.
- The change in land carbon storage,
$$\Delta C_L^c = \beta_L \Delta \mathrm{CO}_2^c + \gamma_L \Delta T^c, \tag{3}$$
where β_L is the sensitivity to the change in CO_2, and γ_L is the sensitivity to climate change.

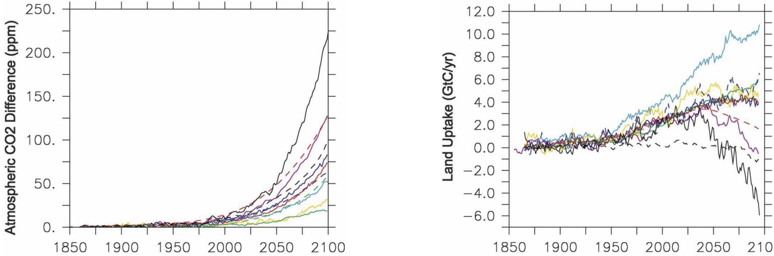
C^{4}MIP Results

Table: Climate-carbon cycle feedback gain, g, along with component sensitivities calculated at year 2100 for the 11 C^{4}MIP models. From Friedlingstein et al. (2006, Table 3).

Model	α K ppm^{-1}	β_L GtC ppm^{-1}	β_O GtC ppm^{-1}	γ_L GtC K^{-1}	γ_O GtC K^{-1}	g Gain
HadCM3LC	0.0066	1.3	0.8	−177	−24	0.31
IPSL-CM2C	0.0065	1.6	1.6	−98	−30	0.15
IPSL-CM4-LOOP	0.0072	1.3	1.1	−20	−16	0.06
CSM-1	0.0038	1.1	0.9	−23	−17	0.04
MPI	0.0082	1.4	1.1	−65	−22	0.20
LLNL	0.0068	2.8	0.9	−70	−14	0.10
FRCGC	0.0059	1.2	1.2	−112	−46	0.21
UMD	0.0056	0.2	1.5	−40	−67	0.14
UVic-2.7	0.0063	1.2	1.1	−98	−43	0.20
CLIMBER	0.0053	1.1	0.9	−57	−22	0.10
BERN-CC	0.0061	1.6	1.3	−105	−39	0.13
Average	0.0061	1.35	1.13	−79	−30	0.15

The 11 C^{4}MIP models varied by a factor of

- 8 in the gain of the carbon cycle feedback (g),
- 9 in the climate sensitivity of land storage (γ_L), and
- 14 in the concentration sensitivity of land storage (β_L).



Spread in the projected atmospheric CO_2 increase due to feedbacks (left) and total land carbon uptake (right) from 11 models participating in the C^{4}MIP Experiment. From Friedlingstein et al. (2006, Figure 1).

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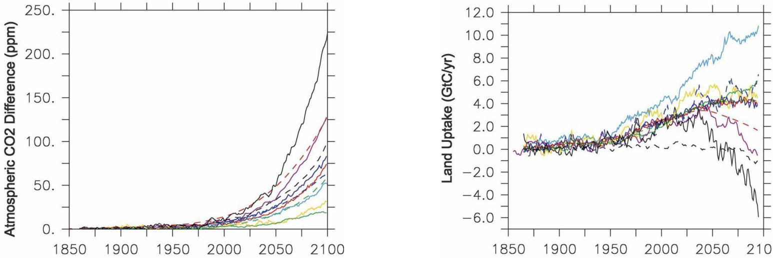

Spread in the projected atmospheric CO$_2$ increase due to feedbacks (left) and total land carbon uptake (right) from 11 models participating in the C^{4}MIP Experiment. From Friedlingstein et al. (2006, Figure 1).

No comparisons were made to observations.
This is the next crucial step for reducing uncertainties!

Reducing Uncertainties Using Observations

To reduce feedback uncertainties using contemporary observations,

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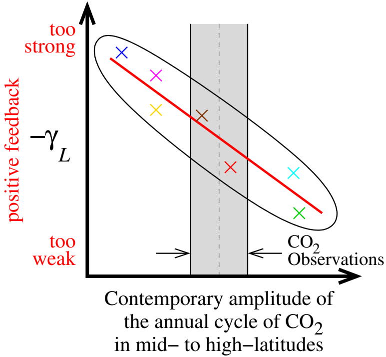
Reducing Uncertainties Using Observations

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.

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

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

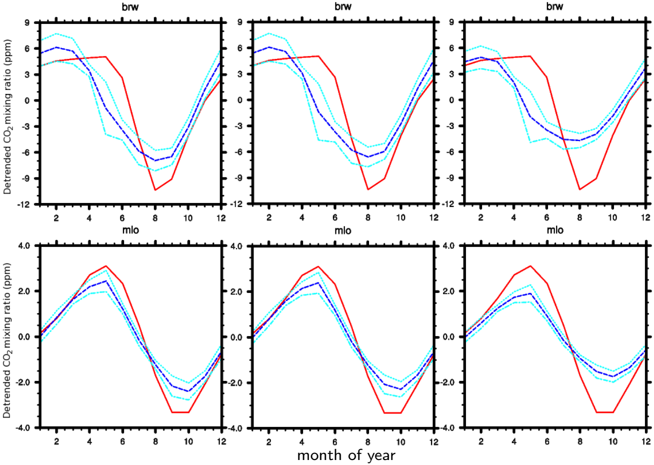
$Q_{10} = 1.5$ $Q_{10} = 2.0$ $Q_{10} = 3.0$

Barrow (BRW)

71.32° N, -156.61° E

Mauna Loa (MLO)

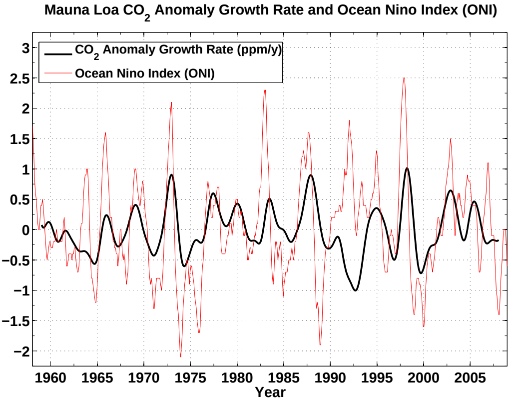
19.54° N, -155.58° E



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

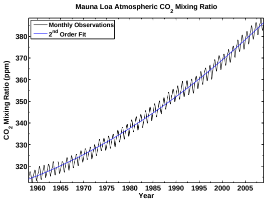
Hypothesis 2 – *Interannual to Decadal Time Scale*

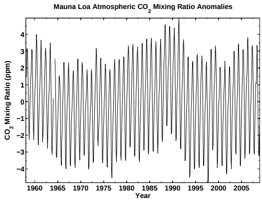
The relationship between El Niño-Southern Oscillation (ENSO) and observed CO_2 anomalies at Mauna Loa may be exploited to evaluate ocean and terrestrial model responses.

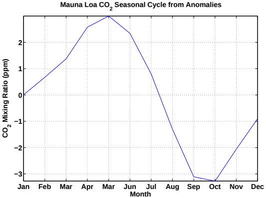


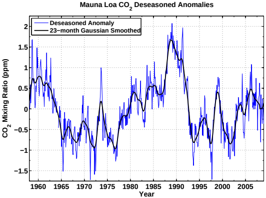
CO_2 Dependence on El Niño-Southern Oscillation (ENSO)

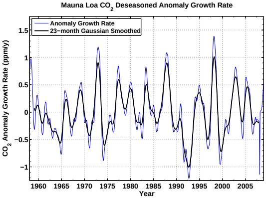
- Keeling and Revelle (1985) described a shutdown in upwelling and biological activity during El Niño years, resulting in a shutdown of CO_2 out-gassing.
- Many others have confirmed this response, including Rayner et al., Feeley et al., Baker et al., and others.
- They suggested the deficiency in CO_2 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.

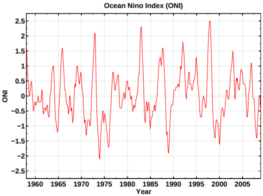

Mauna Loa Atmospheric CO$_2$ Mixing Ratio


Mauna Loa Atmospheric CO$_2$ Mixing Ratio Anomalies

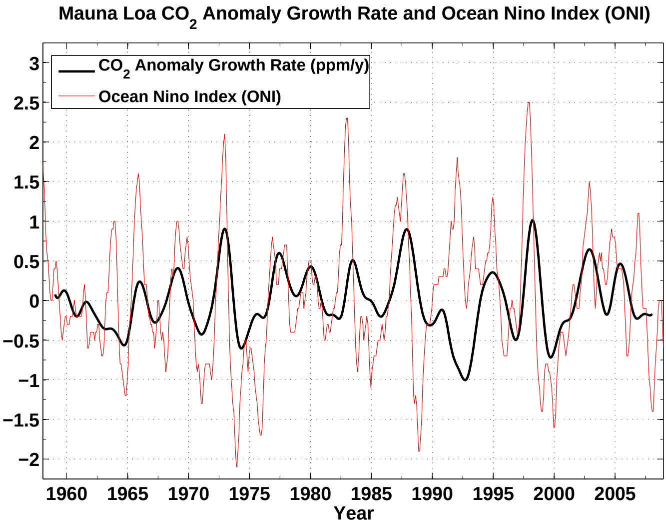

Mauna Loa CO$_2$ Seasonal Cycle from Anomalies


Mauna Loa CO$_2$ Deseasoned Anomalies


Mauna Loa CO$_2$ Deseasoned Anomaly Growth Rate


Ocean Nino Index (ONI)

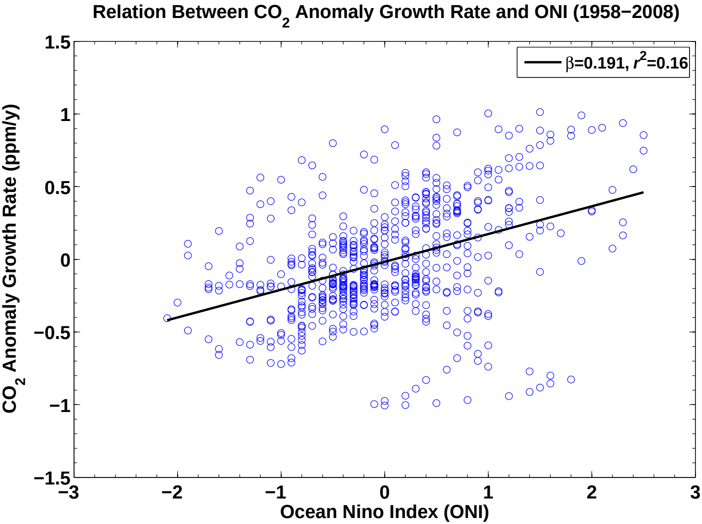
CO_2 Anomaly Growth Rate and Ocean Niño Index



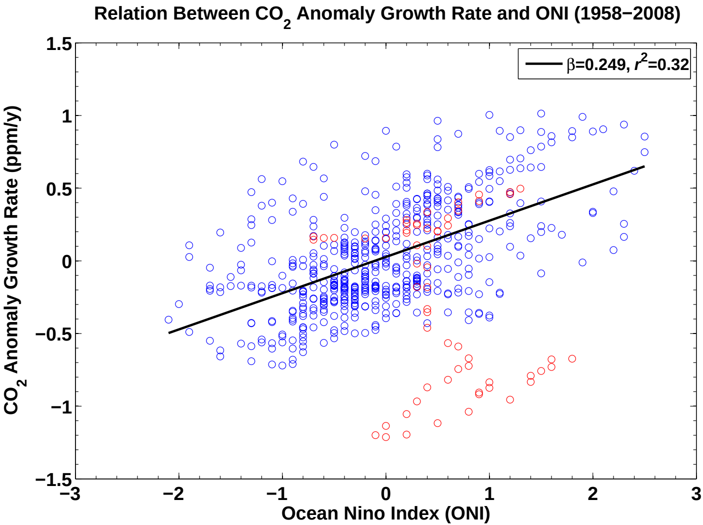
Mount Pinatubo Eruption

- 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

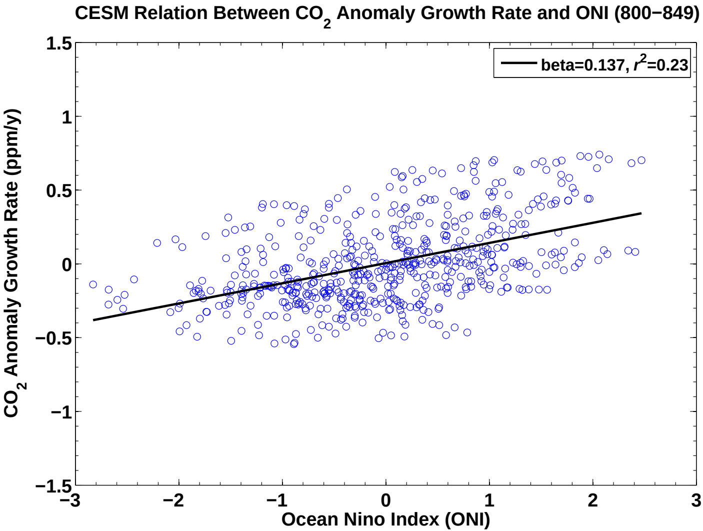
Relation Between CO_2 Anomaly Growth Rate and ONI



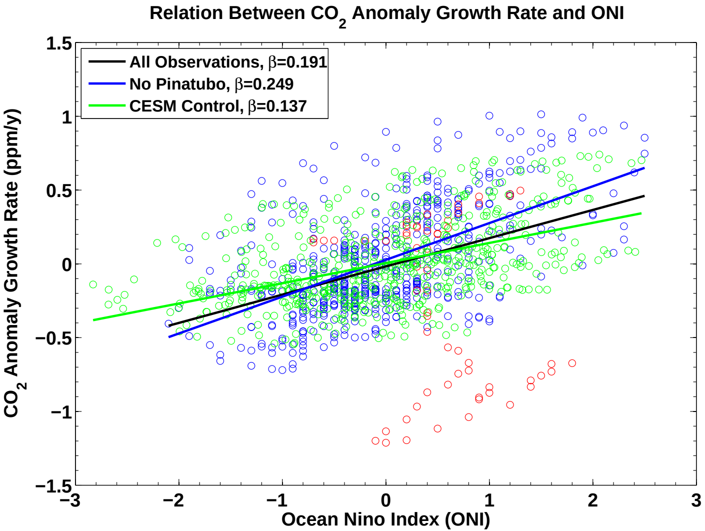
Relation Without 1991–1995 (Pinatubo Period)



Community Earth System Model (CESM) Control Run

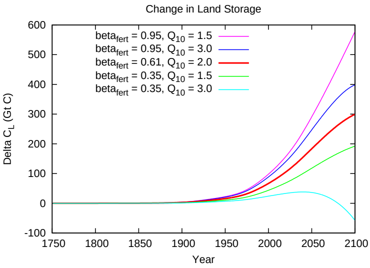


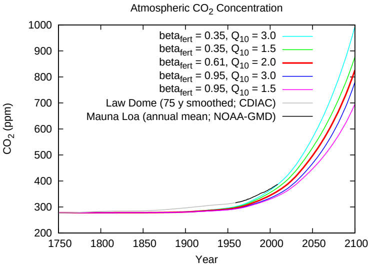
CESM vs. Observations



Hypothesis 3 – *Decadal to Centennial Time Scale*

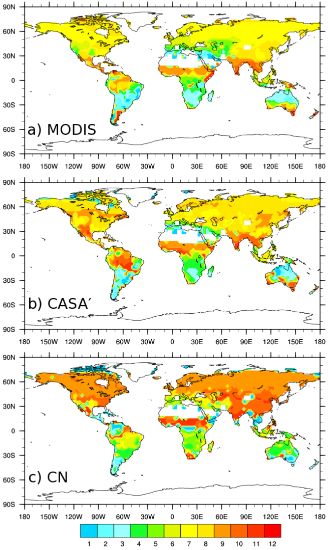
Models with smaller estimates of net terrestrial carbon uptake during the 19th and 20th centuries will have stronger positive climate-carbon cycle feedbacks.





- The sensitivity of ecosystem respiration to temperature may be too high (γ_L too negative), leading to excessive carbon losses.
- The sensitivity of carbon storage to elevated levels of CO_2 may be too low (β_L too small), limiting the magnitude of carbon sinks.

- Prior work has shown the utility of confronting models with measurements.
- The Carbon-Land Model Intercomparison Project (C-LAMP) compared two terrestrial biosphere models with best-available satellite- and ground-based observations (Randerson et al., 2009; Hoffman et al., 2008).
- Comparisons of C-LAMP model results with *in situ* observations demonstrate the inability of models to capture the seasonality of CO_2 in the Amazon Basin.



Month of Maximum LAI

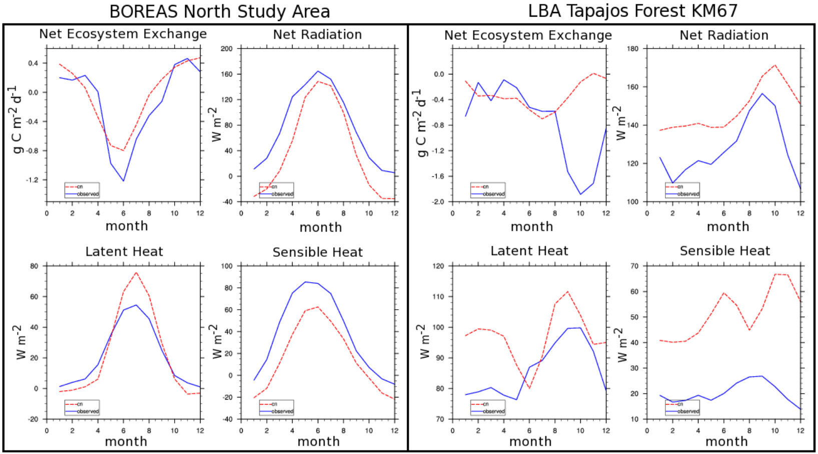


Figure: CLM3-CN model results from C-LAMP comparisons for the BOREAS North Study Area (left) and LBA Tapajós Forest (right) sites (Hoffman et al., 2007). Model results are in red and observations are in blue.

Conclusions and Future Work

- Observations of contemporary variability may be useful for constraining predictions of future trends over longer time scales within Earth System Models.
- Atmospheric CO_2 is an integrator of terrestrial and ocean fluxes with valuable information for constraining model behavior over a wide range of time scales (see also Cadule et al., 2010).
- An International Land Model Benchmarking (ILAMB) activity could use such model evaluation criteria in a freely available diagnostics package.
- ILAMB Meeting will be held at the UC-Irvine in January to begin community definition of such a system.

Questions?

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