CAVEAT

This talk was presented at a symposium of the Royal Society on Feb 23 2010. Since the presentation we have discovered some problems with the underlying simulation. While this does not change the underlying conclusion of the ability of current observations to constrain the future response of the terrestrial biosphere, the calculations themselves should be regarded as displaying the sensitivity of the terrestrial biosphere to CO_2 rather than to joint changes in CO_2 and climate.

Uncertainties in the relationship between concentrations and emissions

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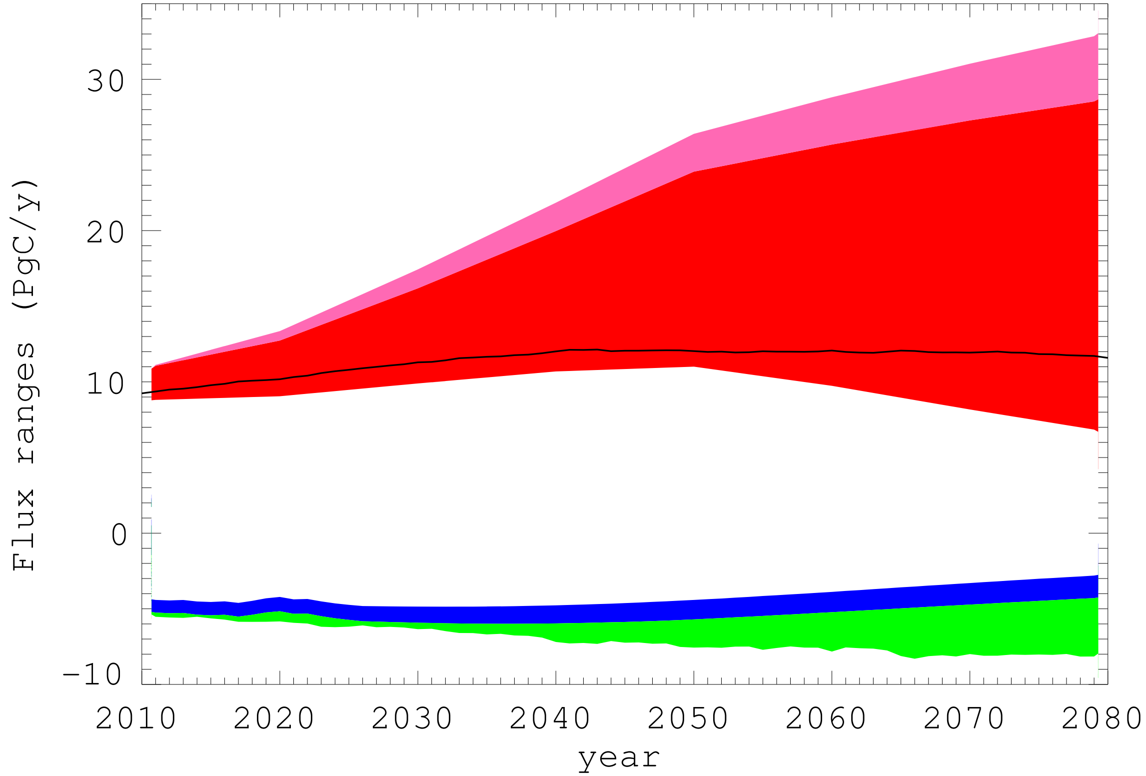
"It's only a model"

(Monty Python and the Holy Grail)

Outline

- Uncertainties in the carbon cycle;
- A simple predictive model and its uncertainty;
- Confronting the model with data;
- Consequences for research and policy.

Motivation



Ranges of global CO_2 fluxes. Red = anthropogenic, blue = ocean, green = land, pink = other vulnerabilities from Raupach et al., Tellus, 2010. Uptakes from IPCC-2007 Fig. 10.21. Black line shows emission scenario.

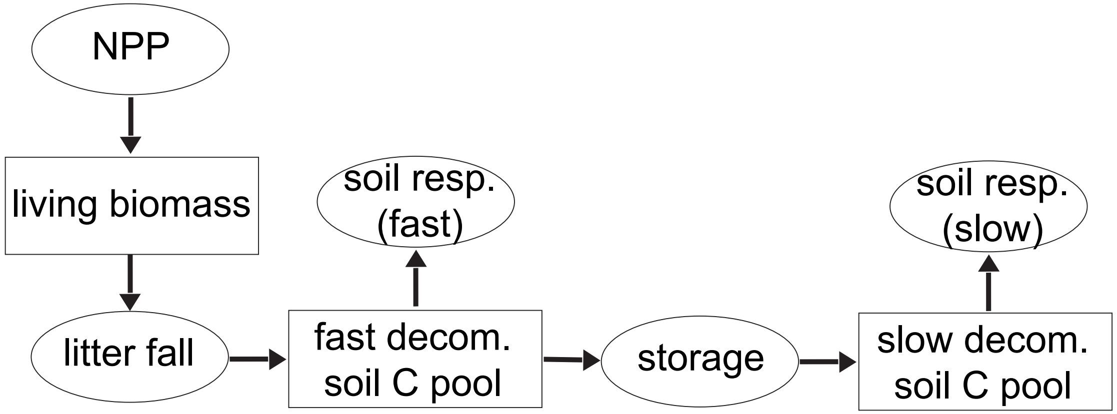
Sources of Terrestrial Model Uncertainty

- Different models include different processes;
- Equivalent processes are described with different equations;
- There are many uncertain parameters in these models.

Exploring Parameter Uncertainty

- Write simple box model of terrestrial carbon cycle
- Climate model → global model → simple model;
- Calculate sensitivities of future uptake to inputs;
- Calculate uncertainty of future uptake as function of uncertainty in input parameters;
- Assimilate current data and study reduced uncertainty on future uptakes.

Simple Model



$$\begin{aligned}\mathrm{NetUptake} = \quad & \mathbf{Production} - (1-\mathbf{K}) \times \mathbf{LitterDecomposition} \\ & -\mathrm{SoilOutgassing}\end{aligned}$$

$$\mathrm{SoilOutgassing} \propto \mathrm{SoilPool} \times \omega^{\kappa} \mathbf{Q}_{10}^{T_a/10}$$

where ω = soil moisture and T_a = air temperature.

$$\frac{\partial \mathrm{SoilPool}}{\partial t} = \mathbf{K} \times \mathbf{LitterDecomposition} - \mathrm{SoilOutgassing}$$

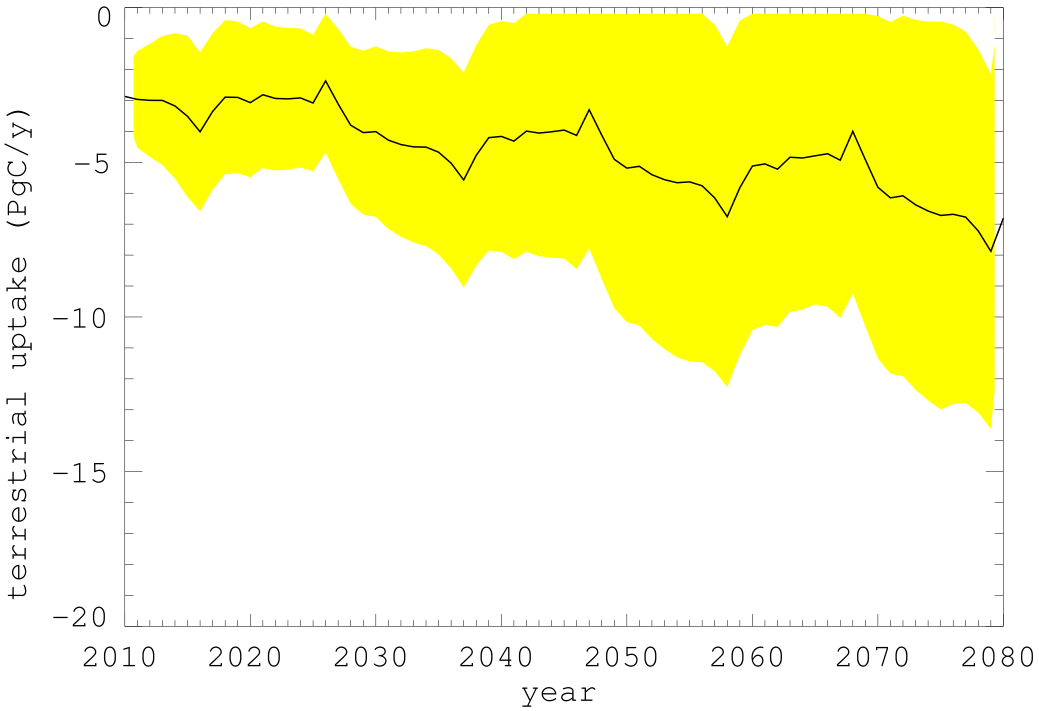
Technical Details

- Need derivatives of outputs of simple model and global model with respect to their inputs;
- Simple model can be differentiated by hand;
- Global model differentiated by the software “Transformation of Algorithms in FORTRAN” `http://www.fastopt.com`.

$$\text{Uncertainty}(\text{uptake}) = J \times \text{Uncertainty}(\text{parameters}) \times J^T$$

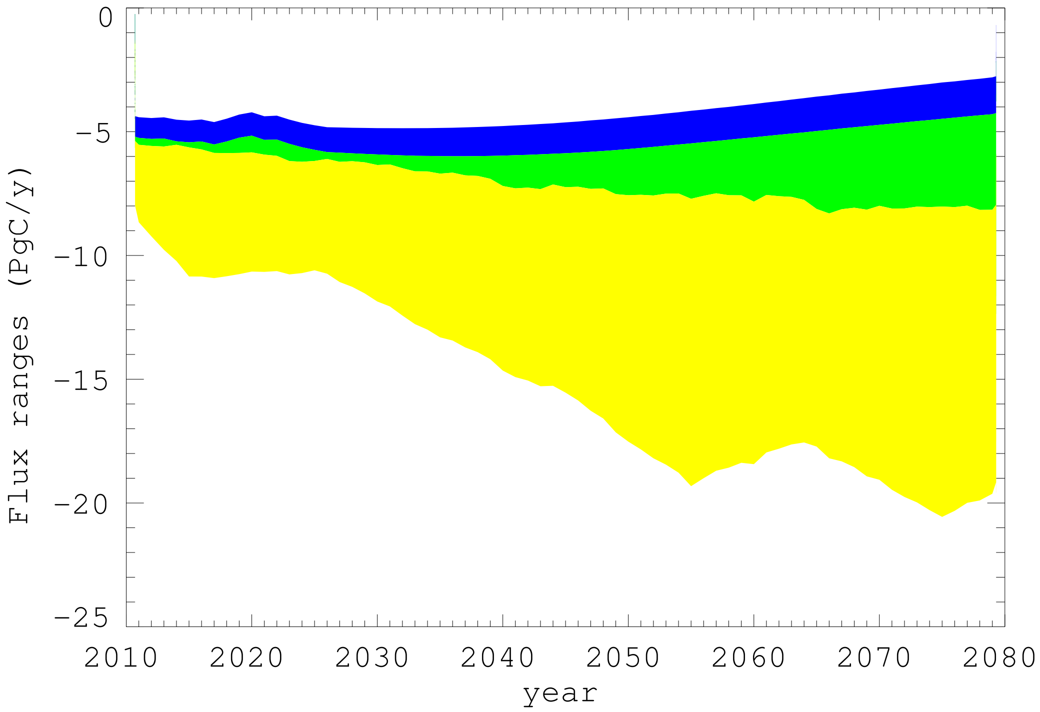
where J is derivative and T is transpose.

Uptake from Prior Model



Terrestrial uptake from prior model and its 90% confidence interval. Uptake is anchored at its 2000–2010 value.

Comparison with Other Uncertainties



Range of uptakes, blue = ocean, green = land from IPCC models. The yellow band represents the 90% confidence interval of the uncertainty in the simple model.

What is responsible for the uncertainty?

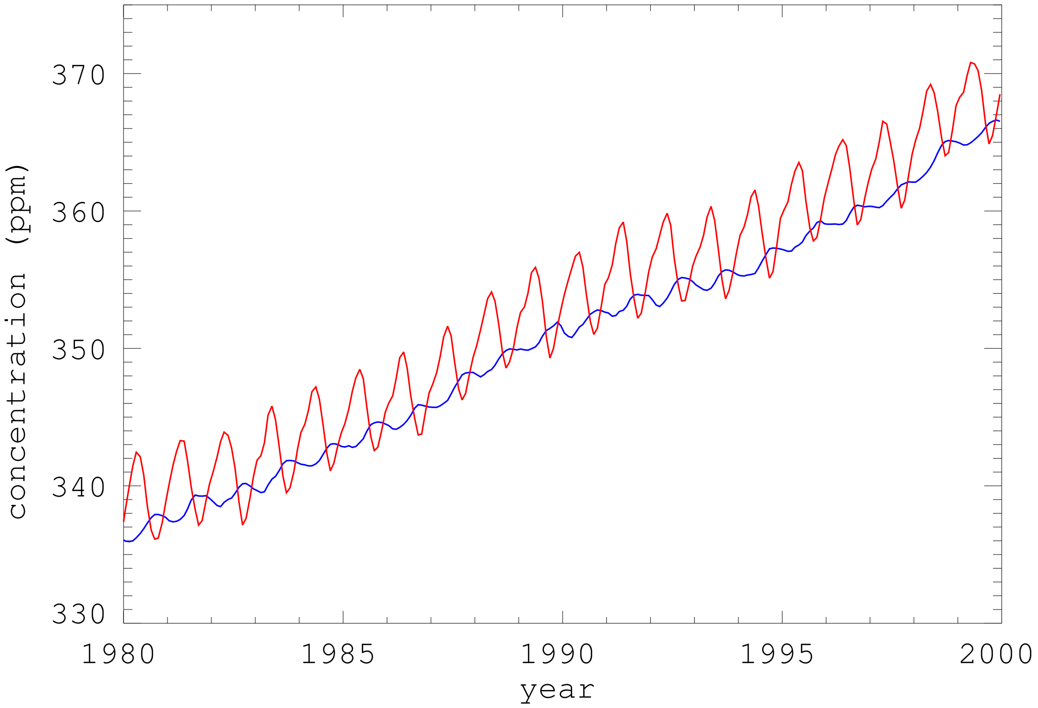
$$\mathrm{SoilOutgassing} \propto \mathrm{SoilPool} \times \omega^{\kappa} \mathbf{Q}_{10}^{T_a/10}$$

where ω = soil moisture and T_a = air temperature.

$$\frac{\partial \mathrm{SoilPool}}{\partial t} = \mathbf{K} \times \mathbf{LitterDecomposition} - \mathrm{SoilOutgassing}$$

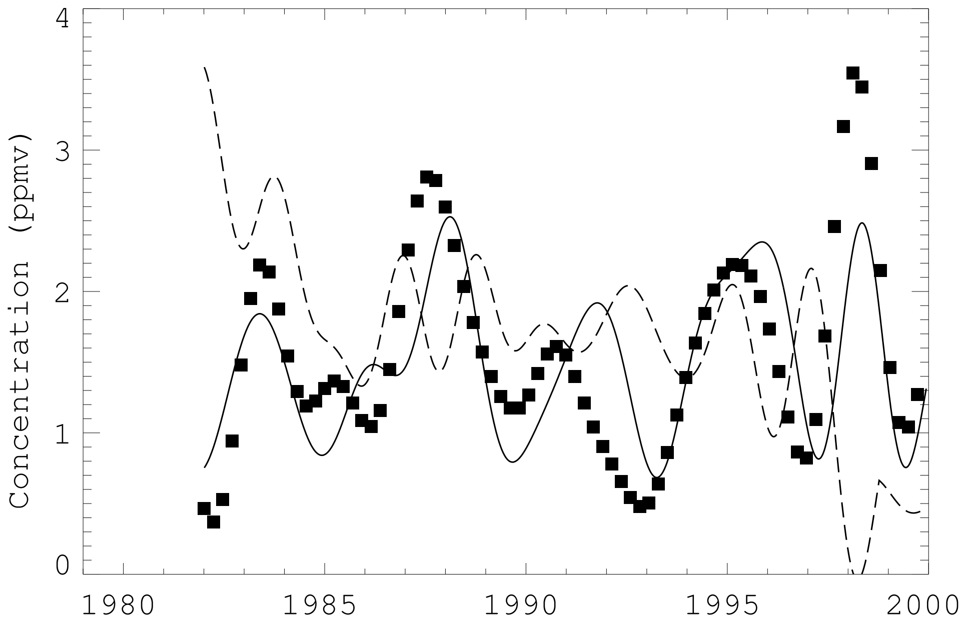
- We can check which of the 59 parameters of the simple and global models is most responsible for the uncertainty;
- $\mathbf{K}$ and $\mathbf{Q_{10}}$ are the largest contributors.

Examples of Atmospheric Concentration Data



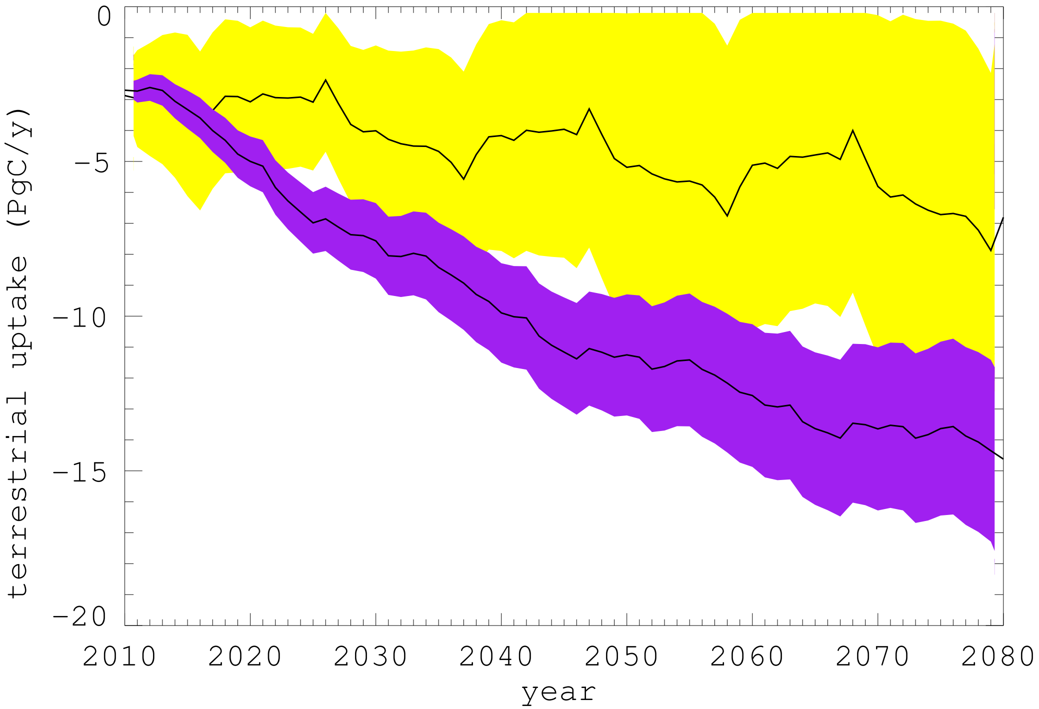
Timeseries of CO_2 concentration from Mauna Loa Hawaii and South Pole. Note the trend, seasonal cycle at Hawaii and interannual changes in the growth rate.

Fitting Atmospheric Growth Rate



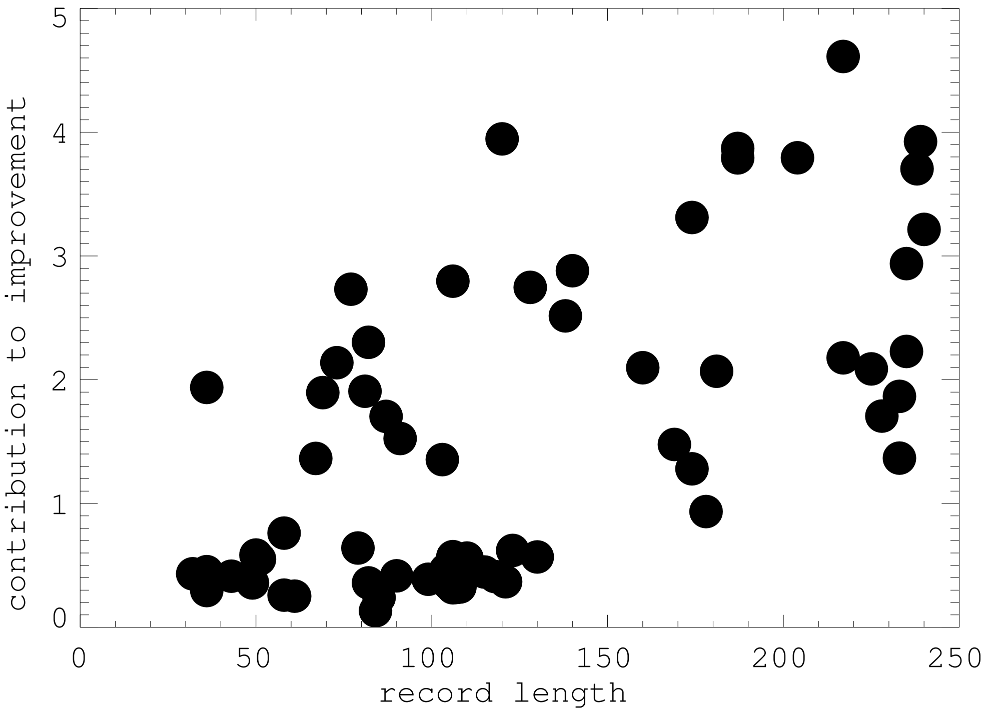
Smoothed global growth rate, squares = obs, dashed = prior, solid = optimised. Note the low-growth events in the observed and optimised.

Result with Optimised Params



Mean and 90% confidence interval for the model with initial (yellow) and optimised (purple) parameters. Black lines show the mean in either case.

Which Data Improved the Estimate?



- Use singular value decomposition to assess contribution of each station to reducing uncertainty in $\mathbf{K}$;

- Stations have from 32 to 240 measurements so normalize contribution by station length;

Policy Implications

- Current data may suggest a greater role for the terrestrial biosphere in removing future CO_2 than previously thought;
- This suggests increased importance in forest protection;
- Notwithstanding this, the clearest point of intervention remains reduction of fossil fuel emissions.

Implications for Research

- We have methodologies to constrain the future evolution of the carbon cycle using current data;

- Long-term observations not only monitor for surprises but directly address policy questions;

- Soil processes remain the largest source of uncertainty over future uptake.