The impact of CO₂ fertilization on the global terrestrial carbon cycle and interannual changes in CO₂ studied through a carbon cycle data assimilation system

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Introduction

The terrestrial carbon cycle has the potential to provide major feedbacks on climate change, but major uncertainties in the spatial and temporal pattern of these feedbacks lasts. To probe the behavior of the current carbon cycle and clarify those uncertainties, CCDAS has been developed (Rayner *et al*., 2005; Scholze *et al*., 2007).

Several previous modelling studies of terrestrial ecosystems and atmospheric CO_2 observations have come to the conclusion that there has been an increased terrestrial carbon uptake from the 1980s to the 1990s, and this has been at least partially caused by the terrestrial carbon cycle' s response to external forcing (e.g. Keeling *et al*., 1996; Nemani *et al*., 2003; Myneni *et al*., 1997). Possible causes that have been cited are enhanced photosynthesis through rising atmospheric CO_2 or extended growing season through increasing temperatures, although their effects might not necessarily be positive all the time.

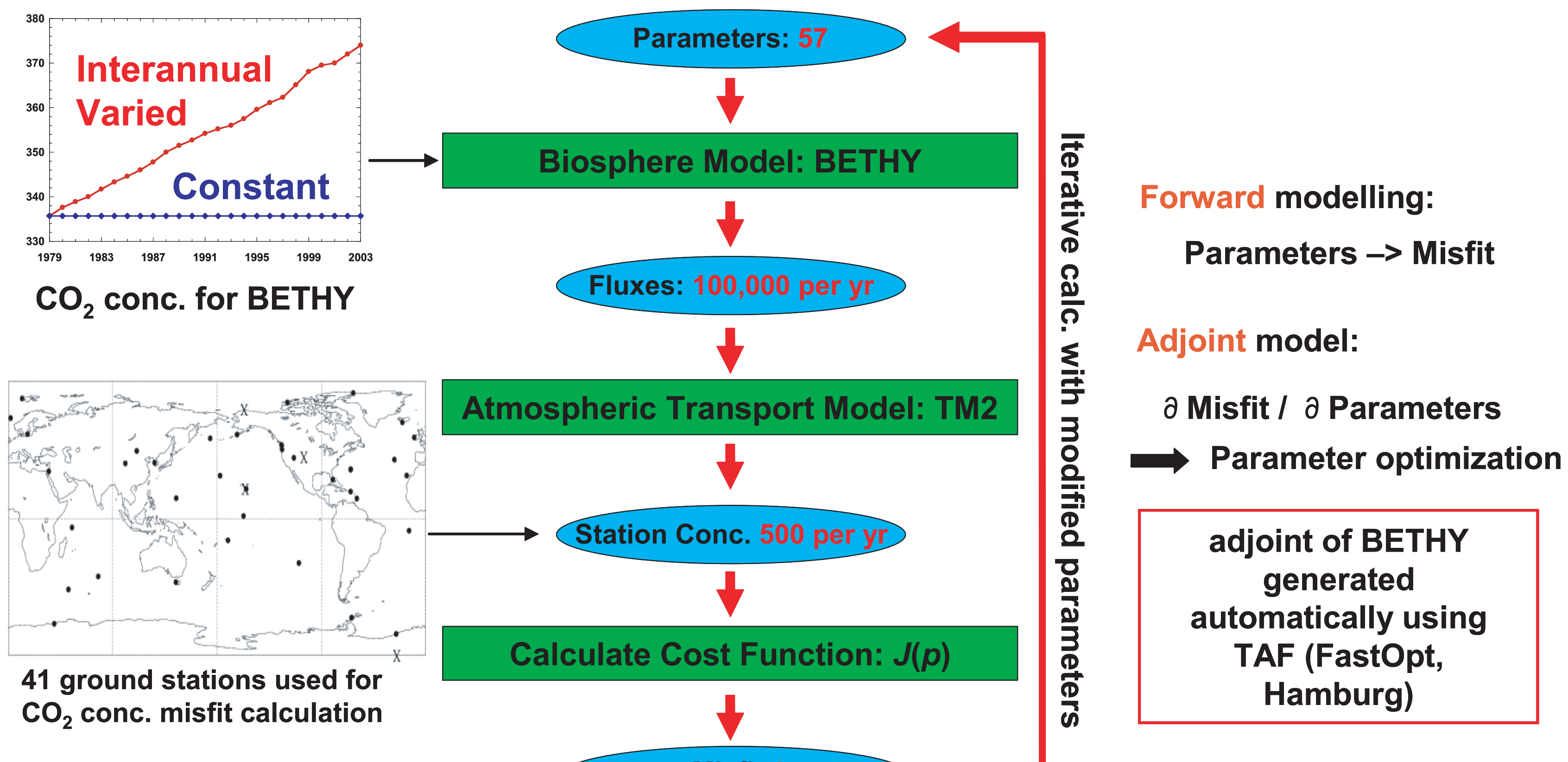
For this study, the CCDAS is modified to incorporate the effect of CO_2 fertilization and by allowing interannual changes of CO_2 concentration to impact on the photosynthesis scheme of the terrestrial biosphere model. With the optimized parameters and the optimized terrestrial carbon fluxes, this presentation shows the preliminary results of ongoing research and attmepts to extract some insights in terms of the sensitivity of terrestrial carbon cycle to increases in atmospheric CO_2 during those two decades, and also tries to set the direction of next step of this study.

Model descriptions

Carbon Cycle Data Assimilation System (CCDAS)

CCDAS combines the terrestrial biosphere model BETHY (Biosphere Energy Transfer Hydrology Scheme) and the atmospheric transport model TM2, and is capable of both forward and inverse modeling of terrestrial carbon fluxes. Optimal parameters of BETHY are obtained by fitting against atmospheric CO_2 observation at ground stations. The terrestrial CO_2 fluxes are calculated by BETHY using satellite-derived fAPAR and prescribed climate data on a 2° x 2° gridded cells, and are then transported to the remote monitoring sites by TM2 on a 7.8° x 10° grid resulting in simulated atmospheric CO_2 concentrations. The differences in atmospheric CO_2 concentration between simulation and observations are minimized by iterative calculations of terrestrial fluxes with newly assigned parameters, based on the derivative of a "cost function *J*(*p*)" with respect to the model parameters (Figure 1).

In this study, constant CO_2 concentration (Const) and interannually varied CO_2 concentration (IAV) over the optimization period are given to CCDAS as forcing to the photosynthesis process in BETHY respectively. Results are compared to investigate the CO_2 fertilization effect on the fluctuation of atmospheric CO_2 concentration.



CO_2 conc. for BETHY

41 ground stations used for CO_2 conc. misfit calculation

Parameters: 57

Biosphere Model: BETHY

Fluxes: 100,000 per yr

Atmospheric Transport Model: TM2

Station Conc. 500 per yr

Calculate Cost Function: *J*(*p*)

Misfit 1

Iterative calc. with modified parameters

Forward modelling:

Parameters –> Misfit

Adjoint model:

∂ Misfit / ∂ Parameters

➡ Parameter optimization

adjoint of BETHY generated automatically using TAF (FastOpt, Hamburg)

Fig. 1. A schematic diagram of the Carbon Cycle Data Assimlation System

Cost Function (*J*(*p*))

$$J(\vec{p}) = \frac{1}{2}[\vec{p} - \vec{p}_0]^T \mathbf{C}_{p_0}^{-1} [\vec{p} - \vec{p}_0] + \frac{1}{2}[\vec{y}(\vec{p}) - \vec{y}_0]^T \mathbf{C}_{y_0}^{-1} [\vec{y}(\vec{p}) - \vec{y}_0] \tag{1}$$

where, *J*(*p*) is cost function of an optimized parameter set *p*. p_0 is a priori parameter set. Cp_o shows the uncertainty for the prior parameter *p* in the form of covariance matrices. *y*(*p*) is CO_2 concentration calculated by parameter *p*. y_0 is observation of CO_2 concentraion. Cy_0 expresses the uncertainty for the observations y_0. T and -1 express the transpose and inverse of matrices.

Acknowledgements

This study was supported by the Postdoctoral Fellowships for Research Abroad, Japan Society for the Promotion of Science, Japan, and the QUEST project, Natural Environment Reserach Council, U.K.

Preliminary results

Global carbon dynamics

Spatial distribution of the difference in NEPs shows that the fertilization effects on terrestrial carbon sequestration is largely positive in forest ecosystems, such as Tropical, Temperate and Boreal forests, and largely negative in non-forest dominated ecosystem, such as Boreal tundra and Tropical savanna (Figure 2). Difference in global averaged NEP varies within a range of -0.8 to 0.8 Pg C yr^{-1}.

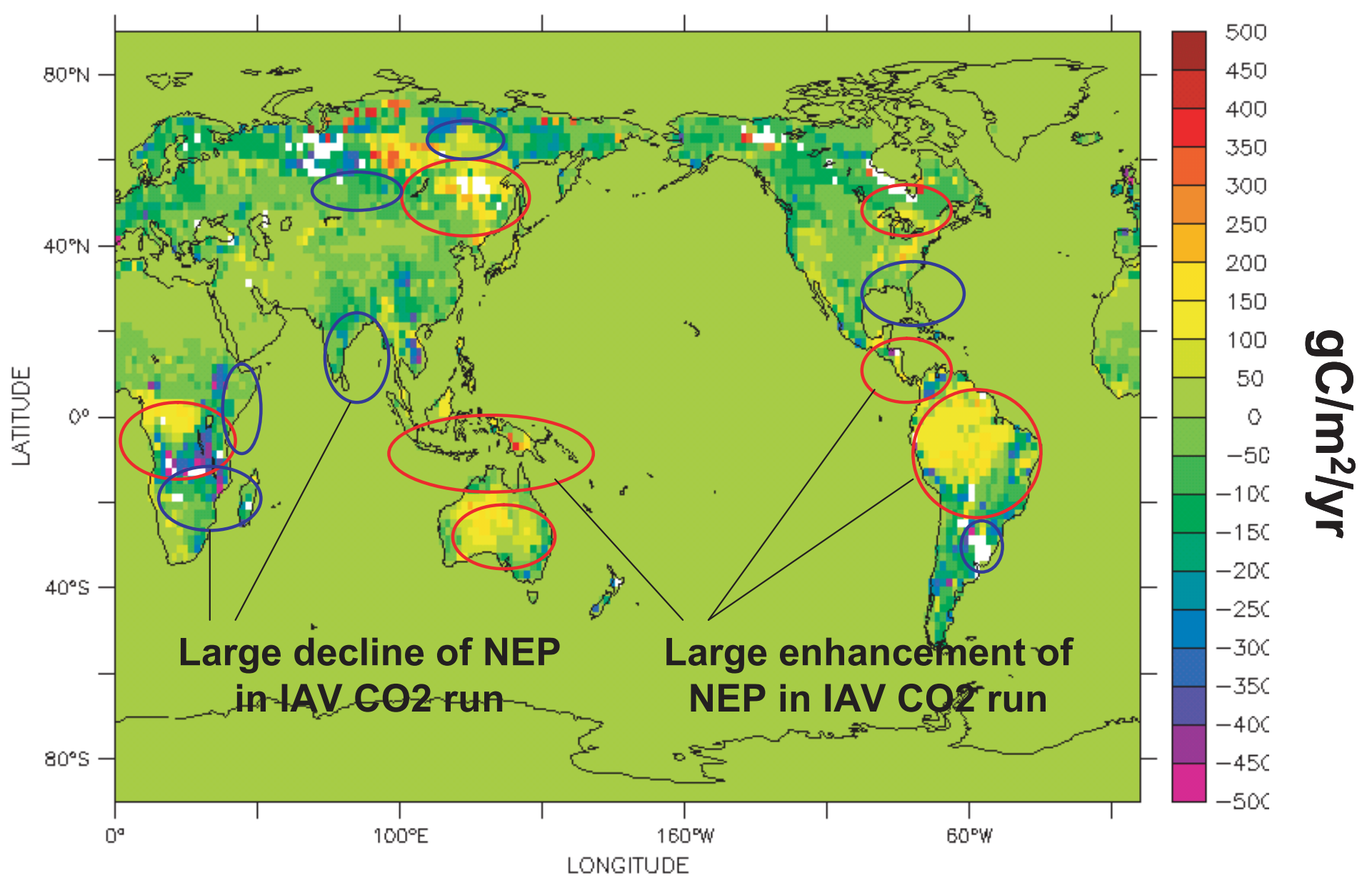


Figure 2. Difference in NEP simulation between with IAV CO_2 run and with Const CO_2 run (averaged for 1979-2003).

Growth rates in global averaged CO_2 concentration show that both simulated values move along with observation moderately, and those increase slightly with time series (Figure 3). On the other hand, the difference between two simulations is small. The amplitude of seasonality in atmospheric CO_2 concentration, calculated as the difference between maximum and minimum CO_2 concentration for each year at five observational sites (Point Barrow, Cold Bay, Mauna Loa, Samoa, and South Pole), does not show large differences in that long-term trends among the two simulations. Thus these two facts could suggest smaller significance of fertilization effect on seasonality of CO_2 concentration.

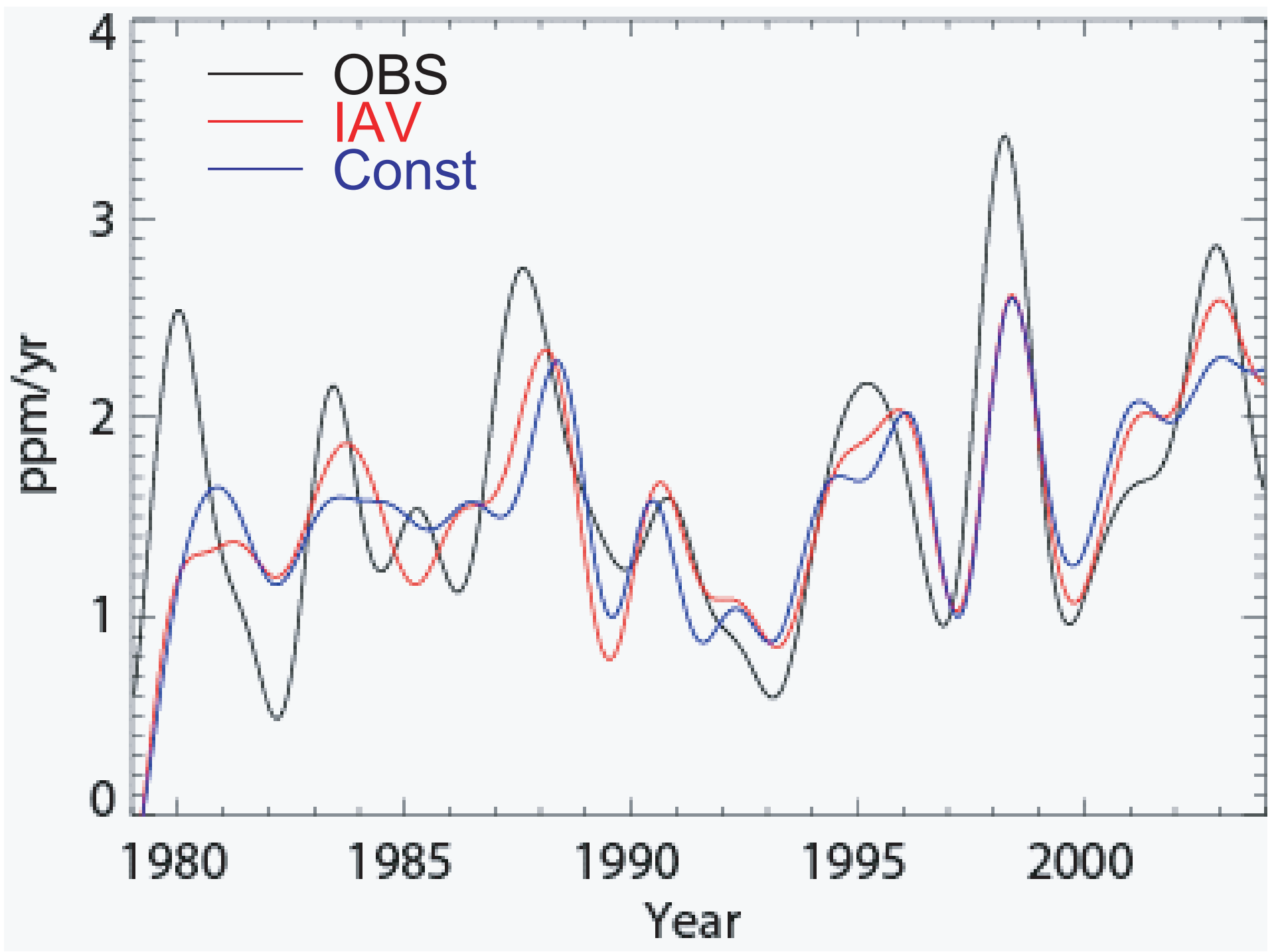


Figure 3. Growth rates in global averaged CO_2 concentration from observation (OBS) and the runs with interannually varied CO_2 conc. (IAV) and constant CO_2 conc. (Const). Data are calculated as averaged with Mauna Loa and South Pole sites' data.

Parameter optimization

Cost function value against CO_2 concentration is slightly larger in IAV-CO_2 run than that in Const-CO_2 run (Table 1), and this might indicate that CO_2 fertilization effect did not work to reduce the gap between observational CO_2 and simulated CO_2 effectively. On the other hand, however, gradient values are still high and this indicates that parameter optimizations have not been done properly and there seems to be multiple peaks in the field of cost function, which cause the diffculty obtaining the rightly minimized cost functions. Indeed, in this study, identical atmospheric CO_2 concentration is assigned for global terrestrial ecosystems during a year, although there should be seasonality and latitudinal trends in that. Further research with more precise forcing settings in seasonal and spatial changes of CO_2 forcing, could give more solid information.

Table 1. Cost function and gradient values of optimized parameters for the runs with constant CO_2 conc. (Const-CO_2) and interannually varied CO_2 conc. (IAV-CO_2)

	Cost-C	Cost-P	Cost-C+P	Gradient
Const-CO_2	5759.7	805.0	6564.7	23887
IAV-CO_2	6029.5	726.1	6755.6	12525

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