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 last. To probe the behavior of the current carbon cycle and clarify those uncertainties, CCADAS has been developed (Rayner et al., 2005; Scholze et al., 2007).

Several previous modelling studies of terrestrial ecosystems and atmospheric CO₂ 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; Myrdal et al., 1997). Possible causes that have been cited are enhanced photosynthesis through rising atmospheric CO₂ and/or extended growing season through increasing temperatures, although their effects might not necessarily be positive all the time.

For this study, the CCADAS is modified to incorporate the effect of CO₂ fertilization and by allowing interannual changes of CO₂ 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 attempts to extract some insights in terms of the seasonality of the terrestrial carbon cycle to increasing atmospheric CO₂ during those two decades, and also tries to set the direction of next step of this study.

Model descriptions

Carbon Cycle Data Assimilation System (CCADAS)

CCADAS 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. Optimized parameters of BETHY are obtained by fitting against atmospheric CO₂ observation at ground stations. The terrestrial CO₂ fluxes are calculated by BETHY using satellite-derived JAFAR and prescribed climate data on a 2° x 2° grided cells, and are then transported to the remote monitoring sites by TM2 on a 7.8° x 10° grid resulting in simulated atmospheric CO₂ concentrations. The differences in atmospheric CO₂ 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)($)” with respect to the model parameters (Figure 1).

In this study, constant CO₂ concentration (Const) and interannually varied CO₂ concentration (IAV) over the optimization period are given to CCADAS as forcing to the photosynthesis process in BETHY respectively. Results are compared to investigate the CO₂ fertilization effect on the fluctuation of atmospheric CO₂ concentration.

Cost Function (J(p))

\[ J(p) = \frac{1}{2} \left[ \frac{\hat{y} - \hat{y}}{\sigma_y} \right] C_y^{-1} \left[ \frac{\hat{y} - \hat{y}}{\sigma_y} \right] + \frac{1}{2} \left[ \frac{\hat{y} - \hat{y}}{\sigma_y} \right] C_y^{-1} \left[ \frac{\hat{y} - \hat{y}}{\sigma_y} \right] \]

where, J(p) is cost function of an optimized parameter set p. \( \sigma_y \) is a priori parameter set. \( \sigma_y \) shows the uncertainty for the prior parameter set. \( \sigma_y \) is the form of covariance matrices. \( \frac{\hat{y} - \hat{y}}{\sigma_y} \) is CO₂ concentration calculated by parameter p. \( \sigma_y \) is observation of CO₂ concentration. \( \frac{\hat{y} - \hat{y}}{\sigma_y} \) expresses the uncertainty for the observations \( \frac{\hat{y} - \hat{y}}{\sigma_y} \) and - I express the transpose and inverse of matrices.

Acknowledgements

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Preliminary results

Global carbon dynamics

Spatial distribution of the difference in NEP 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 ecosystems, 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 CO₂ run and with Const CO₂ run (averaged for 1979-2003).

Growth rates in global averaged CO₂ concentration show that both simulated values move along with observations 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 CO₂ concentration, calculated as the difference between maximum and minimum CO₂ 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 CO₂ concentration.

Figure 3. Growth rates in global averaged CO₂ concentration from observation (OBS) and the runs with interannually varied CO₂ conc. (IAV) and constant CO₂ conc. (Const). Data are calculated as averaged with Mauna Loa and South Pole sites’ data.

Parameter optimization

Cost function value against CO₂ concentration is slightly larger in IAV-CO₂ run than that in Const-CO₂ run (Table 1), and this might indicate that CO₂ fertilization effect did not work to reduce the gap between observational CO₂ and simulated CO₂ 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 difficulty obtaining the right minimized cost functions. Indeed, in this study, identical atmospheric CO₂ 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 CO₂ forcing, could give more solid information.

Table 1. Cost function and gradient values of optimized parameters for the runs with constant CO₂ conc. (Const-CO₂) and interannually varied CO₂ conc. (IAV-CO₂)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Const-CO₂</th>
<th>Cost-P</th>
<th>Cost-C+P</th>
<th>Gradient</th>
</tr>
</thead>
<tbody>
<tr>
<td>Const-CO₂</td>
<td>5759.7</td>
<td>805.0</td>
<td>6564.7</td>
<td>23887</td>
</tr>
<tr>
<td>IAV-CO₂</td>
<td>6029.5</td>
<td>726.1</td>
<td>6755.6</td>
<td>12525</td>
</tr>
</tbody>
</table>

References


