Simulation of the biospheric contribution to the seasonal cycle of atmospheric CO_2 by a physiologically based global biosphere model

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The seasonal cycle of atmospheric CO_2 mirrors –in particular on the northern hemisphere– the seasonal CO_2 uptake and release by the land biota. Furthermore, the amplitude of the seasonal cycle of atmospheric CO_2 shows a gradual increase over the time period 1958–1990. It has been suggested that this increase is related to changes in net photosynthetic uptake and respiratory release of CO_2, possibly induced by the rising CO_2 concentration of the atmosphere.

During photosynthesis CO_2 is assimilated into organic material and with some time lag it is released again to the atmosphere by heterotrophic respiration. Photosynthesis depends critically on the ambient CO_2 concentration whereas heterotrophic respiration does not depend on CO_2.

The possible contribution of the global land biosphere to the changes in the observed seasonal cycle of atmospheric CO_2 is explored by simulations with the global biosphere model SILVAN and the three dimensional atmospheric transport model TM2 (Keeling et al. 1989, Heimann 1995). The biosphere model has a spatial resolution of 0.5 degrees horizontally and considers potential vegetation. It is forced by monthly climate data, has a daily time step and generates a water balance internally. The most important model features are physiologically based schemes to determine net primary productivity (NPP) and phenology.

The standard version of the model is forced by the Cramer–Leemans climate database (Leemans and Cramer 1991). It predicts global and regional NPP and Net Ecosystem Production from which the TM2 generates seasonal cycles of atmospheric CO_2 concentrations comparing favourably to observations.

In three sensitivity experiments the biospheric carbon cycle model was forced with observed data:
Exp.1: increasing observed atmospheric CO_2–concentration from 310 in 1948 to 355 ppmv in 1992.
Exp.2: observed temperatures 1948–9292, fixed atmospheric CO_2–concentration (310ppmv).
Exp.3: observed atmospheric CO_2–concentration and temperature records 1948–1992.

The generated monthly net carbon flux data were transferred into the TM2. The TM2 then produced simulation results for particular locations, which we compared with observations. For the atmospheric transport we used always the same wind fields, those of the ECMWF–analyses for 1987.

All data, simulated and observed, have been detrended with the same algorithm, by subtracting a piecewise linear trend function.

We compared the simulation results with observed atmospheric CO_2 concentration data at Mauna Loa (19°32′ N, 155°35′ W, 3397m) (Keeling and Whorf 1994), which represent one of the longest records of monthly CO_2–concentration measurements and are, within limits, representative for the global mean.

The observed seasonal cycle results mainly from biospheric CO_2–exchanges (Keeling et al. 1989). The simulations with increasing CO_2 underestimate the seasonal cycle by about 20% and lag the observations by a month or less for March to August and somewhat more for the remainder of the year.

Minimal and maximal mean monthly CO_2 concentration annually attained at Mauna Loa

The observations show a decrease of the minima by 0.016 ± 0.0038 ppmv y^{-1} and an increase of the maxima by 0.018 ± 0.0046 ppmv y^{-1}. Bacastow et al. (1985) obtained for the period 1958–1982 a decrease of the minima by 0.020 ± 0.008 ppmv y^{-1} and an increase of the maxima by 0.013 ± 0.006 ppmv y^{-1}, however using a different detrending technique.

In the first experiment with solely increasing CO_2 concentration the decrease of the minima is 0.019 ± 0.00048 ppmv y^{-1} and the increase in the maxima 0.017 ± 0.00044 ppmv y^{-1}.

The simulation results of experiment two with constant CO_2 concentration and observed temperature forcing do not show any trend (0.0011 ± 0.0017 ppmv y^{-1} and -0.0018 ± 0.0014 ppmv y^{-1} respectively).

The results of the third experiment show again de– and increases: 0.016 ± 0.0018 ppmv y^{-1} and 0.015 ± 0.0013 ppmv y^{-1} respectively. Interestingly are the de– and increases in this case somewhat smaller than in the case with increasing CO_2 concentration only.

The temporal variation of the minima and maxima does not match the observations at Mauna Loa consistently. However, this might be a result of the missing precipitation and radiation anomalies and the usage of one year of wind fields only.

Relative amplitude of the seasonal cycle of atmospheric CO_2 concentration at Mauna Loa Generally, the relative amplitude, λ^j, of a year, j, is obtained by fitting the mean annual cycle to the seasonal cycle of the year j, thus minimizing: $\sum_{m=1}^{12} y_m^j - \lambda^j \bar{y}_m$, where the y_m^j define the seasonal cycle of the year j, and the $\bar{y}_m$'s represent the mean seasonal cycle. The mean seasonal cycle is different for each dataset of mean monthly CO_2 concentrations. This should however not affect the comparability of the trends in the amplitude. Fig. 1 depicts the relative amplitude of the seasonal cycle of the observed and simulated mean monthly CO_2 concentrations.

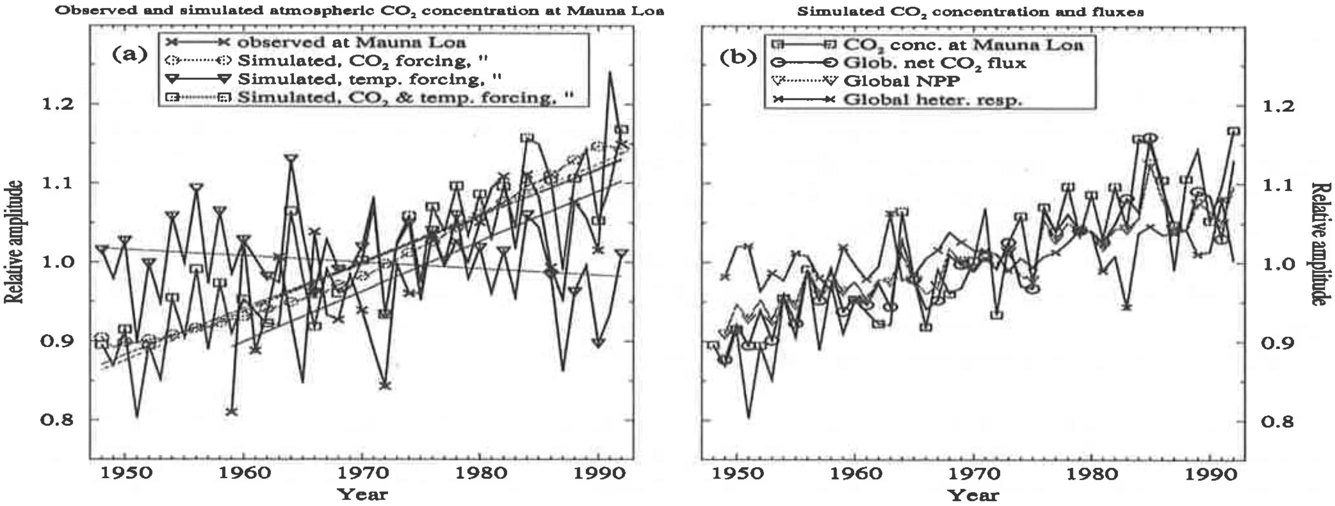

Figure 1: Relative amplitudes of (a) observed and simulated annual cycles of atmospheric CO_2 at Mauna Loa, (b) simulated annual cycles of atmospheric CO_2 at Mauna Loa, global net CO_2 flux, global NPP and global heterotrophic respiration.

The observations at Mauna Loa show an increase of 0.0064 ± 0.0012 units per year or 0.79% per year relative to the value of 1958. Bacastow et al. (1985) found an increase of 0.73% per year for 1958–1982 and Keeling et al. (1989) give 0.84% until 1985, again with a different detrending technique.

In experiment one an increase of 0.00062 ± 0.0017 per year is simulated. The results of the second experiment show an insignificant small negative trend (-0.00081 ± 0.0006 per year). The third simulation reveals again an increase of 0.0059 ± 0.00053 units per year (0.66% relative to 1948). For the period from 1958 onwards the trend is slightly larger: 0.006 ± 0.0008 or 0.62% relative to 1958 per year.

The temporal variation of the simulated amplitude from experiment three does match the observations reasonably well with notable exceptions in 1963, 66, 67, 71, 81, and 92.

To clarify how the simulated increase originates we considered for the third experiment the relative amplitude of the seasonal cycle of atmospheric CO_2 concentration at Mauna Loa, the global net CO_2–flux, global NPP, and global heterotrophic respiration shown in Fig. 1b. The results show that the increase in the amplitude of the seasonal cycle in atmospheric CO_2 results in the model simulation from the increase in the NPP–amplitude due to the simulated CO_2–fertilization effect. Consequently it may be concluded that the observed increase of the relative amplitude follows from a CO_2 fertilization on terrestrial NPP. However the here used biosphere model simulates an unrealistic large terrestrial net CO_2 sink in the last years of the simulations although the temporal variation matches the observations reasonably. Thus it might be that the increase of the amplitude is not a good indicator for the size of a terrestrial carbon sink or the so far unconsidered precipitation variations interfere with the CO_2 fertilization.

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