Simulating changes in the terrestrial biosphere over glacial/interglacial timescales

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Abstract

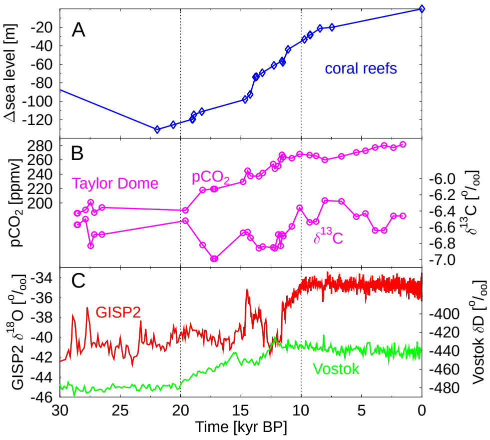
The state of the terrestrial biosphere during the Holocene and the Last Glacial Maximum (LGM) was estimated from data bases and steady state simulations in former studies. Here, we used these previous estimates and run a simple globally averaged box model of the terrestrial carbon stocks forced by various paleo records (temperature, CO_2, sea level) from the Last Glacial Maximum (LGM) over termination I to the Holocene to determine which forcing factors might be appropriate to explain observed changes in the biosphere. Former forcing strength of this type of model on recent climate changes were to large to explain glacial/interglacial variations. The terrestrial carbon stock at LGM seemed to consist of about 1600 PgC, 600 PgC less than in preindustrial times. During the transition the oceanic release of carbon during the last 20 ky seemed to be in phase with the atmospheric CO_2 record, but four times larger than the CO_2 increase due to the build-up of the terrestrial stocks. Calculated changes in the isotopic signature of oceanic $\delta^{13}C$ correspond well with data and suggest not only a dominant role of the biosphere during the stable climate conditions such as the LGM or the Holocene, but also a relevant influence on atmospheric $\delta^{13}C$ during the transition.

Introduction

Variations of the earth climate determined also the changes in the carbon stocks of the terrestrial biosphere. It is currently discussed that the glacial/interglacial changes in atmospheric pCO_2 and $\delta^{13}C$ were mainly controlled by processes in the ocean, while the isotopic signature of CO_2 during the Holocene and the LGM might point to dominant variations in the terrestrial biosphere carbon stocks (Indermühle et al. 1999; Broecker et al. 2001; Fischer et al. 2003).

Here, we try to add to current discussions by a transient modelling approach driven by paleoclimatic records. This directly implies the use of a simple model, otherwise missing data constraints might bias model dynamics.

Time depending driving forces of the model. A: sea level changes derived from coral reef terraces (Fairbanks, 1990). B: atmospheric CO_2 concentrations measured in the Taylor Dome ice core (Smith et al., 1999). C: Isotopes records in ice cores as proxies for temperature changes. GISP2, Greenland (Grootes und Stuiver, 1997) and Vostok, Antarktis (Jouzel et al., 1987).

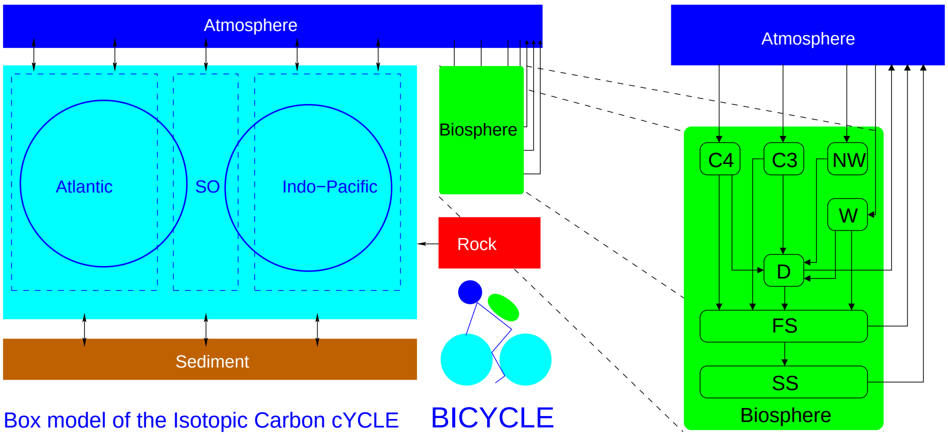


Model and Data

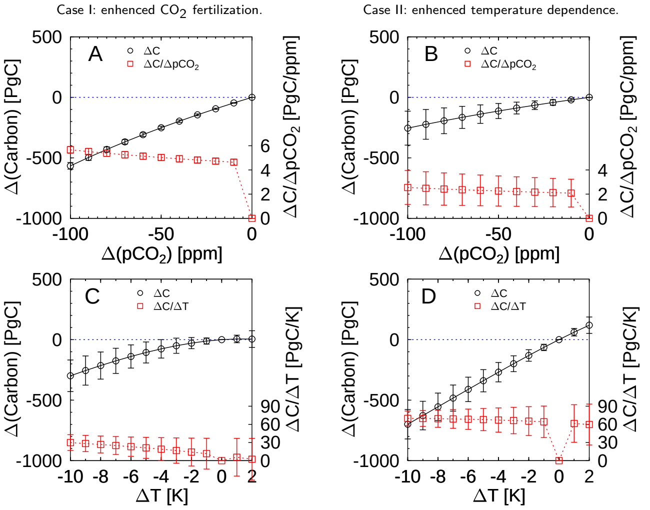
The box model of the terrestrial biosphere used here was based on previous studies (Emanuel et al. 1984; Kheshgi & Jain 2003). We finally parameterized our model with data from literature which led to a representation of 2200 PgC (vegetation: 700 PgC; soils: 1500 PgC) in the terrestrial biosphere during preindustrial times.

The model was forced with various paleo records, which changed through CO_2 fertilization, metabolic changes in NPP and respiration, and available land area the amount of carbon bound in the terrestrial biosphere. While sea level change had only minor impacts on the carbon storage at land ($\sim 4\%$), both temperature and CO_2 effects were solely capable of explaining the observed glacial/interglacial increase in the terrestrial biosphere. Thus, we identified acceptable forcing functions by a intensive sensitivity study and by comparison with other models.

Structure of the model BICYCLE (Box model of the Isotopic Carbon cYCLE), whose terrestrial biosphere was used here. Compartments: C4 and C3 ground vegetation, non-woody (NW) and woddy (W) parts of trees, detritus (D), fast (FS) and slow (SS) decomposing soil. Arrows indicate the fluxes of carbon.



The impact of different climate amplitudes in CO_2 and temperature on total biospheric carbon was tested in steady state simulations.


Case I: enhenced CO_2 fertilization.

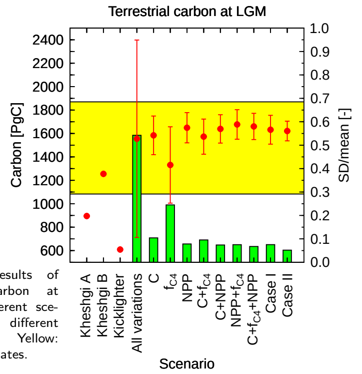
Case II: enhenced temperature dependence.

Results

Forcings used in recent studies were always too strong to explain the glacial terrestrial carbon content. The average terrestrial C at the LGM based on 10000 different forcing combinations was stabil around 1600 PgC, but its uncertainties was largely reduced if various filter functions were additionally applied.

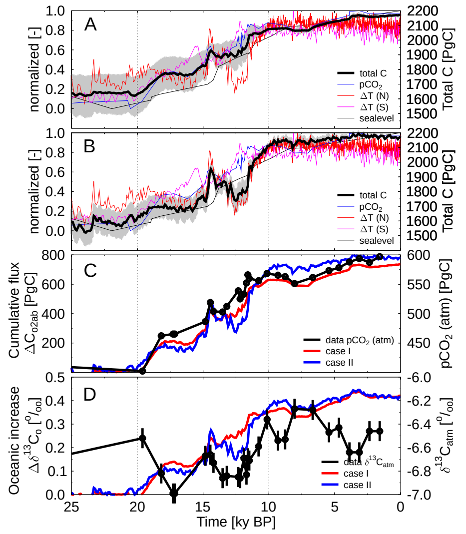
We identify two cases of about 15 simulations whose results correspond well with former case studies. They differ in the strength of CO_2 fertilization and temperature effects.

It was now possible to determine the resulting carbon fluxes of the ocean to the atmosphere/biosphere subsystem by mass balance calculations. The ocean released about 800 PgC during the transition, from which a fourth stayed in the atmosphere and 3/4 cummulated in the terrestrial stocks. Oceanic inorganic carbon was becoming 0.4‰ heavier during the G/IG transition, which was in good agreement with data constraints. This implies that the terrestrial biosphere might also be the driving forces for the dynamics in atmospheric $\delta^{13}C$ during the transition.



Simulation results of terrestrial carbon at LGM for different scenarios and different targets/filters. Yellow: previous estimates.

Transient modeling results of the simulated total biospheric carbon. A: Case I with enhenced CO_2 fertilization. B: Case II with enhenced temperature dependence. Averages (thick black line) and 1 SD (grey area) are shown. Cumulative carbon fluxes from atmosphere/biosphere to the ocean (C: total carbon. D: isotopic signature). Simulations of case I (enhenced CO_2 fertilization) and case II (enhenced temperature dependence) compared with Taylor Dome ice core data.



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