Research Group RESPIC — Palaeoclimatic Changes in the Carbon Cycle
Here: Special Emphasis on the Terrestrial Biosphere

Peter Köhler and Hubertus Fischer
Alfred Wegener Institute for Polar and Marine Research, PO Box 12 01 61, 27515 Bremerhaven, Germany
email: pkoehler@awi-bremerhaven.de, huhscher@awi-bremerhaven.de

Abstract

The state of the terrestrial biosphere during the Holocene and the Last Glacial Maximum (LGM) was estimated from pollen data bases and steady state simulations in former studies. However, the amount of carbon bound in the terrestrial stocks varied considerably. Hence, we narrow down this range of terrestrial carbon at the LGM by a transient simulation study over the last glacial cycle (125 ky) and try to determine the amplitudes of the different possible driving forces (temperature, atmospheric carbon dioxide partial pressure and sea level). We developed a simple model of the terrestrial biosphere consisting of seven well-mixed boxes. By applying well defined boundary conditions of the total terrestrial carbon stock, average isotopic signature, and net primary production, the range of the terrestrial carbon at LGM can be focused to 1500–1700 PgC, equivalent to a reduction from interglacial times to the LGM of 500–700 PgC. This falls well within the range of former studies (LGM: 1100–1900 PgC) but reduces the range of uncertainty significantly. Simulation results were biased towards higher carbon stocks (~120–150 PgC) if we abstained from our transient modelling approach and analyzed steady states. This disequilibrium effect gives us reasons to argue for considering the time-dependent nature of any driving forces, since fast temperature changes in the northern hemisphere, where 2/3 of all land area is situated, did prevent the system from reaching equilibrium. However, it is so far not possible to definitely name the forcing strength of CO₂ and temperature. Measurements of δ¹³C on atmospheric carbon dioxide in Antarctic ice cores and biogenic aerosols potentially can help to narrow down this range of terrestrial carbon at LGM to 1500–1700 PgC. The effect of different temperature forcings was small. A comparison with steady state results for the climate situation at LGM highlighted a disequilibrium effect of the system (scenario D); Fast climate fluctuations and long turnover times of some compartments prevent the system from reaching equilibrium and thus steady state approaches might be systemically biased.

Modelling approach

We developed a conceptual model of the terrestrial biosphere after the work of Emanuel et al. (1984). Additionally, a soil compartment with long turnover time (τ ~ 1000 yr) and a distinction between C3 and C4 plants — which allow us to use different photosynthetic pathways and discriminate δ¹³CO₂ with different fractionation factors — were incorporated. δ¹³C in air bubbles within the ice will be investigated. Atmospheric measurements on marine biogenic aerosols potentially can help to narrow down this range of terrestrial carbon at LGM to 1500–1700 PgC. The effect of different temperature forcings was small. A comparison with steady state results for the climate situation at LGM highlighted a disequilibrium effect of the system (scenario D); Fast climate fluctuations and long turnover times of some compartments prevent the system from reaching equilibrium and thus steady state approaches might be systemically biased.

Results

The amplitudes of the various forcings we proposed were not clear. Therefore, we performed a sensitivity analysis on all free parameters spanning 2916 different scenarios. The boundary conditions filtered out only 97 scenarios in which the simulated biosphere would fall within our defined target ranges. Since 2/3 of the land area are located in the northern hemisphere the temperature signals of GISP2 (Greenland) was taken in a first approach as global signal. Here, a mixture of GISP2 and Vostok temperature was also investigated (scenario B, C). We found, that the additional constraints on NPP and especially average isotopic signature δ¹³C of the biosphere restricted the simulated terrestrial carbon stocks at LGM to 1500–1700 PgC. The effect of different temperature forcings was small. A comparison with steady state results for the climate situation at LGM highlighted a disequilibrium effect of the system (scenario D); Fast climate fluctuations and long turnover times of some compartments prevent the system from reaching equilibrium and thus steady state approaches might be systemically biased.

Targets of the research group RESPIC

Ice cores represent an unique climate archive. Within the framework of EPICA (European Project for Ice Coring in Antarctica, Fig. 1) a new highly resolved ice core in Dronning Maud Land at the Atlantic sector of Antarctica is drilled (depth before drilling season 2002/2003: 438.80 m). Our investigations on this ice core are focused on the carbon cycle. With a new method using a gas chromatography isotope ratio monitoring mass spectrometer on atmospheric CO₂, measurements on marine biogenic aerosols will be envisaged. Here, the module of the terrestrial biosphere consisting of seven well-mixed boxes. By applying well defined boundary conditions of the total terrestrial carbon stock, average isotopic signature, and net primary production, the range of the terrestrial carbon at LGM can be focused to 1500–1700 PgC, equivalent to a reduction from interglacial times to the LGM of 500–700 PgC. This falls well within the range of former studies (LGM: 1100–1900 PgC) but reduces the range of uncertainty significantly. Simulation results were biased towards higher carbon stocks (~120–150 PgC) if we abstained from our transient modelling approach and analyzed steady states. This disequilibrium effect gives us reasons to argue for considering the time-dependent nature of any driving forces, since fast temperature changes in the northern hemisphere, where 2/3 of all land area is situated, did prevent the system from reaching equilibrium. However, it is so far not possible to definitely name the forcing strength of CO₂ and temperature. Measurements of δ¹³C on atmospheric carbon dioxide in Antarctic ice cores as proposed in the RESPIC project and a coupling to an ocean box model will enable our approach to disentangle both driving forces.

Fig. 2: Modelling concept of a coupled ocean-atmosphere-terrestrial biosphere model with special emphasis on the structure of the biospheric module C4: C₄ ground vegetation, C3: C₃ ground vegetation, NW: non-woody parts of trees, W: woody parts of trees, D: detritus, FS: fast decomposing soil, SS: slow decomposing soil. Arrow indicates C-fluxes.


Fig. 4: Results: Targets from literature. A: ΔT from GISP2 only. B: ΔT from 3.3 (GISP2-Vostok) mixture. C: ΔT from 2.3 (GISP2-Vostok) mixture. D: Steady state simulation. E: ± uncertainty offset. F: Some forcings out at work allowed.

Fig. 5: Examples of different scenarios (A-F) applied to terrestrial carbon simulator. The relative influence of temperature and CO₂ was not determined so far, but might be possible with the future data on δ¹³CO₂ measured in this project.

Fig. 6: Results: Targets from literature. A: ΔT from GISP2 only. B: ΔT from 3.3 (GISP2-Vostok) mixture. C: ΔT from 2.3 (GISP2-Vostok) mixture. D: Steady state simulation. E: ± uncertainty offset. F: Some forcings out at work allowed.