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

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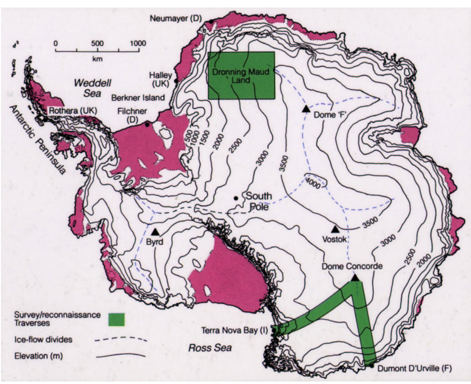
Abstract

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. Here, we narrow down this range of terrestrial carbon at the LGM by a transient simulation study over the last glacial cycle (125 kyr) and try to determine the amplitudes of the possible different 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 modeling approach and analyzed steady states. This disequilibrium effect give 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 CO_2 and temperature. Measurements of $\delta^{13}C$ 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.

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: 438.80m). 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 (GCirmMS) the isotopic signature of CO_2 enclosed in air bubbles within the ice will be investigated. Atmospheric $\delta^{13}CO_2$ so far was only measured for the last 29 kyr (Smith et al. 1999) because the extraction of CO_2 from clathrates in deeper ice might fractionate $\delta^{13}CO_2$ and bias the results. Therefore, a new sublimation method has to be established in this project. Together with additional measurements on marine biogenic aerosols — potentially a proxy for productivity in the surface waters — a quantitative interpretation of the global carbon cycle in a conceptual model of the ocean-atmosphere-biosphere system will be envisaged. Here, the module of the terrestrial biosphere is analysed in a stand-alone application and from boundary conditions given in the literature the terrestrial carbon stocks at the Last Glacial Maximum (LGM) will be investigated.

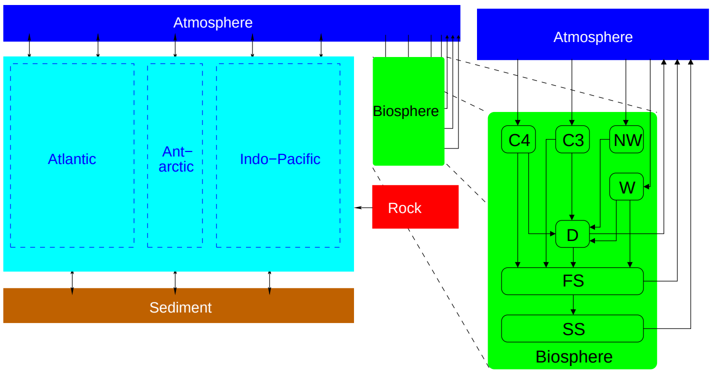
Fig. 1: Research areas of the European Project for Ice Coring in Antarctica. Our study is focused on the new core drilled in Dronning Maud Land.



Modelling approach

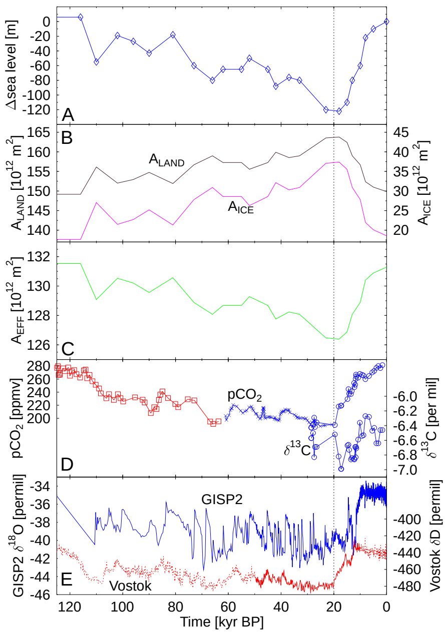
We developed a conceptual model of the terrestrial biosphere after the work of Emanuel et al. (1984). Additionally, a soil compartment with long turnover time ($\tau \sim 1000$ yr) and a distinction between C_3 and C_4 plants — which use different photosynthetic pathways and discriminate $\delta^{13}CO_2$ with different fractionation factors — were incorporated (Fig. 2). Changes in the terrestrial carbon stocks from interglacial to glacial climate conditions were driven by CO_2 fertilization, temperature based metabolic changes in net primary production (NPP) and respiration and climate induced successional changes between both ground vegetation and trees and C_3 and C_4 plants. We run our model in a transient mode from the last interglacial (125 kyr BP) to the LGM (20 kyr BP) and applied as boundary conditions the current knowledge of terrestrial carbon stocks in vegetation and soil, NPP and average isotopic signature $\delta^{13}C$ of the terrestrial carbon for both interglacial and glacial times (e.g. Adams & Faure 1998, Crowley 1995, François et al. 1998, Prentice et al. 1993, Otto et al. 2002).

Fig. 2: Modelling concept of a coupled ocean-atmosphere-biosphere model with special emphasis on the structure of the biospheric module: C4: C_4 ground vegetation; C3: C_3 ground vegetation; NW: non-woody parts of trees; W: woody parts of trees; D: detritus; FS: fast decomposing soil; SS: slow decomposing soil. Arrows indicate C-fluxes.



Our forces were driven by various data sets on sealevel change, area available for vegetation, and climate informations from ice cores (Fig. 3). We proposed that globally averaged atmospheric temperature change had an amplitude of $\sim 5^\circ$C from LGM to preindustrial times. We compiled all ice core archives from various cores (Taylor Dome, Vostok, GISP2) on a common time scale (GISP2) via CH_4 synchronization whenever available (10–50 kyr BP).

Fig. 3: Data sets which run our driving forces. A: sealevel change (as in Cuffey & Vimeux 2001). B: Land area A_{LAND}; area covered by land ice & lakes A_{ICE} (Adams & Faure 1998). C: Effective area available for vegetation. D: Atmospheric CO_2 and $\delta^{13}CO_2$ concentrations. E: and δD as proxy for atmospheric temperature from ice cores (GISP2, Vostok). (Ice cores: Barnola et al. 1987, Grootes & Stuiver 1997, Indermühle et al. 2000, Petit et al. 1999, Smith et al. 1999)

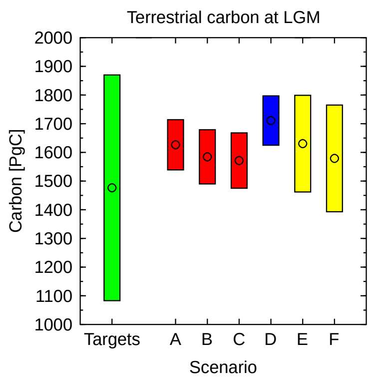


Results

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 (scenario A, Fig. 4). Latter, 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 $\delta^{13}C$ 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 systematically biased.

We therefore strongly argue for transient modelling approaches. Even if we allowed a large error estimate in our approach the range of terrestrial carbon at LGM was still narrowed significantly (scenario E, F). The relative influence of temperature and CO_2 was not determined so far, but might be possible with the future data on $\delta^{13}CO_2$ measured in this project.

Fig. 4: Results: Targets from literature. A: ΔT from GISP2 only. B: ΔT from 3:1 (GISP2:Vostok) mixture. C: ΔT from 2:1 (GISP2:Vostok) mixture. D: Steady state simulation. E: 5% uncertainty offset. F: Some forcings not at work allowed.



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