PROPOSING A MECHANISTIC UNDERSTANDING OF ATMOSPHERIC CO_2 DURING THE LATE PLEISTOCENE – A CONTRIBUTION TO THE EPICA CHALLENGE

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ABSTRACT

Paleo-climate records in ice cores revealed high variability in temperature, atmospheric dust content and carbon dioxide. The longest CO_2 record from the Antarctic ice core of the Vostok station went back in time as far as about 410 kyr BP showing a switch of glacials and interglacials in all those parameters approximately every 100 kyr during the last four glacial cycles with CO_2 varying between 180-300 ppmv [*Petit et al.,* 1999]. New measurements of dust and the isotopic temperature proxy deuterium of the EPICA Dome C (EDC) ice core covered the last 740 kyr, however, revealed glacial cycles of reduced temperature amplitude [*EPICA community members*, 2004]. These new archives offer the possibility to propose atmospheric CO_2 for the pre-Vostok time span as called for in the EPICA challenge [*Wolff et al.,* 2004]. Here, we contribute to this challenge using a box model of the isotopic carbon cycle [*Köhler et al.,* 2005] based on process understanding previously derived for Termination I. Our results show that major features of the Vostok period are reproduced while prior to Vostok our model predicts significantly smaller amplitudes in CO_2 variations.

METHODS

Our box model of the isotopic carbon cycle BICYCLE [*Köhler et al.,* 2005] consists of ten ocean reservoir in three depth layers distinguishing Atlantic, Indo-Pacific, and Southern Ocean (SO), a seven compartment terrestrial biosphere [*Köhler and Fischer*, 2004] and considers also fluxes of dissolved inorganic carbon and alkalinity between ocean and sediments through $CaCO_3$ sedimentation and dissolution processes.

The model was used previously [*Köhler et al.,* 2005] to quantitatively interprete the observed variations in the three atmospheric carbon records ($p CO_2$, $\delta^{13}C$, $\Delta^{14}C$) over Termination I (20-10 kyr BP). Especially the temporal informations contained in the carbon isotopes enabled us to reduce the degrees of freedom of the simulated carbon cycle system in a way to come to best guess results which not only reproduce these atmospheric carbon records reasonable well, but also to be in line with evidences from other paleo informations.

Here, BICYCLE is forced by the new EDC deuterium and dust records as proxies for SO sea surface temperature (SST) and iron fertilization of marine biology in the SO, respectively, and marine sediment records (ODP980, ODP677, SPECMAP, Pacific lysocline reconstructions) to depict observed changes in ocean circulation (North Atlantic deep water (NADW) formation, SO vertical mixing), other physical (SST, sea level, sea ice cover) and biogeochemistry ($CaCO_3$ sedimentation/dissolution, terrestrial biosphere) processes.

RESULTS

From the nine contributions to the EPICA challenge [*Kull et al.*, 2004; *Wolff et al.*, 2005] ours here represents the most complete attempt as it was tried to gain an understanding of underlying processes and not only to come to the best correlation with so far measured data. Nevertheless, each of these approaches tested a different theory which might have had large impacts on the global carbon cycle in the past. However, we think that based on the high nonlinearity of the carbon cycle it is necessary to include all known and relevant processes on these long time scales to come to robust conclusions.

Our results show that major features of the Vostok period are reproduced while prior to Vostok our model predicts significantly smaller amplitudes in CO_2 variations. The main contributions (in decreasing order) to the variations in $p CO_2$ were given by changes in $CaCO_3$ sedimentation/dissolution, SO vertical

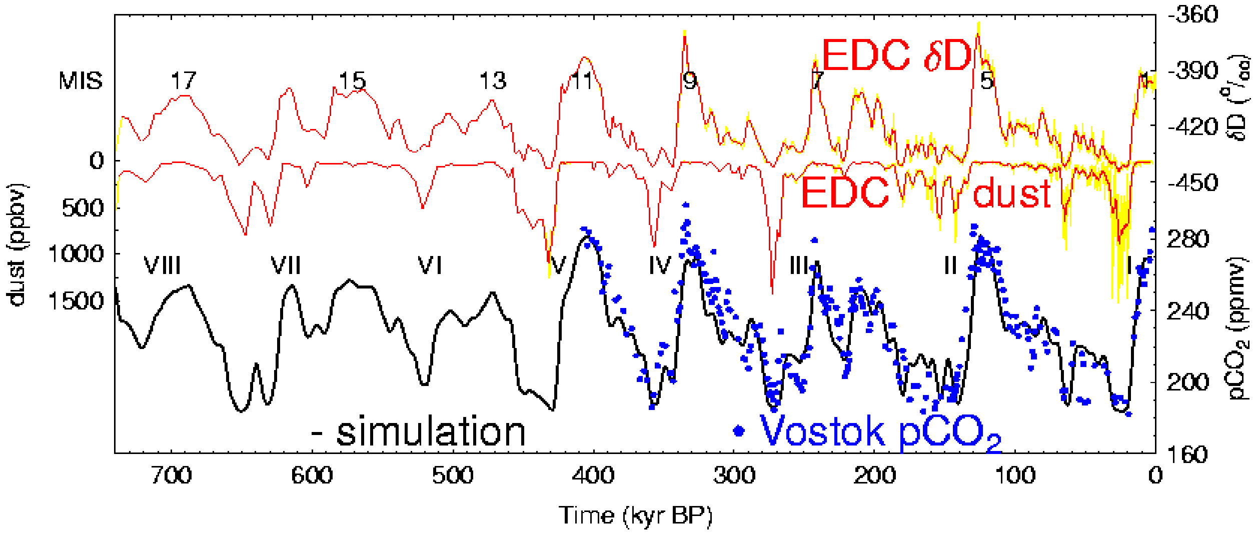

Fig. 1. Simulated and measured atmospheric $p\text{CO}_2$ over the EDC period. Additionally EDC deuterium and dust records are shown [*EPICA community members*, 2004]. Vostok $p\text{CO}_2$ data [*Petit et al.*, 1999] plotted on the orbitally tuned age scale [*Shackleton*, 2000]. Marine Isotope Stage (MIS) during interglacials and Terminations I to VIII are labeled.

mixing, sea surface temperature, iron fertilization of the marine export production in the SO, and NADW formation. Changes in sea level, sea ice cover, and terrestrial carbon storage were processes enlarging the observed $p\text{CO}_2$ rise by up to 50 ppmv during terminations. While most processes were reduced in their magnitude during the terminations of the pre-Vostok period, the absolute contribution of iron fertilization changed only slightly. Thus, the relative importance of biogeochemical processes is enhanced from 45% to 60% during these early terminations. The contribution of physical processes (ocean temperature, sea level, sea ice) to the $p\text{CO}_2$ rise during terminations stayed always below 20%, while ocean circulation contributed on average 50% during the Vostok era (including Termination V) but only 30-40% during Termination VI and VII.

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