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RESPIC - PALEOCLIMATIC CHANGES IN THE GLOBAL CARBON CYCLE

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1 Summary

Within RESPIC new $\delta^{13}CO_2$ and aerosol records derived from the EPICA (European Project for Ice Coring in Antarctica) ice core currently drilled in Dronning Maud Land (DML), Antarctica, are reconstructed. For this purpose a novel analytical method was developed allowing for the first time to measure $\delta^{13}CO_2$ on ice core samples with a precision of 0.05 ‰. These analyses revealed an 0.5 ‰ increase in $\delta^{13}CO_2$ over the penultimate termination. Aerosol records show 12 times higher dust and 3 times higher sea salt fluxes during the last glacial maximum compared to the Holocene, representing important constraints for carbon cycle modeling. Using our multibox model BICYCLE we were able to quantitatively reproduce the 80 ppmv increase in CO_2 over the last glacial/interglacial transition and to hindcast CO_2 changes for previous glacial cycles, where ice core data is not available yet. Major factors affecting glacial carbon reservoirs are a deep stratification of the Southern Ocean (SO), changes in sedimentation rates of $CaCO_3$ and dust induced iron fertilization of marine biological productivity in the SO.

2 Aim of the research

The overarching goal of RESPIC is the quantitative reconstruction of temporal changes in the global carbon cycle (GCC). To this end new high-resolution atmospheric records from the EPICA ice cores are derived imposing important boundary conditions on the GCC. Quantitative interpretation of changes in atmospheric CO_2 is achieved by a new multibox model of the GCC together with assimilation of proxy data from various paleoarchives.

3 Principal results

Reliable modelling of paleoclimatic changes in the GCC requires robust constraints on atmospheric and environmental changes in the past. In this context continuous records on atmospheric aerosol species (mineral dust (Ca^{2+}), sea salt (Na^+), biogenic sulfur species (methanesulfonate, SO_4^{2-})) over the last 180,000 yrs have been derived for the EPICA DML ice core (75°S, 0°W), reflecting environmental changes in the Atlantic sector of the SO. Together with our EPICA partners equivalent records from the Indian Sector of the SO were measured on the EPICA Dome C ice core (75°S, 123°E) covering the last eight glacial cycles (EPICA community members, 2004). With these records important information on environmental conditions (iron fertilization, sea ice extent, marine biogenic sulfur emissions) are at hand in unprecedented temporal resolution. The main results of these records are a 12 times higher mineral dust, hence iron, flux to the SO during the last glacial maximum (LGM). A three times higher sea salt flux points to an equivalent increase in sea ice coverage during the LGM implying considerable changes in water mass stratification and gas exchange. In contrast methanesulfonate is partly subject to postdepositional changes (Fundel et al., 2005, Weller et al., 2004) and does not show an unambiguous change in marine sulfur emissions.

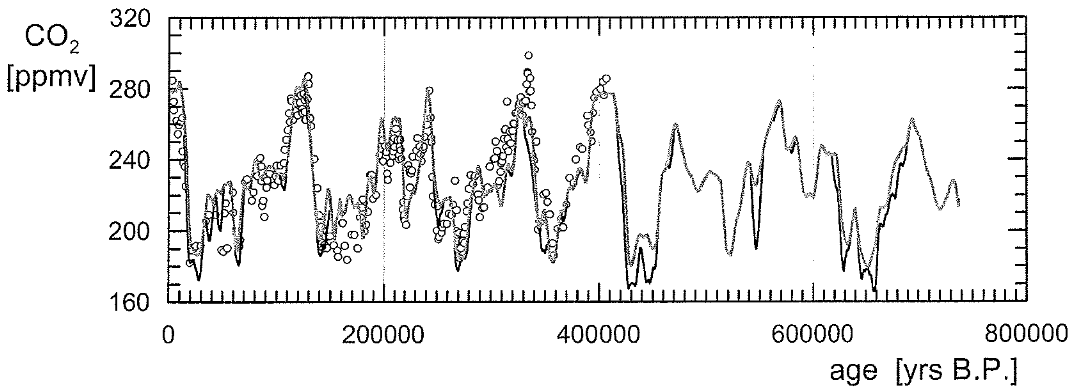

Figure 1. Hindcasted CO_2 concentrations (grey and black line) over the last 8 glacial cycles using BICYCLE and various ice (EPICA community members, 2004) and marine sediment data to constrain environmental boundary conditions. Circles represent measured CO_2 concentrations from the Vostok ice core over the last 420,000 yrs (Petit et al, 1999) for comparison plotted on the orbital tuned age scale by Shackleton (2000).

Furthermore, $\delta^{13}CO_2$ represents an important constraint to quantify marine and biospheric carbon fluxes (Fischer et al., 2003). Previous analyses suffered from unsatisfying accuracy and/or resolution of the $\delta^{13}CO_2$ records. In addition clathrate formation in deeper ice (> 700 m) did not allow quantitative extraction of $\delta^{13}CO_2$ from ice cores using traditional dry extraction techniques. Within RESPIC a novel sublimation extraction and gas chromatography isotope ratio monitoring mass spectrometry (irm GCMS) technique was developed (Schmitt & Fischer, 2005). This allowed for a quantitative and fractionation free CO_2 extraction both from bubble and clathrate ice. With this method we were able to achieve a precision of 0.05 ‰ for $\delta^{13}CO_2$ analyses on deep EPICA DML ice, where annual layers are suffciently thin to average over 10-20 years. Based on this high precision, which is about two times better than previously reported ice core analyses, an 0.5 ‰ change in $\delta^{13}CO_2$ over the penultimate glacial/interglacial transition could be derived. In shallower ice, however, bubble enclosure leads to significantly higher $\delta^{13}CO_2$ variability on the centimeter scale.

Quantification of glacial/interglacial changes in the GCC is based on our new carbon cycle model BICYCLE, consisting of multibox representations of the ocean (including abiotic and biotic carbon cycling), the terrestrial biosphere (Köhler & Fischer, 2004) and the atmosphere. The boxmodel approach allows for transient modelling of the GCC to be sufficiently constrained by the temporal evolution in boundary conditions as derived from ice core and other proxy archive data. This transient modeling approach effectively reduces the degrees of freedom and excludes some of the potential GCC change scenarios. Using BICYCLE we were able to quantitatively reproduce the 80 ppmv glacial/interglacial change in CO_2 (Köhler et al., 2005). According to our model the CO_2 increase is caused by the interplay of different effects, with deep stratification of the glacial SO, changes in sedimentation rates of $CaCO_3$ and increased glacial marine productivity representing the major factors. In contrast, the direct effect of changing sea ice coverage on gas exchange and the strength of North Atlantic deep water formation are less important. Using this knowledge gained over the last termination, we used BICYCLE to hindcast atmospheric CO_2 changes over the last 8 glacial cycles (Köhler & Fischer, 2005) before ice core CO_2 concentrations are available from the EPICA Dome C ice core (Wolff et al., 2004). As shown in Fig. 1 our model is able to reliable predict CO_2 changes over the last 420,000 years and reveals a significantly reduced amplitude in glacial/interglacial CO_2 changes for previous glacial cycles, which are characterised by reduced temperature variations.

4 Main conclusions

Paleoclimatic changes in the GCC are dominated by changing environmental conditions in the SO and changing sedimentation rates of $CaCO_3$ occurring in all ocean basins. In this respect ice core aerosol concentrations represent most important boundary conditions constraining the impact of iron fertilization and sea ice coverage over the SO.

5 Next steps

Our novel method for high precision $\delta^{13}CO_2$ analyses opens up a new path to quantify marine and terrestrial carbon fluxes using BICYCLE. Accordingly, we will derive records of $\delta^{13}CO_2$ over MIS 4-6 until the end of RESPIC in June 2006. Ice core aerosol concentrations will be interpreted in terms of environmental changes over the last glacial cycles. Respective publications are currently in preparation. Further improvement of the model BICYCLE can be envisaged by implementing output from dynamic global vegetation models, allowing for simulation of vegetation changes during warm periods and the glacial inception.

6 Policy relevance and application

Reliable projections of future changes in the global carbon cycle and climate requires an inside knowledge of the processes which govern such changes. Paleoclimatic reconstructions represent crucial groundtruthing for corresponding modelling approaches. Accordingly, RESPIC represents an important contribution to the validation of carbon cycle modelling and the understanding of the coupling between climate and the atmosphere. The development of high-precision mass spectrometric techniques for very small gas samples may result in industrial applications of this new technique and opens the door to a multitude of geoscientific and atmospheric studies where most often sample sizes are limited.

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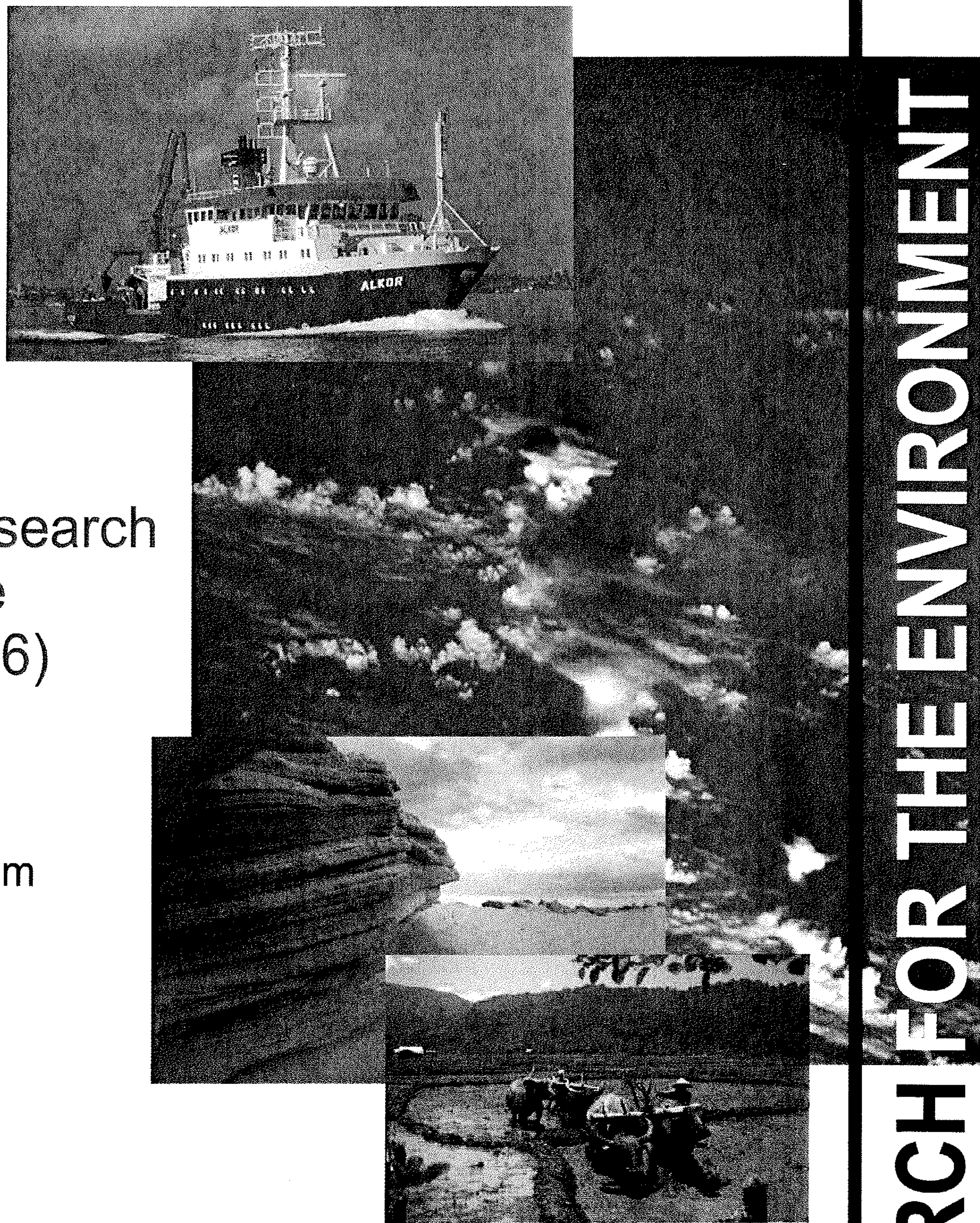

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