On the interpretation of the stable carbon isotope ratio, δ^{13}C, during the last 2,000,000 years:

From millennial-scale variability in atmospheric δ^{13}CO$_2$ to the Mid Pleistocene Transition in deep Pacific δ^{13}C

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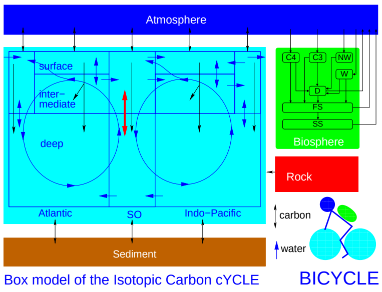
Abstract

The ratio of the stable carbon isotopes, δ^{13}C, contains valuable information on the processes which are operating on the global carbon cycle-climate system. It can help to pinpoint, which exchange processes among the different reservoirs of the global carbon cycle significantly alter atmospheric CO$_2$ as δ^{13}C is recorded in ice cores and benthic organisms buried in the sediments, respectively. Here we show with the help of the carbon cycle box model BICYCLE [Köhler et al., 2005; Köhler and Fischer, 2006] how much additional information on carbon cycle and climate dynamics might be extracted from δ^{13}C and where we find significant limitations. Our time frame of interest is spanning from the variability during fast climate fluctuations of the Dansgaard/Oeschger (D/O) events to the rise in the glacial/interglacial amplitudes and the shift in the frequency spectra from 40 kyr to 100 kyr during the Mid Pleistocene Transition (MPT) [Köhler and Bintanja, 2008].

The Model

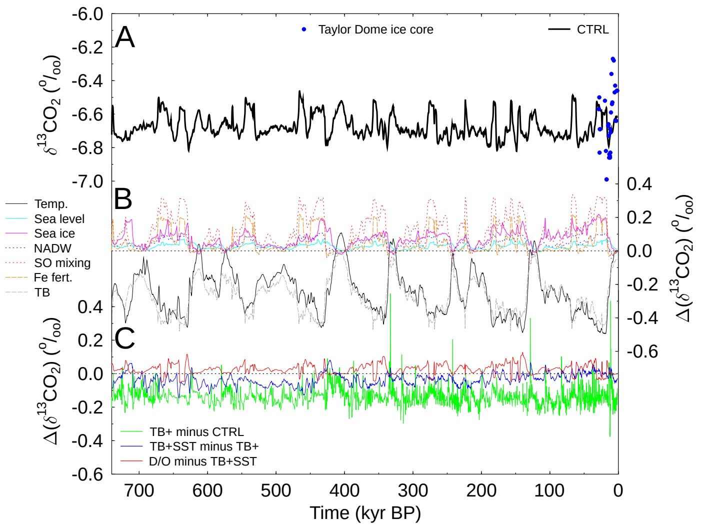


Southern Ocean vertical exchange (red arrow) is related to SST after MPT, but decoupled from SST before, which we call **Southern Ocean Decoupling Hypothesis**.

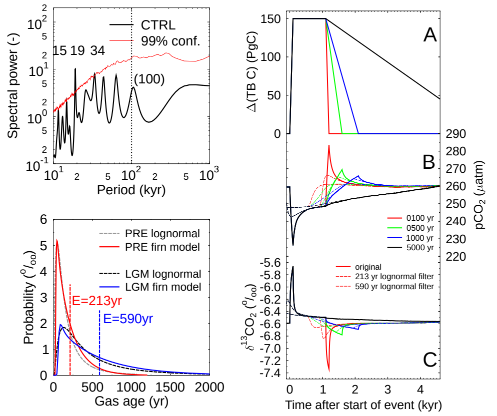
Conclusions

(1) Based on our model convolution of various independently dated climate records there is no 100-kyr cycle in atmospheric δ^{13}CO$_2$.
(2) Millennial-scale climate variability leads to fast changes in the terrestrial C cycle. The corresponding δ^{13}CO$_2$ signal is dilluted quickly through gas exchange with the ocean.
(3) The δ^{13}CO$_2$ amplitude which is recorded in ice cores depends on the gas age distribution in the firn, which dampens the recorded signal (60% at LGM in EPICA Dome C).
(4) We suggest a decoupling of SST in the Southern Ocean from the vertical mixing rates before the Mid Pleistocene Transition (before 1,000,000 years) to find glacial/interglacial amplitudes in δ^{13}C in the deep Pacific which are in line with reconstruction.
(5) The 400 kyr cycle found in all deep ocean δ^{13}C reconstructions and its complete lack in δ^{18}O (and in our simulation results) still holds some surprises in the understanding of the carbon cycle-climate interactions.

Millennial-scale variability in atmospheric δ^{13}CO$_2$

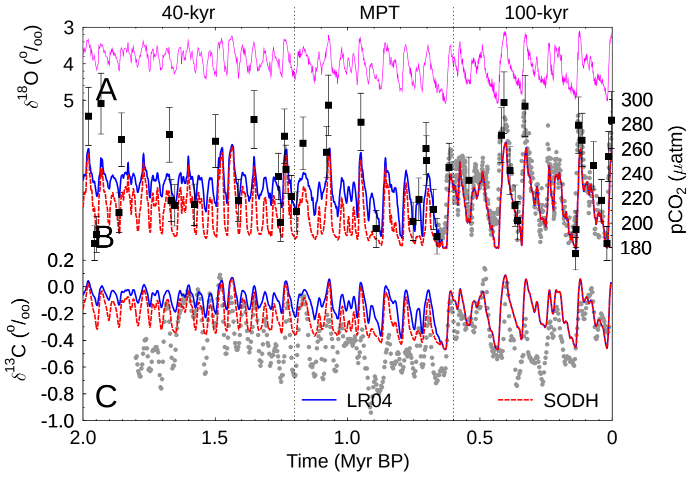


Simulated atmospheric δ^{13}CO$_2$ record over the last 740 kyr (A) does not contain any significant power in the 100 kyr periods (see power spectra below) due to opposing effects of the terrestrial biosphere and the different marine carbon pumps (B) Also: Taylor Dome ice cores data [Smith et al., 1999]. C: No millennial scale variability in CTRL: TB+: Fast changes in terrestrial carbon storage. TB+SST: Scenario TB+ and fast changes in North Atlantic SST. D/O: Scenario TB+SST and fast changes in Atlantic meridional overturning.

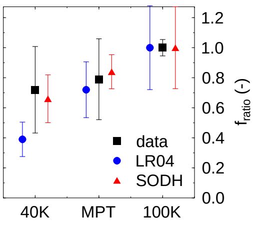


Left top: Maximum entropy spectral analysis (MESA) of δ^{13}CO$_2$ in CTRL . **Left bottom:** Gas age distribution as function of climate state, here preindustrial (PRE) and LGM conditions. Calculation by Joos & Spahni [2008], approximated by lognormal functions. **Right:** Simulation of terrestrial carbon uptake of 150 PgC (δ^{13}C = –22‰) in 100 yr, followed after 1 kyr by the release of 150 PgC within 100, 500, 1000, 5000 years (A) and effects on atmospheric pCO$_2$ (B) and δ^{13}CO$_2$ (C). Thick lines: Original results. Thin and thinnest lines: After filtering with a lognormal function with mean gas age distribution of 213 yr (PRE) and 590 yr (LGM) to mimic amplitude attenuation during gas enclose in the ice.

Mid Pleistocene Transition in deep Pacific δ^{13}C

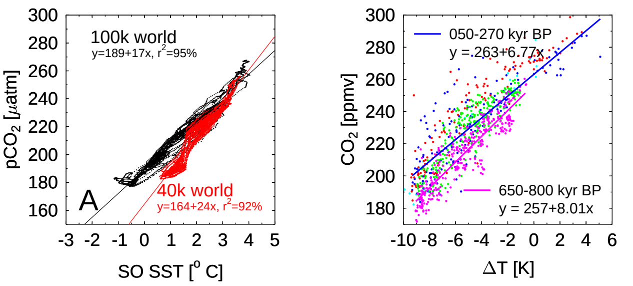


(A) LR04 deep ocean benthic δ^{18}O stack [Lisiecki and Raymo, 2005], and (B) simulated and measured atmospheric pCO$_2$ and (C) deep Pacific δ^{13}C over the last 2,000,000 years. Grey: data from ice cores (B) and sediments (C), black: reconstructed pCO$_2$ based on δ^{11}B from planktic foraminifer [Hönisch et al., 2009]. Scenario LR04: Climate is similarly related to the LR04 benthic δ^{18}O prior and after the MPT. Scenario SODH: The Southern Ocean Decoupling Hypothesis.



Left: Glacial/interglacial amplitudes in deep Pacific δ^{13}C normalised to the 100k-world (fratio = 1) in data and both simulation scenarios (LR04, SODH).

Below: As consequence of the Southern Ocean Decoupling Hypothesis the relation between Southern Ocean temperature and CO$_2$ breaks up (left). This is also seen in the latest CO$_2$ data set from EPICA Dome C between Antarctic temperature and CO$_2$ (right) [Lüthi et al., 2008].



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Hönisch et al. (2009) Science 324:1551ff. Köhler et al., (2005) GBC 19:GB4020. Köhler & Bintanja (2008) Climate of the Past 4:311ff. Köhler & Fischer (2006) Climate of the Past 2:57ff. Joos & Spahni (2008) PNAS 105:1425ff. Lisiecki & Raymo (2005) Paleoceanography 20:PA1003. Lüthi et al. (2008) Nature, 453:379ff. Petit et al. (1999) Nature 399:429ff. Raymo et al. (1997) Paleoceanography 12:546ff. Raymo et al. (2004) Paleoceanography 19:PA2008. Smith et al. (1999) Nature 400:248ff. Siegenthaler et al. (2005) Science 310:1313ff.