THE EPICA CHALLENGE (2)

predicting CO_2 over 800,000 years

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Predicting EPICA pCO_2 back to 800 kyr

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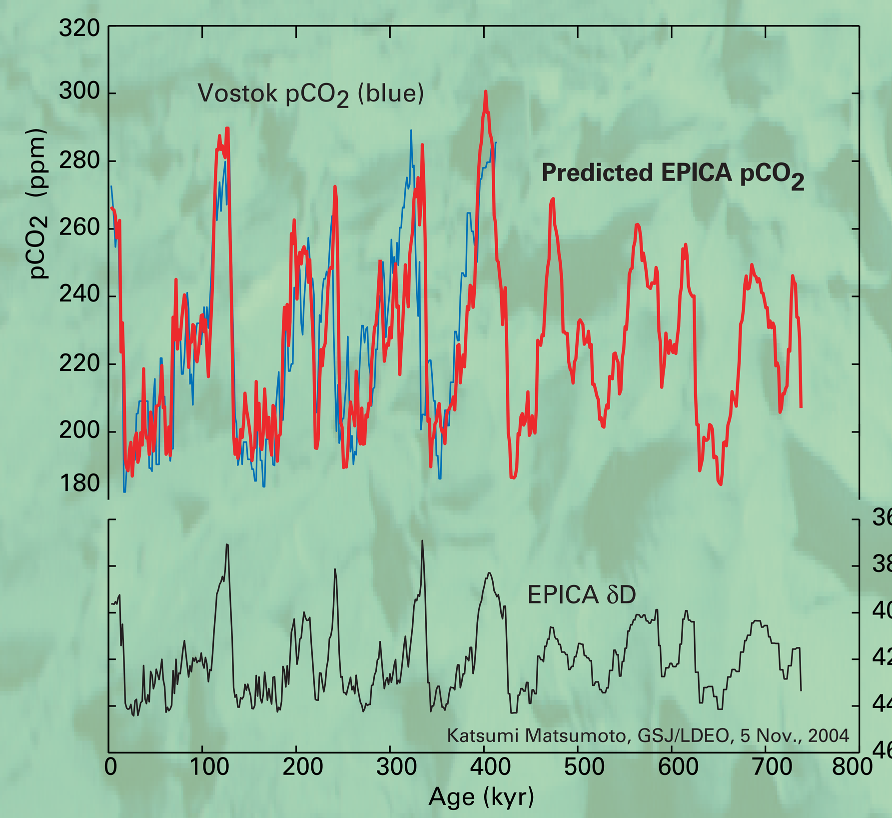
A multiple linear regression model was first obtained for VOSTOK pCO_2 using: (1) VOSTOK δD and dust; (2) paleoceanographic proxies of deep ocean carbonate dissolution, NADW, and ice volume; and (3) calculated insolation at different latitude bands. The model can explain much of the 420-kyr VOSTOK pCO_2 record (r^2=0.83). This model was then applied to EPICA using its δD and dust records together with (2) and (3). The predicted EPICA pCO_2 is primarily determined by δD, which can account for 60-80 ppm of about 100-ppm pCO_2 amplitude over glacial-interglacial cycles. Proxies of deep ocean carbonate dissolution and ice volume exert secondary controls and can explain up to 20 ppm each.

The offset between the predicted EPICA pCO_2 and measured VOSTOK pCO_2 where they overlap is perhaps most prominent during the glacial termination going from stage 10 to 9. This is due to the discrepancy in the timing of the termination between VOSTOK δD and EPICA δD. The timing of peak interglacial stage 9 is also offset between the two by about 10 kyr, which appears too large. Therefore, I suggest that the age model of either VOSTOK or EPICA (more likely the latter) is incorrect.



EPICA Challenge: Predicting pCO_2

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Introduction:
As the authors of this challenge are all involved in the CO_2 measurements that are now under way, we would like to submit this as a contribution "hors concours" to the EPICA Challenge. Although we have knowledge of some preliminary results, our method is based only on published measurements and should therefore be objective.

Method:
Our method uses only the deuterium and dust records from Dome C. It is based on the assumption that different mechanisms influencing CO_2 like sea surface temperature, sea ice extent could be linked with the temperature recorded in Dome C. The iron supply to the Southern Ocean could be linked with the dust record of Dome C.
We therefore assume that the CO_2 evolution can be approximated by a combination of the deuterium and dust records.
In order to quantify the "influence" of each the deuterium and dust record for the CO_2 concentration we optimized the following relationship with the published Dome C measurements from the Holocene to 22 kyrBP:

$$pCO_2(t) = 188\,ppmv + 55\,ppmv \cdot \left(\frac{440‰ + \delta D(t+800\,yr)}{50‰}\right) + 32\,ppmv \cdot \left(\frac{3 - \log(dust(t+800\,yr)/1\,ppb)}{2}\right)$$

Age t in yrBP

Back to 22 kyr a correlation of $r^2 = 0.95$ is achieved using these parameters. For comparison the correlation of deuterium only with CO_2 is $r^2 = 0.92$. Note that the best correlation was found assuming a lag of the CO_2 concentration compared to deuterium and dust of 800 yr ($r^2 = 0.89$ without lag).

A short comparison with the Vostok CO_2 record (Fig. 1) shows that the amplitudes in the CO_2 of the last four cycles are reproduced surprisingly well with this method.

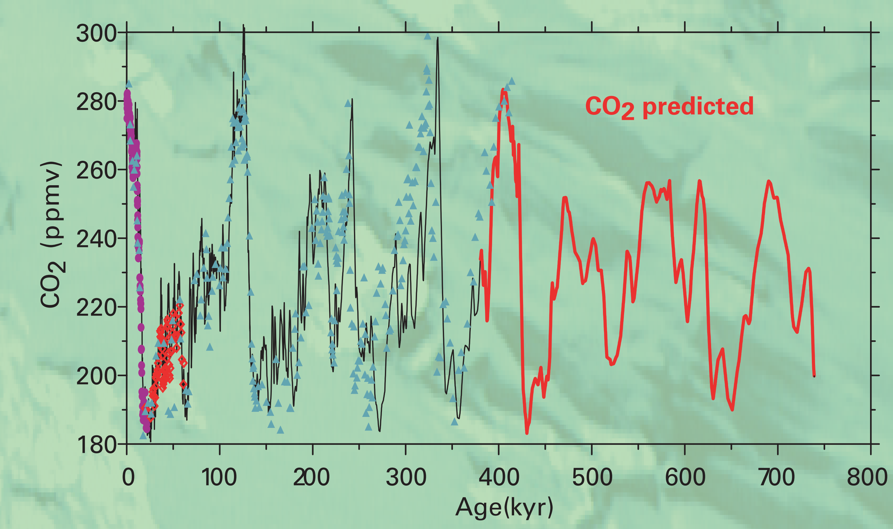

Figure 1: Purple dots: Dome C CO_2 Holocene and termination I records from Dome C (Monnin et al., 2001/2004).
Red diamonds: Taylor Dome CO_2 record (Indermühle et al., 2000).
Green triangles: Vostok CO_2 record (Petit et al., 1999).
Red line: Estimated CO_2 concentration using the relationship presented above.

EPICA Challenge: CO_2 prediction back to 800 kyr

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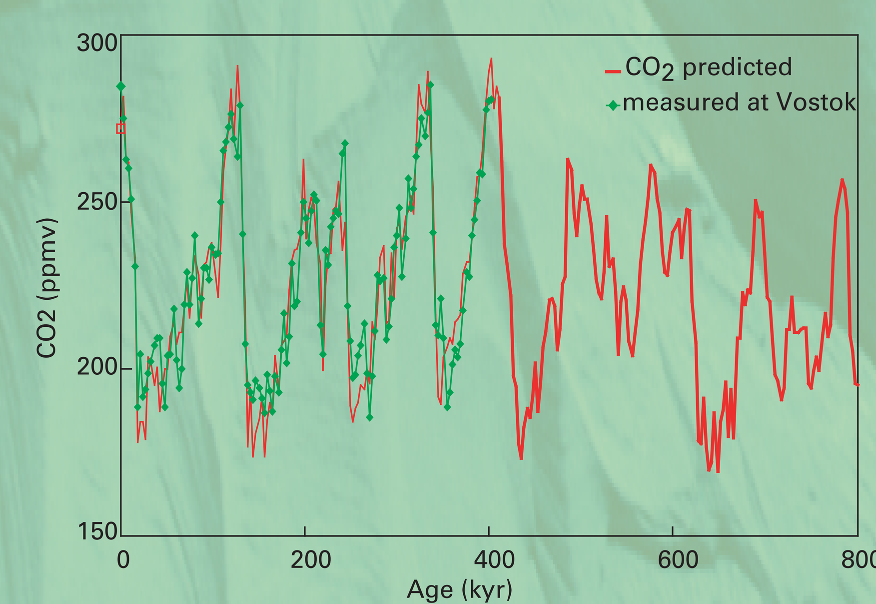
I (Shackleton, Science 2000) showed how the best geological time scale for the past 400 ky can be developed using in particular the O-18 record of atmospheric oxygen in the Vostok ice core. I designed an orbital model for this record and tuned the observed signal to it. In that paper the same techniques were used to improve the orbital tuning of the marine benthic foraminiferal O-18 record. Subsequently I showed that the marine O-18 record can be modelled using an orbital component and a carbon dioxide component (Shackleton 2001,The Role of Carbon Dioxide in the Ice Age Cycles, EUG Abstract). In order to respond to the EPICA challenge from a marine perspective I have inverted this exercise and have predicted the carbon dioxide record from the benthic oxygen isotope record after subtracting the part that is linearly related (with appropriate lags) to orbital forcing. The isotope record used is a splice of records from the East Pacific and I have not re-tuned the earlier part for the present challenge.



Predicting atmospheric CO_2 content, 414 to 738 kyr before the present

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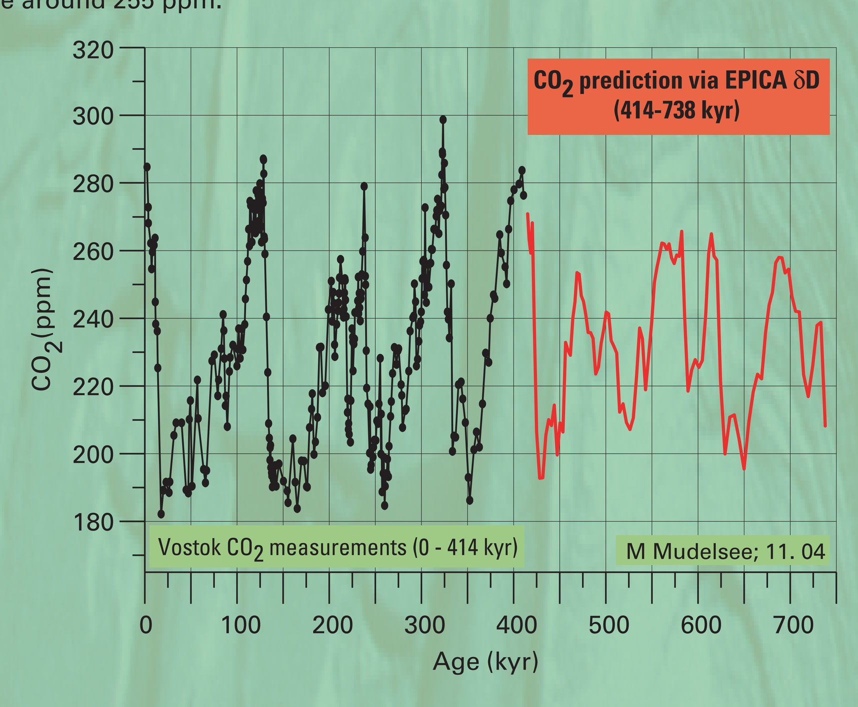
Method:
Prediction of atmospheric CO_2 content for the interval 414 to 738 kyr. The prediction is based on a lagged regression between the Vostok CO_2 (y variable) (Petit et al. 1999 Nature 399:429) and the EPICA δD (x variable) (EPICA community members 2004 Nature 429:623) records for the interval 0 to 414 kyr. The regression equation is given by

$y(t) = a + b\,x(t+l)$, where t is time, a and b are regression parameters and l is a time lag.

The parameters are estimated using a least-squares criterion (Mudelsee 2001 Quaternary Science Reviews 20:583), with the following result:
a = 922 ppm, b = 1.646 ppm/‰ and l = –2.0 kyr. The regression equation is then applied to the EPICA δD record to predict CO_2 for the interval 414 to 738 kyr.

The main characteristics of the predicted CO_2 record are:
(1) CO_2 variations lag behind δD variations (temperature) by 2.0 kyr.
(2) CO_2 minima (in glacials) are around 200 ppm.
(3) CO_2 maxima (in interglacials) are around 255 ppm.



EPICA Challenge

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Below are the results from a conceptual model (Paillard and Parrenin, 2004) that predicts the global ice volume and the atmospheric CO_2 concentration, using only the insolation forcing as an input. The basic idea developed in this model, that deglaciations are triggered by glacial maxima and that the mechanism should involve atmospheric CO_2, follows Paillard (2001). The implementation of this idea shown here (Paillard and Parrenin, 2004) suggests that the low CO_2 values during glacial times are linked to increased deep ocean stratification. This stratification is broken when the Antarctic ice sheet reaches its maximum extent as a consequence of the glacial maximum. This leads to a rapid increase in atmospheric CO_2 and consequently to the deglaciation. The model is dimensionless and the results have been scaled on the figure below to correspond roughly to the observed glacial-interglacial variability recorded at Vostok.

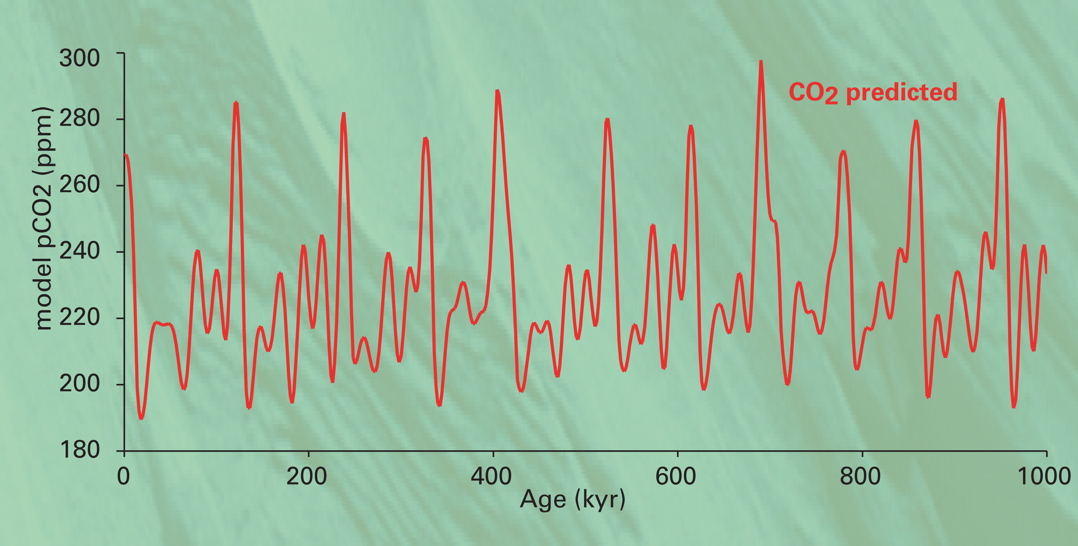

Figure : Results from the conceptual model (Paillard et Parrenin, 2004) for the last million years, after scaling.

Paillard, D. (2001). Glacial cycles: Toward a new paradigm. Reviews of Geophysics 39, 325-346.
Paillard, D., and Parrenin, F. (2004). The Antarctic ice-sheet and the triggering of deglaciations. Earth and Planetary Science Letters 227, 263-271.