Tuning the air content and $\delta O_2/N_2$ EDC ice core records on local summer insolation.

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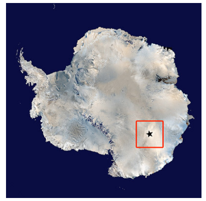
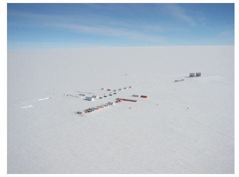




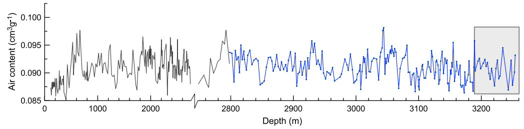
Abstract

A new method of dating the long glacial-interglacial ice core records has emerged during the last 10 years. It is based on properties measured on the air extracted from the ice that are used as proxies of local summer insolation. This dating method is referred to as "local orbital tuning dating". It is an almost absolute dating, providing we better understand the link between the influence of the local summer insolation on the snow grains at the surface and the measured properties in the ice, namely the content and the $\delta O_2/N_2$ ratio of the air enclosed in the ice. Changes in these two properties have already shown convincing correlations with orbitally forced local summer insolation on several Antarctic and Greenland long ice core records.

We present here new air content (*V*) data obtained along the Antarctic EPICA Dome C (EDC) ice core. These data extent the existing record, which covers the last 430 ka (thousands of years before present), to about 800 ka (time resolution of 2 ka on the average). The spectral properties of the new 430 – 800 ka *V* record are primarily obtained by continuous wavelet transform (CWT) analysis. The spectral signature of *V* is compared to its specific Integrated Summer Insolation (ISI) target and the time delay between the *V* signal and its ISI target is calculated. The spectral signatures of *V* and the insolation targets are compared for the 800-440 ka BP period (this work) and the 440-0 ka BP period (Raynaud et al., 2007). The differences between the two periods are discussed. Finally we compare the orbital tuning of EDC by using air content with the one recently obtained on the same core for more specific periods using $\delta O_2/N_2$ (Landais et al., 2012).

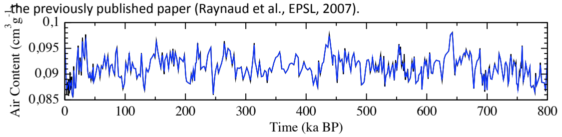
Extension of the EDC air content record (new data)

We have completed the air content (*V*) measurements along the EPICA Dome C (EDC) ice core from 115 m to 3254 m depth with an average time-resolution of 2 ka according to EDC3 time scale (Parrenin et al., 2007).



The new data obtained in the depth range between 2798 and 3254 m extend the existing record (Raynaud et al., 2007), which covered the last 430 ka, to about 908 ka. In both cases the measurements have been performed at LGGE using the barometrical method (Lipenkov et al., 1995). The overall error of the *V* values after correction for cut-bubble effect amounts 1%. The replication of the results is found to be better than 1% and independent on the time of ice core storage (1 to 5 years after drilling), which rules out significant gas loss due to the diffusion of air molecules through ice. It has been shown that the bottom 60 m of the EDC ice core are affected by flow disturbance (grey box, Jouzel et al., 2007). So, in the following analysis, we only consider the last 800 ka of the *V* record obtained above ~3190 m.

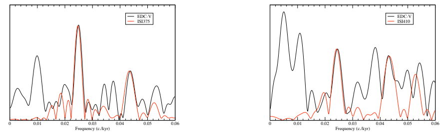
The original data (**black**) are interpolated at 1 ka time step (**blue**) (EDC3 time scale). The record is analysed as two sub-intervals, i.e. 800-440 ka BP and 440-0 ka. The 'cut-off' at 440 ka BP is chosen (1) to include the whole MIS 11 in a single sub-interval and (2) to agree with the previously published paper (Raynaud et al., EPSL, 2007).



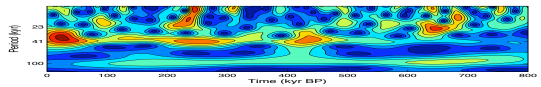
The tuning target (ISI)

1. TMT

The *V* record is compared in the frequency domain to the local Integrated Summer Insolation (ISI), defined as the sum over the year of the daily insolation (Berger, 1978; Laskar et al, 2004) exceeding some threshold. The best agreement, considering the relative amplitude in the TMT analysis at the obliquity and precession frequencies is obtained with ISI375 for the interval 440-0 ka BP (left) and ISI410 for the interval 800-440 ka BP (right).



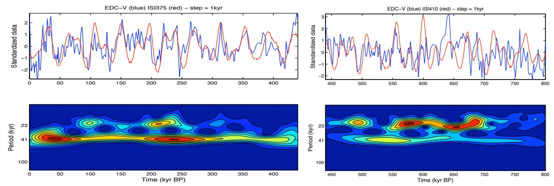
2. Continuous wavelet transform (CWT)



The continuous wavelet transform (Mallat, 1998;Torrence and Compo, 1999) of ISI targets and *V* shows a strong signal in the **obliquity band** in both insolation (not shown) and air content (see figure). This signal is **stronger over the most recent period than over the oldest part of the record**. Moreover, a 100-ka component is also present in the *V* record.

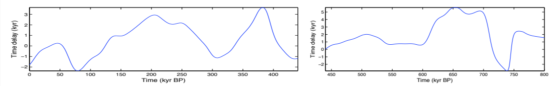
Time delay

The **cross-wavelet** analysis confirms the correlation in the obliquity-band between *V* and ISI.

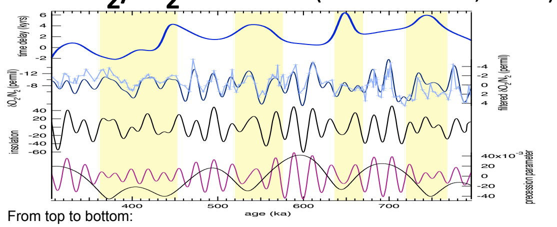


Three **filtering methods** were tested to filter the signal in the 15-46 ka band, i.e. the CWT (the 0.067-0.022 ka^{-1} component of the signal is kept), a piecewise linear filter [sharp slopes at the edges (< 10^{-5} ka^{-1}), band pass (0.044±0.022 ka^{-1}) (Analyseries software, Paillard et al., 1996)], and a finite-duration impulse response filter with a Kaiser window [MATLAB software; Kawamura et al. (2007)]. They give similar results.

The **time delay** between the *V* and ISI records is computed in the 15-46 ka band. The cross-wavelet spectrum of two series, computed from their CWT, provides an estimate of their local phase difference in the time-frequency space. Its integration over a frequency interval provides the instantaneous time lag between the two series in the corresponding frequency band.



Orbital constraints derived from the $\delta O_2/N_2$ record (Landais et al., 2012)



From top to bottom:

−Time delay between $\delta O_2/N_2$ and local summer insolation (21 Dec insolation at 75S).

−$\delta O_2/N_2$ from the EDC ice core (light blue: raw data; dark blue: 1 ka re-sampled and band pass filtered between 15 and 100 ka). Vertical axes are reversed.

- −$\delta O_2/N_2$ has been measured over the deeper part of the EDC ice core (300-800 ka) with an average sampling time of 2.5 ka.
- The $\delta O_2/N_2$ record has been corrected for gas loss effect (except for the periods 380-480 ka and 700-800 ka - ice stored at -50°C).

−75S summer insolation on 21 December.

−Precession (purple) and eccentricity (black).

The time periods highlighted in yellow correspond to large variations in the time delay of $\delta O_2/N_2$ vs. insolation and with low eccentricity.

During the intervals with low eccentricity (around 400 ka and 750 ka), the matching between $\delta O_2/N_2$ and the different insolation curves is ambiguous because some local insolation maxima cannot be identified in the $\delta O_2/N_2$ record (and vice versa).

Conclusions

- The obliquity component of the *V* record is stronger in the most recent part (440-0 ka BP) of the record than in the oldest part (800-440 ka BP).
- The time delays between *V* and its insolation target and between $\delta O_2/N_2$ and its insolation target are showing different behaviours, while they were very similar for the Vostok ice core (Lipenkov et al., 2011). We propose different potential causes for this disagreement can be identified.
  - The choice of the insolation target
  - The filtering method and the filtering interval
  - The quality of the $\delta O_2/N_2$ data must be improved
  - The disagreement appears to be much larger at low eccentricity values
- Therefore further study must be completed before providing a new time scale based on a combination of air records.
- The range of time delays for both *V* and $\delta O_2/N_2$ supports the EDC3 age scale within its published uncertainty (6 ka; Parrenin et al., 2007).

References

Bender, 2002. Earth Planet. Sci. Lett. 204, 275-289.
Berger, 1978. J. Atmos. Sci. 35 (12), 2362-2367.
Landais, A., et al. 2012. Climate of the past, 8, 191-203.
Laskar, J. et al, 2004. Astron. and. Astrophys 428, 261-285. 210.1051/0004-6361:20041335.
Lipenkov, V. et al., 2011. Quaternary Science Reviews, 30 (23-24), 3280-3289. doi:10.1016/j.quascirev.2011.07.013
Mallat, S., 1998. A Wavelet Tour of Signal Processing. Academic Press, San Diego.
Parrenin et al., 2007. Clim. Past, 3, 485–497.
Raynaud, D. et al., 2007. Earth Planet. Sci. Lett. 261, 337-349.
Torrence, C. and Compo, G.P., 1999. Bull. Am. Meteorol. Soc. 79, 61-78.