Constraints on the atmospheric carbon dioxide (CO2) deglacial rise based on its stable carbon isotopic ratio increase (δ13CO2)

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ABSTRACT

The analysis of air bubbles trapped in polar ice permits the reconstruction of atmospheric components over various timescales. Past evolution of greenhouse gases, such as carbon dioxide (CO_2), lies on the frontline of paleorecords understanding. Within this study, the glacial – interglacial oscillations of CO_2 will be examined for the last 160,000 years. This period encompasses two deglaciations.

The simultaneous analysis of the stable carbon isotope composition ($\delta^{13}CO_2$) allows to better constrain the global carbon cycle. Based on the different isotopic signatures of the ocean and the terrestrial biosphere (major reservoirs responsible for the CO_2 oscillations on a glacial – interglacial scale), $\delta^{13}CO_2$ contributes in distinguishing the major sources of CO_2 for the studied periods.

The LGGE method of gas extraction from ice was used in combination with a new instrumental setup to investigate the CO_2 mixing ratio and its stable carbon isotope composition in air from the two last deglaciations at the EPICA Dome Concordia site in Antarctica.

Being challenged from the different ice properties corresponding to the two major periods (being in bubble form for the last and in clathrate form for the penultimate deglaciation), the resulting averaged 3-expansion 1-sigma uncertainty (0.98 and 1.87 ppmv for CO_2, respectively), accompanied by an averaged 0.1‰ 1-sigma for $\delta^{13}CO_2$ for both periods were satisfying enough to exclude any artefact scenario in the experimental protocol.

The resolution of our results (~250 and ~520 years, for last and penultimate deglaciation) allows us to divide Terminations (T) into sub-periods, based on the different slope CO_2 experiences. For T-I (last deglaciation), the four sub-periods revealed climatic events for both hemispheres (*e.g.*: Heinrich I, Bölling/Alleröd, Antarctic Cold Reversal, Younger Dryas), as also shown from polar and oceanic proxies. For the case of T-II (penultimate deglaciation), a similar dynamic pattern

between CO_2 and $\delta^{13}CO_2$ is seen as for T-I, but the synchronization of oceanic events (e.g. Heinrich 11) in our atmospheric record is more delicate due to higher data uncertainties one encounters for such timescales (Lototskaya and Ganssen, 1999; Müller and Kukla, 2004; Pahnke and Zahn, 2005; Skinner and Shackleton, 2006).

Our results show a 76 ppmv CO_2 increase throughout T-I, which is coherent with previously published studies (Barnola et al., 1987; Smith et al., 1999; Monnin et al., 2001). The $\delta^{13}CO_2$ shows a deglacial 0.6‰ decrease accompanying the CO_2 rise, showing clear trends during the different sub-periods. T-II shows similar trends as for T-I but of a larger magnitude: we therefore observe a 104 ppmv rise associated with an overall 0.9‰ decrease.

Several scenarii can explain the abrupt deglacial CO_2 increase, but there is presently no consensus on the exact causes and their respective role. Still, it is presumed that the ocean reservoir contributes the most (Archer et al., 2000; Sigman and Boyle, 2000). As a first interpretation of the obtained T-I coupled CO_2 and $\delta^{13}CO_2$ dataset, the use of two C cycle box models is applied (Paillard et al., 1993; Köhler et al., 2005), validating the initial dominant oceanic role.

The use of polar and oceanic proxies for the atmosphere and the ocean, superposed with our atmospheric signal should provide some responses on the similarities and differences of both deglaciations. Similarities concern forcing factors and the amplifying role of the climatic system towards the external forcing, while differences are mainly focused on different relative timing and magnitudes. We suggest that both signals of CO_2 and $\delta^{13}CO_2$ for both deglaciations can be principally explained from southern ocean stratification breakdown and decreased efficiency of the biological pump, while the delayed decrease of iron supply and of sea ice extent in the austral ocean could be responsible for the unusual patterns seen in the penultimate, compared to the last deglaciation.

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