Abrupt rise in atmospheric CO_2 at the onset of the Bølling/Allerød: in-situ ice core data versus true atmospheric signals

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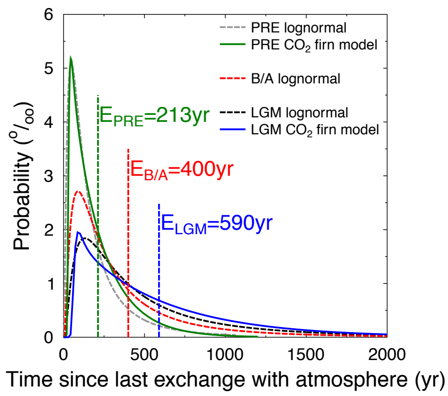
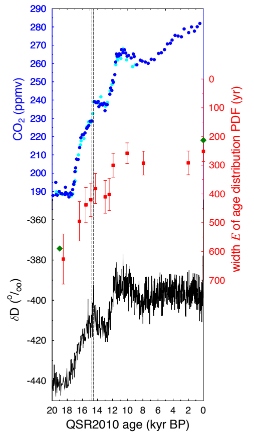
During the last glacial/interglacial transition the Earth's climate underwent abrupt changes around 14.6 kyr ago. Temperature proxies from ice cores revealed the onset of the Bølling/Allerød (B/A) warm period in the north and the start of the Antarctic Cold Reversal in the south. Furthermore, the B/A is accompanied by a rapid sea level rise of about 20 m during meltwater pulse (MWP) 1A, whose exact timing is a matter of current debate. In-situ measured CO_2 in the EPICA Dome C (EDC) ice core also revealed a remarkable jump of 10 ± 1 ppmv in 230 yr at the same time. Allowing for the modelled age distribution of CO_2 in firn we show, that atmospheric CO_2 could have jumped by 20–35 ppmv in less than 200 yr, which is a factor of 2–3.5 larger than the CO_2 signal recorded in-situ in EDC. This rate of change in atmospheric CO_2 corresponds to 29–50% of the anthropogenic signal during the last 50 yr and is connected with a radiative forcing of 0.59–0.75 W m^{-2}. Using a model-based airborne fraction of 0.17 of atmospheric CO_2 we infer that 125 Pg of carbon need to be released to the atmosphere to produce such a peak. If the abrupt rise in CO_2 at the onset of the B/A is unique with respect to other Dansgaard/Oeschger (D/O) events of the last 60kyr (which seems plausible if not unequivocal based on current observations), then the mechanism responsible for it may also have been unique. Available $\delta^{13}CO_2$ data are neutral whether the source of the carbon is of marine or terrestrial origin. We therefore hypothesise that most of the carbon might have been activated as consequence of continental shelf flooding during MWP-1A. This potential impact of rapid sea level rise on atmospheric CO_2 might define the point of no return during the last deglaciation.

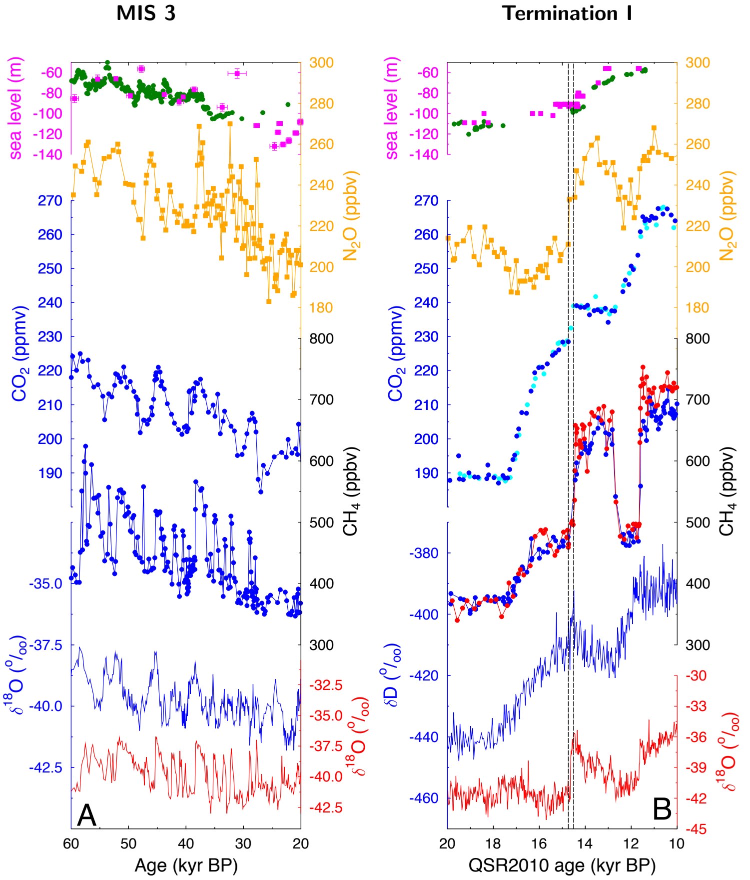
Gas Age Distribution





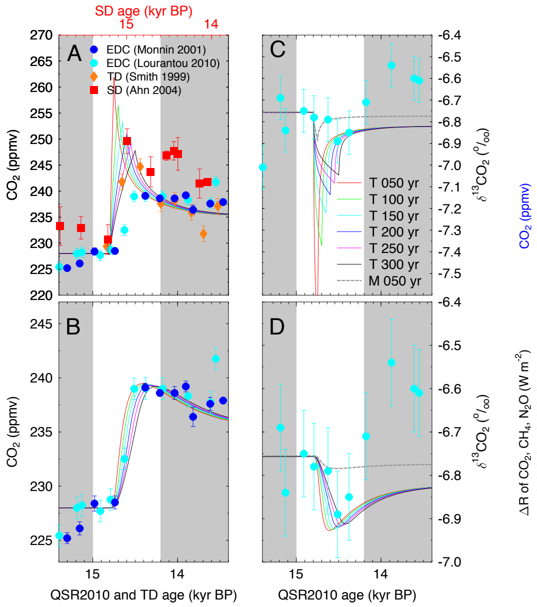
Left: Gas age distribution as function of climate state, here pre-industrial (PRE), Bølling/Allerød (B/A) and LGM conditions. Calculation with a firn densification model (Joos & Spahni 2008) (solid lines, for PRE and LGM) and approximations of all three climate states by a lognormal function (broken). Right: The evolution of the mean gas age ($\pm1\sigma$) during the last 20 kyr calculated with a firn densification model including heat diffusion (Goujon et al. 2003). Green diamonds represent the results for the LGM and pre-industrial climate with another firn densification model (Joos & Spahni 2008). Please note reverse y-axis. Top: EDC CO_2 (Monnin et al. 2001; Lourantou et al. 2010). Bottom: EDC δD data (Stenni et al. 2001). All records on the new age scale (Lemieux-Dudon et al. 2010).

Paleo Records

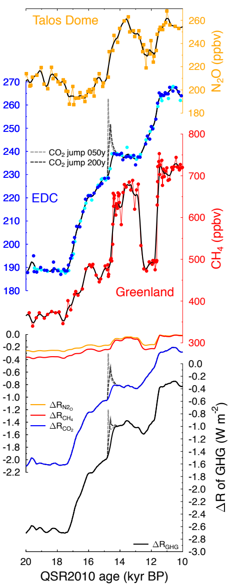


Climate records during MIS 3 and Termination I. From top to bottom: relative sea level, CO_2, CH_4 and isotopic temperature proxies (δD or $\delta^{18}O$) from Antarctica (black) and Greenland (red). (A) MIS 3 data (Ahn & Brook 2008) from the Byrd and GISP2 ice cores. (B) Termination I data from the EDC and NGRIP ice cores (Monnin et al. 2001; Spahni et al. 2005; Stenni et al. 2001; NorthGRIP-members 2004) on the new synchronised ice core age scale (Lemieux-Dudon et al. 2010). Previous (blue) and new (cyan) EDC CO_2 data (Monnin et al. 2001; Lourantou et al. 2010). Sea level in MIS 3 from a compilation (magenta) based on coral reef terraces (Thompson & Goldstein 2007), and the synthesis (green) from the Red Sea method (Siddall et al. 2008) and for Termination I from corals (green) on Barbados, U-Th dated and uplift-corrected (Peltier & Fairbanks 2007), and coast line migration (magenta) on the Sunda Shelf (Hanebuth et al. 2000). Vertical lines in (B) mark the jump in CO_2 into the B/A as recorded in EDC.

Atmospheric CO_2 to Fullfil EDC Data



Radiative Forcing



Left: Simulations of the carbon cycle model BICYCLE for an injection of 125 PgC into the atmosphere. Injected carbon was either of terrestrial (T: $\delta^{13}C = -22.5‰$) or marine (M: $\delta^{13}C = -8.5‰$) origin. Release of C occurred between 50 and 300 years. (A) Atmospheric CO_2 from simulations and from ice cores. Siple Dome (Ahn et al. 2004) (SD, own age scale on top x-axis) and Taylor Dome (Smith et al. 1999) (TD, on revised age scale as in (Ahn et al. 2004)). All CO_2 data synchronised to the CO_2 jump. (B) Simulated CO_2 values of (A) after the application of the gas age distribution potentially be recorded in EDC and EDC data. (C, D) Same simulations for atmospheric $\delta^{13}CO_2$, cyan dots are new EDC $\delta^{13}CO_2$ data (Lourantou et al. 2010). Right: Greenhouse gas records (Talos Dome N_2O, EDC CO_2, Greenland composite CH_4) and their radiative forcing during Termination I. Black lines are running means over 290 yr (to reduce sampling noise) of resamplings with 10 yr equidistant spacing. The two CO_2 jump scenarios are the minimum and maximum injection scenarios from our BICYCLE simulations which are still in line with the in-situ CO_2 data in EDC. The 50-yr and 200-yr injection scenario contains a constant injection flux of either 2.5 and 0.625 PgC yr^{-1}, respectively, over the given time window. The calculated radiative forcing uses equations summarised in (Köhler et al. 2010) including a 40% enhancement of the effect of methane (Hansen et al. 2008).

Meltwater Pulse 1A: The Flooding Hypothesis

Meltwater Pulse 1A (MWP-1A) changed the relative sea level from at maximum –96 m to –70 m. The onset in atmospheric CO_2 falls together with the earliest timing of MWP-1A (grey band) (Hanebuth et al. 2000; Kienast et al. 2003; Deschamps et al. 2009) and might explain 51–93% of the C necessary to be injected into the atmosphere.

References

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