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The ice core record of atmospheric CO2 variability during the Last Glacial Period: new insights from timing and isotopes

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Atmospheric carbon dioxide (CO_2) concentrations during the last glacial period (70,000 – 23,000 years ago) fluctuated on millennial timescales closely following variations in Antarctic temperature. This close coupling has suggested that the sources and sinks driving millennial scale CO_2 changes are dominated by processes in the Southern Ocean. However, recent work revealed centennial-scale increases in CO_2 during abrupt climate events of the last deglaciation which may represent a second mechanism of carbon cycle variability.

Here we analyze a high resolution CO_2 record from the last glacial period from the West Antarctic Ice Sheet (WAIS Divide) that precisely defines the timing of CO_2 changes with respect to Antarctic ice core proxies for temperature, dust delivery, and sea-ice extent down to the centennial-timescale. Although CO_2 closely tracks all these proxies over millennia, peak CO_2 levels most often lag behind all proxies by a few hundred years. This decoupling from Antarctic climate variability is most prominent during the onset of DO interstadial events when CO_2, CH_4 and Greenland temperature all increase simultaneously. Regression analysis suggests that the CO_2 variations can be explained by a combination of two mechanisms: one operating on the time scale of Antarctic climate variability, and a second responding on the Dansgaard-Oeschger time scale.

Recent $\delta^{13}C$-CO_2 data from the last glacial period support our finding that CO_2 variability is the sum of multiple mechanisms. The Antarctic climate variability is likely associated with the release of respired organic carbon from the deep ocean. Superimposed on these oscillations are two types of centennial-scale changes: CO_2 increases and $\delta^{13}C$-CO_2 minima in the middle of Heinrich stadials and ii) CO_2 increases and small changes in $\delta^{13}C$-CO_2 that at the onset of DO interstadial event.

To provide a comprehensive and quantitative constraint on the mechanisms of CO_2 variability during the last glacial period, we run a large suite of transient box model experiments (n = 500) forced with varying combinations of forcings based on proxy time-series (e.g. AABW formation, NADW formation, ocean temperature, dust delivery, and sea-ice extent). Using data constraints from the ice core records of CO_2, $\delta^{13}C$-CO_2 and mean ocean temperature, we arrive at an ensemble of scenarios that can explain a large amount of the centennial and millennial-scale variability observed in the ice core record. Parsing this into a series of factorial experiments we find that Southern Hemisphere processes can explain 80% of the observed variability and

Northern Hemisphere processes account for the remaining 20%. A further breakdown on the level of individual mechanisms is marred by the high degree of correlation between carbon cycle forcings likely operating in the Southern Hemisphere. None-the-less, our results highlight how multiple mechanisms operating over multiple timescales may have interacted during the last glacial period to drive changes in atmospheric CO_2.