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Isotopic Constraints on Holocene Carbon Cycle Dynamics

Content

During the latter half of the Holocene, atmospheric CO_2 slowly rose about 25 ppm until the onset of the Industrial Revolution. The drivers of this rise, and particularly how they might vary with time, remain unclear. Sources of CO_2 from early anthropogenic land-use change are thought to have been largely offset by the regrowth of peatland, but the precise magnitude and timings of these opposing fluxes are uncertain. Additional sources of CO_2 include the gradual build-up of coral reefs following sea level rise, a widely debated contribution from enhanced volcanism driven by mantle unloading, and an increase burial of deep-sea $CaCO_3$.

We present a new record of the concentration and isotopic of atmospheric CO_2 from the South Pole Ice Core over this crucial time interval. Reliable atmospheric gas concentrations are recorded to at least 6,500 years BP; older sections are gradually compromised due to the preferential formation of CO_2 clathrates in the bubble-clathrate transition zone. The coverage includes the bulk of the 25 ppm increase CO_2 during the later Holocene with an average resolution of 125 years and precisions of 0.6 ppm for CO_2 and 0.02 per mil for δ^{13}C-CO_2(1-sigma standard deviation of replicates)

The broad trends in the data show a slight increase in δ^{13}C-CO_2 from 6,500 to 4,000 years BP followed by a more substantial decrease towards the last millennium. Superimposed on these trends are previously unresolved variations in δ^{13}C-CO_2 on the order of 0.10 per mil that oscillate with periodicities about 1,000 years.

To diagnose and quantify sources histories we use a carbon cycle model capable of deconvolving atmospheric CO_2 and/or δ^{13}C-CO_2 changes based on a variety of mechanisms (a so-called single/double deconvolution technique). The early CO_2 rise up to about 4,000 years BP can be attributed to a combination of reef building, volcanic emissions and $CaCO_3$ compensation with some minor high-frequency changes in land carbon storage. Our top-down constraints changes are broadly consistent with the magnitude from bottom-up estimates, however, the timings of all proposed changes in reef and volcanic emissions tend to occur earlier than indicated by the ice core data.

Starting about 3,000 years BP, a source of CO_2 from land carbon turns on that drives most of the CO_2 increase thereafter and outpaces the regrowth of peatlands. The strength of this source generally exceeds the rate of change of all anthropogenic land-use scenarios until converging with the very high-end scenarios during the last millennium. This divergence could be due to land-use being under-estimated from about 3,000 to 1,000 years BP or a hitherto unidentified natural source of carbon. Superimposed on this source are oscillations that show local maxima in a land carbon source at ~2,900, 1,800 and 1,000 years BP (~950 BCE, 150 CE and 950 CE).

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