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Last millennium atmospheric CO_2

by Elisabeth Michel

The first continuous measurements of atmospheric CO_2 (1) indicated that its concentration was increasing as a result of human activities. Since then, the impact of this increase on our environment, and more specifically on the future climate, has been investigated using 1-D to 3-D models of different complexity. In the 1980s, records from ice core archives of the atmospheric CO_2 and of its stable isotope composition since 1750 A.D. (2, 3) revealed the exponential increase of its concentration and the correlated decrease of $\delta^{13}C$ (Suess effect). Using these records, model studies have often assumed a pre-industrial equilibrium state before 1750 A.D., with a constant atmospheric carbon dioxide concentration of 280 ppmv. However, to predict future impact of the anthropogenic perturbation on the carbon cycle, it is necessary to document past natural changes. First, this will allow us to check that models reliably represent the global carbon cycle by reproducing these changes, and second, the anthropogenic perturbation interacts with the natural variations so it is necessary to take the latter into account to predict the future environment.

Over the Pleistocene glacial-interglacial cycles, climate and atmospheric carbon dioxide have been closely linked. Ice core records have shown that during glacial periods the atmospheric CO_2 concentration was reduced to two-thirds compared to warm interglacials (4). On a smaller scale, during the last millennium the Earth has undergone climate changes that have influenced human societies. There are now ice core records from Antarctic sites indicating that CO_2 concentrations in the air bubbles underwent changes on the order of 10 ppmv during this period (5, 6). However, ice core records are not direct atmospheric records. Beside physical processes occurring in the firn before the trapping of air bubbles, diffusion and gravitation, small CO_2 production *in situ* due to chemical reactions with impurities (7, 8, 9) possibly occurs and alters by a few

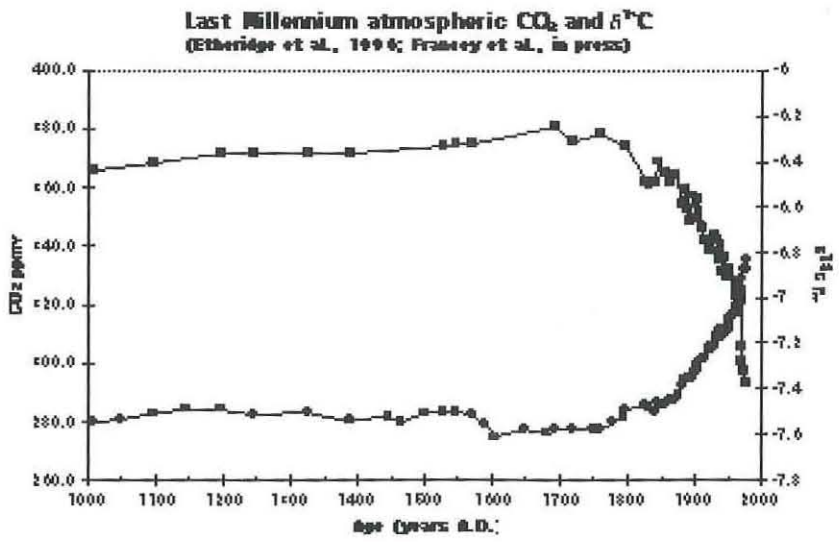

Figure 1. Atmospheric CO_2 and its stable isotopic composition reconstructed from Law Dome ice cores, Antarctica.
1: CO_2 atmospheric concentration;
n: isotopic $\delta^{13}C$ composition of the CO_2.

ppmv the original signal. The impurities concentrations are much lower within Antarctic than Greenland cores, so the probability of artefacts within records the last millennium records from Antarctic ice cores should be rather small.

For the beginning of this period, from 1000 to 1400 A.D., the two CO_2 records (5,6) have a lower resolution and they possibly show a different behaviour, so it is difficult to assess the real atmospheric CO_2 variations during that time. Other records would be needed to document the interesting medieval warm period. In the more recent part of the records, both indicate lower atmospheric CO_2 concentrations by up to 6 ppmv during the 17th and 18th centuries. This period corresponds to the "Little Ice Age" well documented in Europe (10). The Little Ice Age is marked by regional temperature decrease within the northern hemisphere over the continent as well as for sea surface (11, 12).

On Law Dome ice core the isotopic variation $\delta^{13}C$ of the CO_2 from the air bubbles has also been measured but with a lower resolution (13). Before the decrease since 1800 A.D. attributed to human perturbation, the isotopic record also exhibits variability. During the Little Ice Age, while CO_2 atmospheric concentration was lower by 6 ppmv, its isotopic composition was enhanced.

A global sea surface decrease during the Little Ice Age would produce a decrease of the atmospheric CO_2 but also a decrease of its isotopic composition $\delta^{13}C$ due to the temperature dependence of the isotopic fractionation during air-sea exchange.

As for the terrestrial biosphere, a lower temperature could also produce a decrease of atmospheric CO_2 due to a larger decrease for soil respiration than for net primary production. In this case enhanced isotopic $\delta^{13}C$ values would go with the lower CO_2 concentration of the atmosphere. Thus the CO_2 isotope ice record is coherent with regional cooling over the land and is not consistent with a global cooling of the sea surface temperature (13, 14).

The beginning of the CO_2 increase around 1750 A.D., as revealed by the first ice core record (2), has often been attributed to anthropogenic fossil fuel use. In the light of these new records giving the atmospheric CO_2 and $\delta^{13}C$ variations over the last millennium, it appears that the first part of the increase was rather the recovering from the Little Ice Age (14, 15), the human influence on the CO_2 concentration of the atmosphere becoming obvious shortly before 1850 A.D.

These new data documenting the last millennium offer a great opportunity to understand the natural variability of the atmospheric CO_2 on the decadal to centennial time scale. The increasing precision of these ice core data on the more recent period gives new boundary conditions for the carbon cycle model studies. A few other higher resolution records are needed to complete our knowledge of the natural variability over century time scale, in particular to precisely document the Medieval Warm Period. The anthropogenic effects on the carbon cycle are overprinted on such variations and may interact with them, involving the land biota as well as the ocean behaviour. Thus model studies need to be able to reproduce and to take into account the natural variations when modelling the future of the carbon cycle.

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