Paleoclimate and CO_2

Temperature and CO_2 over the Past 400 Thousand years

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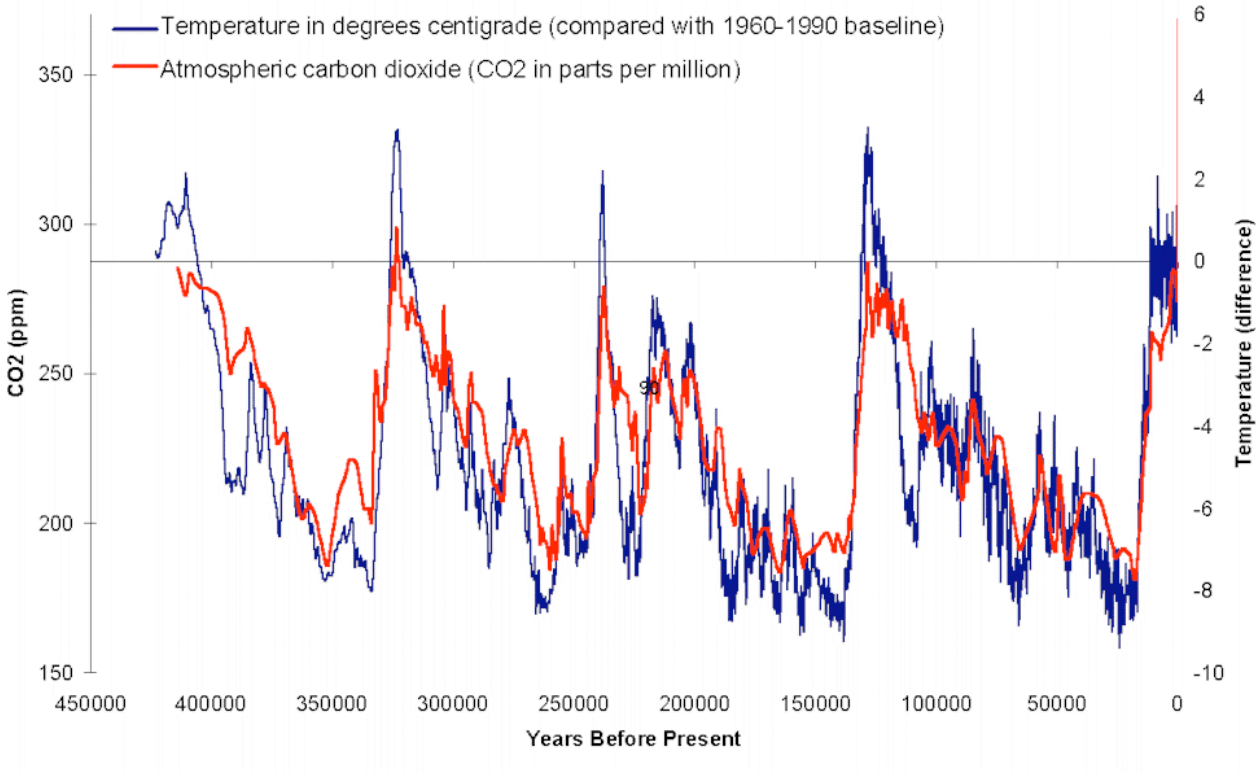

This figure shows the temperature record from the Vostok ice core (dark blue), together with CO_2 (red) from the Vostok ice core, the Law Dome ice core, and from the Mauna Loa monitoring station in Hawaii. The near vertical line on the right represents the change in CO_2 associated with the industrial revolution.

Changes in temperature precede changes in CO_2, with a lag of around 800 years.

There is, overall, a good match between temperature and CO_2 and temperature. One important piece of information that can be determined from ice core data is whether changes in temperature follow or proceed changes in CO_2. Before doing this, it is important to keep in mind sources of error that can complicate the analysis:

1. The resolution of the data are quite low, with each data point representing an average of some 1000 years. As Monnin et al (2001) point out: "*CO2 records from Vostok and Taylor Dome are thought to be the most accurate. However, the time resolution of these two records is too low to provide a history of CO2 changes that shows the detailed evolution of atmospheric CO_2 over the last glacial termination.*"
2. The data are not error free. Not only are there potential experimental errors, but there are difficulties in matching gas age (i.e. CO_2) and ice age (i.e. temperature). Then too there are potential errors in the models that create the signal from the raw data, which may not be perfect. In fact, in the figure shown above, there is an error in the way that the temperature data were calibrated. This has since been corrected. Although this figure does not show the corrected data, the effect can be seen in Cuffey & Vimeux, 2003. The result is a closer match between CO_2 and temperature, especially at the period of the beginning of the last ice age.
3. The CO_2 and temperature signals are not directly comparable. This is because the temperature signal is local, whereas the CO_2 signal is global. As Fischer et al, 1999 point out: "*Note that the CO2 concentrations represent essentially a global signal. In contrast, the geographical representativeness of isotope temperature records may vary from a synoptical to hemispherical scale and accordingly within different cores with increasing variability for shorter time scales.*"
4. There are other factors that affect temperature besides CO_2, such as methane, aerosols and glaciation.

To reduce this problem, it is best to look at multiple ice cores, and to use a variety of analytical techniques (where possible). The ice core record from Dome Concordia, although shorter than that from Vostok, has a higher resolution. Monnin et al (2001) examined the Dome C record, and found a very close correlation between CO_2 and temperature over the last glacial maximum, with CO_2 lagging by, on average, 400 years (however, the *initiation* of the rise in CO_2 lagged the initiation of the rise in temperature by around 800 years).

Fischer et al, 1999 looked at the Byrd, Taylor Dome, and Vostok cores, and reached a similar conclusion: "*Atmospheric CO2 concentrations show a similar increase for all three terminations, connected to a climate-driven net transfer of carbon from the ocean to the atmosphere. The time lag of the rise in CO2 concentrations with respect to temperature change is on the order of 400 to 1000 years during all three glacial-interglacial transitions.*"

Finally, Caillon et al 2003 sought to reduce the potential for error by using argon isotopes to measure temperature, rather than water ice (which gets around the

problem of reconciling gas age and ice age). They found a good correlation between CO_2 and temperature over Termination II, again with CO_2 lagging temperature by around 800 years.

These results fit well with the standard explanation for the Ice Ages, which is that an initial temperature trigger (for example, changes in the earth's orbit), result in release of CO_2 and other greenhouse gases to the atmosphere (for example, release of CO_2 from the ocean as it warms). As the greenhouse gas concentration in the atmosphere builds up, it results in more warming and further release of greenhouse gases (i.e. a feedback cycle).

Although the data, on average, fit this hypothesis very well, there are some inconsistencies. It is likely that these result from one or more of the potential sources of error listed above.

Vostock data are available from http://www.ngdc.noaa.gov/paleo/icecore/antarctica/vostok/vostok.html, Law Dome ice data are available from http://www.ngdc.noaa.gov/paleo/icecore/antarctica/law/law.html, and Mauna Loa data are available from http://cdiac.esd.ornl.gov/trends/co2/sio-mlo.htm.

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