Part II

The Carbon Cycle

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The Sky is Rising!

Callendar, G.S. (1938). The artificial production of carbon dioxide and its influence on climate. *Quarterly Journal of the Royal Meteorological Society*, **64**, 223–240. 17 pages.

This is essentially three papers in one, which combine to assert for the first time that human activity could change the climate of the Earth.

The first leg of the paper is a claim that atmospheric CO_2 is already rising due to human activity. Callendar cited measurements of the CO_2 concentration from around the year 1900, and again from about 1935. The values available to him were very close to modern measurements from fossil air samples preserved in ice cores, and the CO_2 concentration had indeed risen in that time interval. Callendar compared the atmospheric CO_2 rise with industrial emission of carbon, which he underestimated somewhat and so ended up with an airborne fraction of 75%, a bit higher than the current best guess, for his time and ours, of about 50% airborne fraction of emitted CO_2 during a CO_2-emitting era.

Callendar apparently constructs a conceptual picture of the carbon cycle dominated by ocean uptake, but unfortunately does not elaborate very much on how he imagined the carbon cycle to work. He projected the future trajectory of atmospheric CO_2 concentration. Callendar showed the sensitivity of the CO_2 rise to the overturning time scale of the ocean, which he bracketed by values of 2000 and 5000 years (a modern estimate is about 1000 years). Presumably he imagined that the ocean would absorb essentially all of the CO_2 on this time scale, so that a slow mixing time would mean slower CO_2 uptake, and higher atmospheric concentration. It cannot have been obvious that ocean uptake would be slow; gazing at a blue globe of the mostly water-covered Earth, it would be easy to imagine that the ocean would equilibrate quickly, even continuously, with the atmosphere. In this realization, Callendar appears to be ahead of Revelle and Suiss two decades later, who concluded that the ocean would take up CO_2 in only a decade (Fig. 12.1).

Callendar's projections of future evolution of atmospheric CO_2 suffered from his assumption of constant emissions with time, rather than the exponential growth in CO_2 emissions, which has persisted from his day to ours. Arrhenius stated that it would take 1000 years for human activity to double the CO_2 concentration of the atmosphere, and Callendar is not far off from this trajectory either. The two authors spun the conclusion entirely differently, however. Arrhenius figured that there is nothing to worry about because the CO_2 rise is so slow, and that anyway a little warming would be OK. Callendar was astonished that human activity could change CO_2 at all, but thought that anyway a little warming would be OK.

The second leg of Callendar's paper was a recalculation of the radiative impact of rising CO_2 concentration, and its impact on the Earth's temperature. The spectral data were probably better than Arrehnius', but in a few conceptual ways his calculation was a step backward from what Arrhenius had done. Like Plass, Callendar held the temperature of the atmosphere fixed, and calculated the change in the ground temperature by adding to the initial steady state energy balance an additional source of heat from the downward radiation from higher CO_2 concentration. Arrhenius also reasoned out the water vapor feedback, but neither Plass nor Callendar took advantage of his insight.

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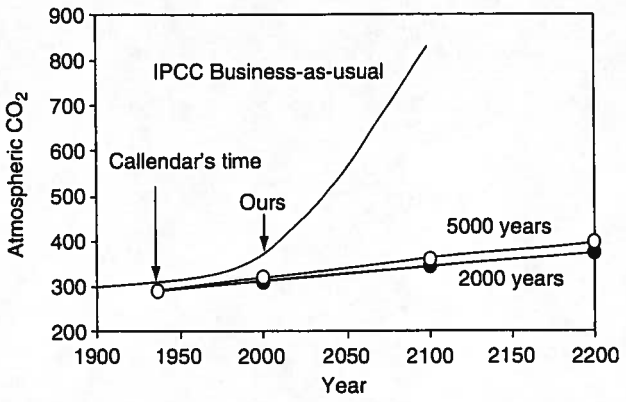

Fig. 12.1 **Projections of atmospheric CO_2 concentration, from Callendar (lines with symbols) and the present (to 2000, followed by IPCC 1992 Business-as-usual Scenario A, line with no symbols). The difference is largely due to exponentially increasing emissions, which Callendar did not anticipate.**

The third leg of the paper was a reconstruction of northern hemisphere temperature variations through time. Callendar considered the urban heat island effect, which turns out to be small but that has been a source of concern as a potential effect to this day. Callendar's reconstruction agrees well with subsequent reconstructions including those presented in the IPCC Fourth Assessment Report. The slight rise in temperature from 1900 to his time looked to Callendar like the signature of global warming. In this regard, Callendar is now believed to be wrong; the human influence on climate is not thought to have risen above natural variability until the 1970s.

John Callendar is probably best known as the first to piece together the carbon cycle of the Earth as it pertains to the question of global warming. This is the thinnest part of the paper. One of the reviewers, whose comments are printed at the end of the paper, asked for more details on Callendar's thinking on the carbon cycle, to which Callendar replied that his musings on this subject were fully eight times longer than the rest of the paper, and he was unable to publish this for lack of space. He might have done better to skimp on some of the more traditional work in the rest of the paper.