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Understanding Increasing CO_2 in the Atmosphere

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Abstract

The carbon cycle is of great importance to understand the influence of anthropogenic emissions on the atmospheric CO_2 concentration, and thus, to classify the impact of these emissions on global warming. Different models have been developed, which under simplified assumptions can well reproduce the observed CO_2 concentration over recent years, but they also lead to quite contradictory interpretations of the human impact. In this contribution we consider, how far such suppositions are realistic or must be made responsible for significant misinterpretations. We present own calculations based on the Conservation Law, which reproduce all details of the measured atmospheric CO_2 concentration over the Mauna Loa Era. From these calculations we derive an anthropogenic contribution to the observed increase of CO_2 over the Industrial Era of only 15%. The importance of only one unitary time scale for the removal of anthropogenic and natural CO_2 emissions from the atmosphere, characterized by an effective absorption time, is discussed.

Keywords: Carbon Cycle; atmospheric CO_2; natural emissions; anthropogenic emissions

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1. Introduction

The Copenhagen Climate Conference and Pre-Conference made it possible to exchange different aspects about one of the most controversially discussed topics in climate science, the carbon cycle.

In this contribution we briefly review the Intergovernmental Panel on Climate Change's (IPCC's) view of increasing CO_2, before comparing this with our own approach (Harde 2023).

Most of the presented results derived from a closer cooperation with the late Murry Salby, whose work on the carbon cycle already more than ten years ago raised significant doubts about the IPCC's explanation, particularly the assertion of an exclusively man-made increase of CO_2.

2. IPCC's Explanation of Increasing CO_2

The IPCC assumes, before 1750 and in good approximation before 1850 the carbon cycle was in balance with an atmospheric CO_2 concentration of about 280 ppmv (in short: ppm) and with in- and outfluxes of approximately 80 ppm/yr.

Over the Industrial Era, so the IPCC, this cycle has come out of balance, now with a concentration of about 410 ppm and an additional flux of 26 ppm/yr, only caused by fossil fuels and land uptake (average over ten years: see AR6 - IPCC's Sitxh Assessment Report 2021, Chap. 5, Fig. 5.12).

Actually, human emissions increased to 4.8 % (5.1 ppm, GCB 2022) of the total emissions, from which about 54 % (2.8 ppm) are directly absorbed by the oceans and land, the rest, the so-called airborne fraction AF with about 46 % cumulates in the atmosphere. This is made responsible for the rapidly rising CO_2 concentrations C_{CO2} over the Industrial Era with approximately 130 ppm.

The removal of this additional CO_2 from the atmosphere is expected to take up to a few hundred thousand years and is described by different adjustment times τ_{Ai}. On the other hand, the residence time τ_R as ratio of the actual concentration to the total emission or absorption is only 3.8 yr.

As balance of the in- and outfluxes, and thus, the CO_2 changes over time this is described by the Conservation Law of CO_2 in the atmosphere:

$$\frac{C_{CO2}}{dt} = e_A(t) - (1 - AF) \cdot e_A(t) = AF \cdot e_A(t) \qquad (1)$$

with $e_A(t)$ as the anthropogenic emission rate (GCB 2022) and (1-AF)$\cdot e_A(t)$ as absorption rate.

Integration of the balance equation then can directly by compared with the monthly measurements at Mauna Loa, Hawaii (Fig. 1, Blue Triangles, CDIAC 2022).

With an airborne fraction AF = 45.6 % and a CO_2 concentration in 1960 of $C_{CO2}(1960)$ = 314 ppm this gives a surprisingly good agreement shown as Pink Diamonds. The year-to-year AF_y is displayed as Green Squares.

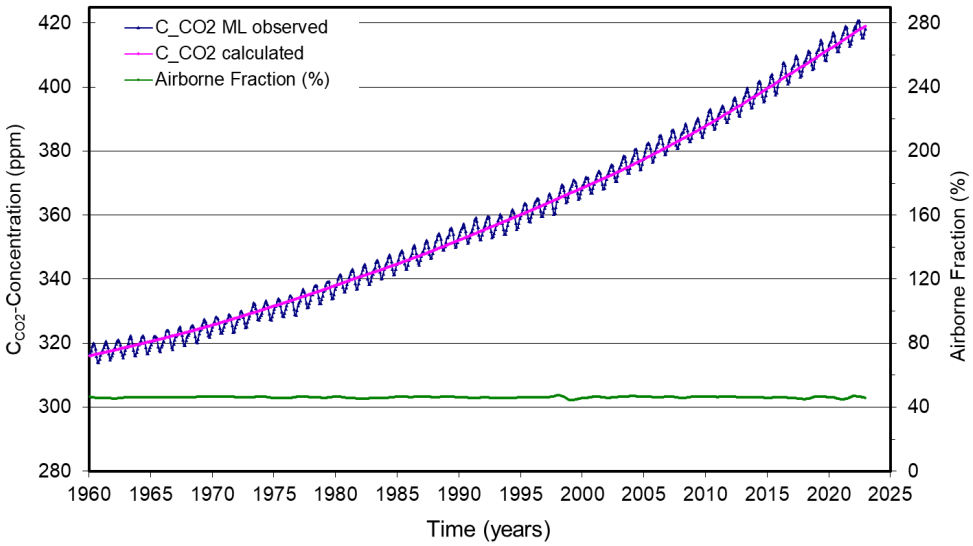

Figure 1: Observed monthly CO_2 concentration at Mauna Loa (Blue Triangles) together with a calculation, only considering anthropogenic emissions $e_A(t)$ and a concentration $C_{CO2}(1960) = 314$ ppm (Magenta Diamonds). Also plotted is the year-to-year airborne fraction AF_y (Green Squares).

But a high correlation is no evidence for the right theory, particularly not, when some basic physical principles are ignored. So, the main inconsistencies of this interpretation are:

- A constant natural cycle and neglection of additional native emissions
  → *contradicts paleoclimatic and actual observations* (Petit et al. 1999; Palmer et al. 2019; Salby & Harde 2021b).
- One fraction of human emissions is cumulating in the atmosphere over several 100.000 yr, the other part is instantaneously absorbed
  → *violation of the Equivalence Principle* (Harde 2019, Subsec. 3.4 and 5.2).
- The absorption is considered to be proportional to the emission, not to the concentration
  → *is in dissent to native decay processes and the ^{14}C-decay after the Nuclear Test Ban Treaty*.
- The more elaborate Bern-Model, also used by the IPCC, considers even 5 different absorption channels, again proportional to the emission and, at least partially, working in series
  → *contradicts observed parallel uptake of different reservoirs* (Harde 2019, Subsec. 5.5).

As some slightly modified version of the simple AF-model, some authors consider a 1st order

absorption $A = C_{A,CO2}/\tau_A$ that scales proportionally to the concentration, but only to the fraction $C_{A,CO2}$ caused by anthropogenic emissions, and which is controlled by a single adjustment time τ_A (e.g.: Siegenthaler & Sarmiento 1993; Dietze 2001; Cawley 2011; Lüdecke & Weiss 2016). Any changes of natural emissions over the Industrial Era are again neglected, instead a constant natural fraction $C_{N,CO2} = 280$ ppmv as in pre-industrial times is assumed. An exchange with extraneous reservoirs is presumed as quasi-closed cycle at a rate $e_N \approx 80$ ppmv/yr and with a turnover or residence time $\tau_R = C_{N,CO2}/e_N = 3.5\ yr$.

For an adjustment time τ_A between 45 yr and more than 100 yr, dependent on the considered boundary conditions, this gives also good agreement with the measurements at Mauna Loa. But again, this results in different timescales and an effectively separate treatment of natural and anthropogenic emissions in these models (see: Harde 2019, Subsec. 5.1; Harde 2023).

3. Our Approach to the Carbon Cycle

3.1 Radiocarbon as Tracer

For a deeper understanding of increasing CO_2, it is worthwhile to look closer to measurements of radiocarbon, which is an ideal tracer for the uptake of atmospheric CO_2 by the biosphere and oceans. While in the early 1960s the concentration of the isotopologue $^{14}CO_2$ was almost twice of the natural concentration, with the stop of the nuclear bomb tests in 1963 it was possible to measure this radiocarbon perturbation over subsequent years.

Plotted in Fig. 2 is the corrected and normalized ^{14}C-anomaly at Vermunt (Levin et al., 1994) as Green Squares, distinguished by seasonal emissions over the first 6 to 7 years, which are explained by the Brewer-Dobson circulation, injecting $^{14}CO_2$ from the stratosphere to the troposphere (see: Harde & Salby 2021; Salby & Harde 2021a). Nevertheless, this decay can be well approximated by a single exponential and an e-folding time τ_{eff} of 10 yr, shown as Magenta Graph. This confirms an absorption proportional to the instantaneous concentration and gives also an orientation for the timescale of this process.

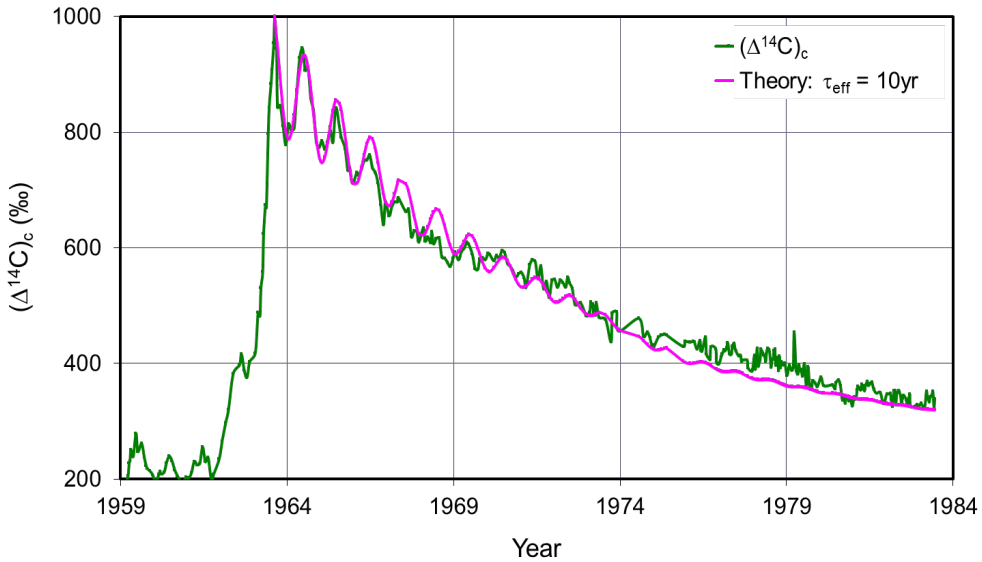

Figure 2: Anomalous ^{14}C measured at Vermunt, $(\Delta^{14}C)_C$ (Green), compared against calculated $(\Delta^{14}C)_C$ with an effective absorption time of $\tau_{eff} = 10\ yr$ (Magenta).

The effective absorption time τ_{eff} accounts for a partial re-emission of directly absorbed $^{14}CO_2$ with a time constant τ, which can even be as short as 1 yr, as follows from these oscillations and similarly, from cross-correlation analyses of interannual CO_2 and temperature fluctuations (Hum-

lum et al. 2013). When these molecules are not completely removed from the upper layers, they can still be re-emitted with a fraction β. The respective balance equation then takes the form:

$$\frac{dC_{C14}}{dt} = e_{NB} + \beta\frac{C_{C14}}{\tau} - \frac{C_{C14}}{\tau} = e_{NB} - (1-\beta)\frac{C_{C14}}{\tau} = e_{NB} - \frac{C_{C14}}{\tau_{eff}}, \qquad (2)$$

with e_{NB} as the native and the attenuating seasonal bomb perturbations (see: Harde & Salby 2021). For an effective absorption time of τ_{eff} = 10 yr and a direct absorption time, e.g., equivalent to the residence time τ_R = 3.8 yr, β becomes 0.62.

What we find for $^{14}CO_2$ as tracer also holds for the total CO_2 cycle.

3.2 Carbon Cycle Including Anthropogenic and Natural Emissions

A consequent approach, which is in agreement with all observations and physical causalities includes also natural emissions (seasonal and temperature dependent contributions), a common CO_2 concentration and only one time scale. The respective Conservation Law then takes the form:

$$\frac{dC_{Co2}}{dt} = e_A(t) + e_N(T,t) - \frac{C_{CO2}}{\tau_{eff}} \qquad (3)$$

$$\text{with:}\quad e_N(T,t) = e_{N0} + e_T(\Delta T,t) + \frac{e_{S0}}{2}\cdot\{1 + cos(\omega(t-t_0) + \phi_e + m\cdot sin\,\omega\,(t-t_0))\},$$

and with: e_{N0} – undisturbed emission rate; $e_T(\Delta T,t)$ - temperature dependent emission rate with ΔT as the temperature anomaly at Hawaii; e_{S0} - seasonal cycle amplitude; ϕ_e - phase term. Implicitly included is the re-emission term $\beta\cdot C_{CO2}/\tau$.

Integration of the conservation law with an effective absorption time of 10 yr is shown as Magenta Diamonds and almost completely covers the Blue Graph of the Mauna Loa measurement (Fig. 3).

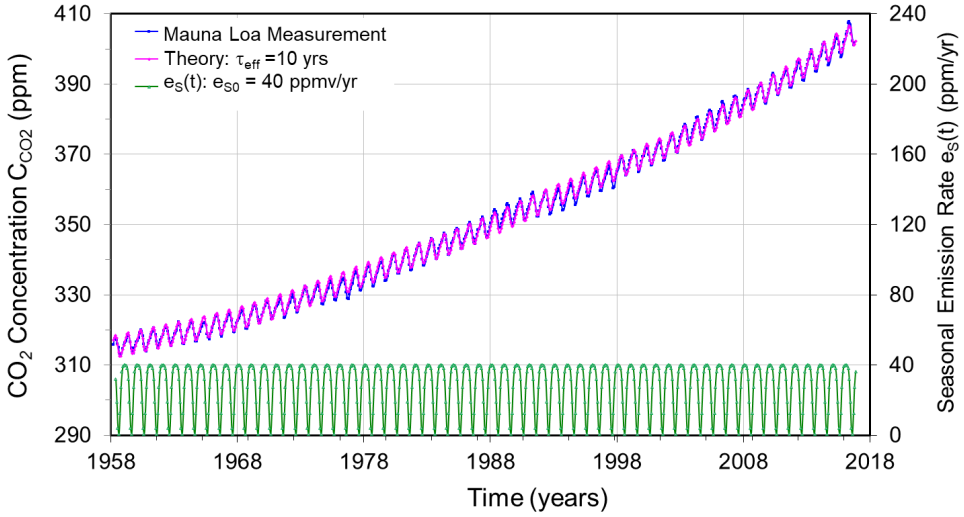

Figure 3: Calculated evolution of CO_2 (Magenta) for an effective absorption time τ_{eff} =10 yr and observed evolution (Blue). Also shown is the seasonal modulation of emission (Green).

The seasonal emission rate with an amplitude of 40 ppm/yr is displayed as Green Triangles and is even 5 to 6 times the human emissions. Not only can the long-time behavior be well reproduced, as with the other models, but even on a magnified scale tracts the calculation the measurement in amplitude and shape, the latter controlled by the phase modulation term (Harde & Salby 2021).

Within some bounds this observed evolution can also be recovered for other values of the emission rate and absorption time. This is a consequence of the fact that the CO_2 concentration is essentially determined by the product of the total emission rate and the absorption time. A change in one can therefore be compensated by a change in the other. However, this only works for τ_{eff}

shorter than 10 -11 yr. For larger absorption times either the long-time evolution is increasing too rapidly, or the seasonal modulation depth gets too small (Harde & Salby 2021). So, these simulations represent an independent but consistent possibility to the ^{14}C-decay to derive an upper limit for the absorption time, which can only be 10 years or shorter.

Fig. 4 shows again the measured CO_2 concentration as Blue Triangles and on top as Magenta Diamonds a calculation for τ_{eff} = 3.8 yrs, equal to the residence time. The anthropogenic emissions, actually with 4.8% of the total flux, is displayed by the lower graph (Plum Squares). Separately plotted is the native CO_2 fraction (Green Dots) and the anthropogenic fraction $C_{A,CO2}$ (Aqua Triangles) with about 20 ppm in 2022 (right abscissa). Relative to the increased concentration of 135 ppm since 1850 the anthropogenic contribution is just 15 %. And this is even a more conservative value, since with a still shorter direct absorption time, as expected under non-equilibrium conditions, the anthropogenic fraction will further reduce (Salby & Harde 2022).

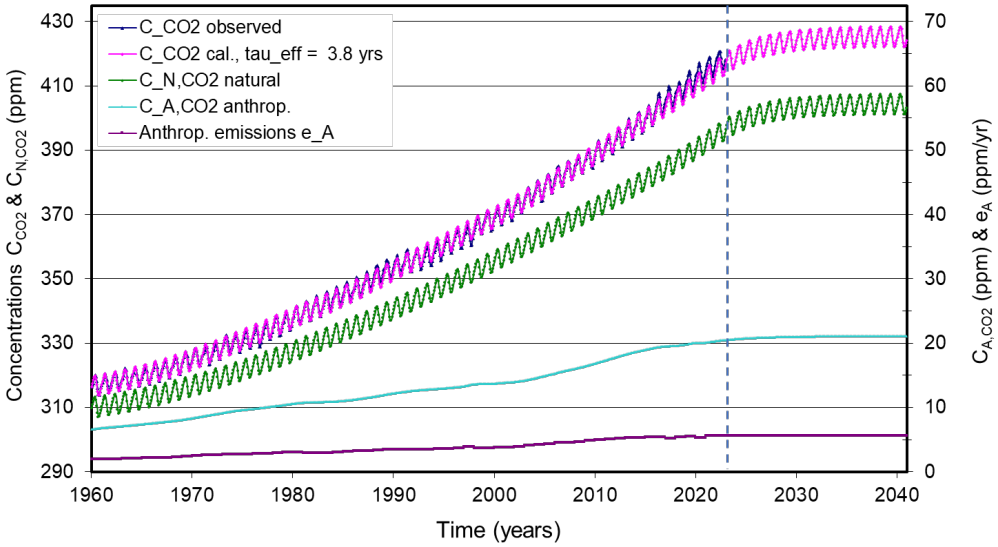

Figure 4: *Observed monthly CO_2 concentration at Mauna Loa (Blue Triangles) together with a calculation for τ_{eff} = 3.8 yr, including anthropogenic and natural emissions (Magenta Diamonds). Also plotted is the concentration $C_{N,CO2}$ (Green Dots) only caused by natural emissions $e_N(t)$, and $C_{A,CO2}$ (Aqua Triangles) caused by the anthropogenic emissions $e_A(t)$ (Plum Squares).*

From these graphs we also see that for a further constant emission (human and natural) the concentration is only additionally increasing by about 10 ppm within less than one decade.

4. Conclusion

Different to the IPCC's interpretation and in agreement with all physical causalities our preceding studies show that the Carbon Cycle is controlled by a 1st order absorption process, acting equivalently for native and anthropogenic emissions and on a single time scale for all molecules.

The effective absorption time cannot be longer than 10 yr, but can even be as short as 1 yr. With anthropogenically caused CO_2 of ≈ 15 % and global warming over the last century by CO_2 of ≈ 0.3°C (see Harde 2022), humans are responsible for global warming of 0.3 °C · 15 % < 0.05 °C.

To further reduce this absolutely negligible contribution, we endanger a secure energy supply and with this a prospering economy and stable standard of living.

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