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Signal Analysis of the Climate: Correlation, Delay and Feedback

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Abstract

One of the ingredients of anthropogenic global warming is the existence of a large correlation between carbon dioxide concentrations in the atmosphere and the temperature. In this work we analyze the original time-series data that led to the new wave of climate research and test the two hypotheses that might explain this correlation, namely the (more commonly accepted and well-known) greenhouse effect (GHE) and the less-known Henry's Law (HL). This is done by using the correlation and the temporal features of the data. Our conclusion is that of the two hypotheses the greenhouse effect is less likely, whereas the Henry's Law hypothesis can easily explain all effects. First the proportionality constant in the correlation is correct for HL and is about two orders of magnitude wrong for GHE. Moreover, GHE cannot readily explain the concurring methane signals observed. On the temporal scale, we see that GHE has difficulty in the apparent negative time lag between cause and effect, whereas in HL this is of correct sign and magnitude, since it is outgasing of gases from oceans. Introducing feedback into the GHE model can overcome some of these problems, but it introduces highly instable and chaotic behavior in the system, something that is not observed. The HL model does not need feedback.

Keywords

Climate, Temporal Series Analysis, Feedback, Correlations, Hypothesis Testing

1. Introduction

Society is threatened by catastrophic climate changes. Scenarios are given in which temperatures will rise significantly and sea levels will rise causing floods that make coastal areas basically uninhabitable. The source of the climate changes is assumed to be the carbon dioxide that is injected into the atmosphere by burning of fossil fuels and which acts as a greenhouse gas. It blocks outward radiation that otherwise might cool the planet.

We have to take a step back and place this idea in a historic perspective. A politician's job is to unite people and problems, real, merely imagined or even created, which can be used for that purpose. As the Club of Rome wrote in their report The First Global Revolution, "In searching for a common enemy against whom we can unite, we came up with the idea that pollution, the threat of global warming, water shortages, famine and the like, would fit the bill" [1]. Problems serve as a means to a political cause rather than politics as a way to solve them. This is an unfortunate reality. Yet, there was thus a need, as shown by political think-tanks, to prove the ideas of global warming.

Evidence for the model of global warming through greenhouse gases was soon found in ice core drillings, where a strong correlation between CO_2 concentrations found in the air bubbles trapped in it and the temperature (measured via oxygen isotope ratios found in similar ice core drillings). Former vice president of the United States Al Gore, in his documentary An Inconvenient Truth, presented us this convincing data that the earth is warming up and that the carbon dioxide is responsible for it, see **Figure 1**. The movie landed him a Nobel Prize for Peace and started a new wave in politics and subsequently a wave in climate research, paid for by the politics that convinced us of the urgency. The movie of Al Gore was very convincing. Thus having achieved the first part of the agenda, a political program was started. One of the items of the program was deviate attention from facts, to never look back at the data or the model, so that attention could be focused on solutions, *i.e.*, mounting political structures such as the Intergovernmental Panel on Climate Change (IPCC). "To help address the chaotic nature of the climate change discourse in the UK today, interested agencies now need to treat the argument as having been won, at least for popular communications. This means simply behaving as if climate change exists and is real, and that individual actions are effective. The 'facts' need to be treated as being so taken-for-granted that they need not be spoken" [2]. The subject is taken fully out of the realm of science and placed into the political arena. Each and every report of the IPCC is based on the workflow of starting with an outline of the conclusions—"IPCC approves outline"—and then nominating experts who can help find corroborating data, as they themselves write in their reports.

A scientist's job, however, is to test hypotheses (independently of politics). A scientist's job is much less noble. It is not to unite people, nor to solve problems of society (whatever people might think), but only to find out the truth as objectively as possible, even if the truth is inconvenient. Many scientists have cast doubt on the simplistic conclusion of Al Gore and the IPCC. Maybe inspired by the adage we all learned in school, "correlation is not causation", they started criticizing the time series itself. We objectively took a look at this same original time series, and checked if it is consistent with the Global Warming hypothesis

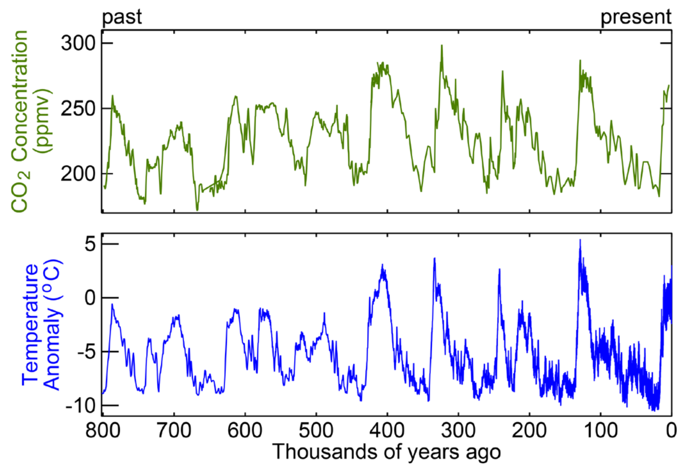

Figure 1. Original data of Al Gore showing the correlation of CO_2 (top) and temperature (bottom) as measured by ice core drillings.

presented by Al Gore. Not because we have a hidden political agenda or defend oil-industry—this research was paid by no one—but because we think that society deserves to know if global warming is really man-made or not. We present here part of our study. There is more going on than simple correlations, as we will show. We will also present an alternative (and older) explanation for the correlation, namely Henry's Law and check simultaneously if this can stand up to scrutiny.

2. Results and Discussion

2.1. Correlation

Figure 1 shows the entire time series of both CO_2 concentration (henceforward abbreviated with [CO_2]) in the atmosphere and temperature for the last 800 thousand years, and we can indeed see that there is a strong correlation between the two. What immediately strikes us is that the temperature swing is some 10 degrees for only 100-ppm [CO_2]-variations; a climate sensitivity of 0.1 K/ppm. What is so remarkable about this is that modern values of [CO_2] go beyond 400 pm, a whopping increase of 125 ppm from pre-industrial values (275 ppm in 1700 [3]), and following the narrative of Al Gore, a staggering temperature rise of 13 degrees is expected. In reality, a meager half a degree is observed, one that is moreover still consistent with a CO_2-independent linear rise that started before the industrial era. It surprises us that this fact does not get more attention. Reality falls a factor twenty-five below the model. The enigma of the missing temperature rise.

Figure 2 presents the same data in a more conventional way. Generally speaking, correlations between two time series $X(t)$ and $Y(t)$ are best shown in this type of correlation plots Y vs. X. **Figure 2** shows this for [CO_2](t) and temperature $T(t)$. In this figure we see a reasonable correlation between temperature and [CO_2], and a linear regression teaches us an observed correlation

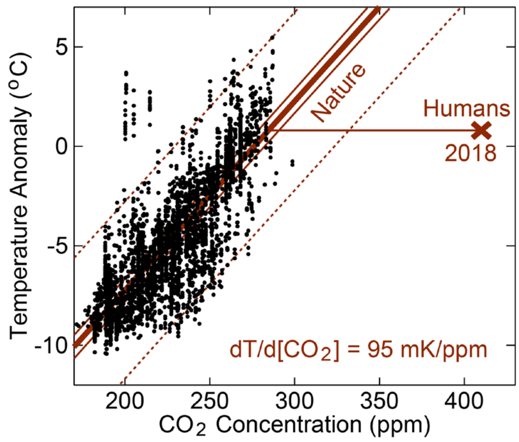

Figure 2. Original data of Al Gore (of **Figure 1**) presented in a correlation format. The brown lines labeled "Nature" are a linear-regression fit with confidence interval shown. The contemporary situation of temperature and $[CO_2]$ is indicated by an "X" and labeled "Humans 2018".

$$(\text{observed:}) \quad \frac{\mathrm{d}T}{\mathrm{d}[CO_2]} = 95\ \text{mK/ppm}, \tag{1}$$

coefficient of (the fit with confidence intervals is shown in brown and labeled "Nature"). The contemporary CO_2 and temperature situation is indicated with an "X" and labeled "Humans 2018"; 410 ppm and +0.8˚C. As can be seen, the temperature falls way below the value based on a simple correlation, about 12 degrees; the contemporary situation falls outside the confidence interval. Apparently there is more going on than a simple straightforward correlation between the two in which the CO_2 changes are the driving force behind the temperature.

Another interesting and relevant fact that has since the movie of Al Gore been established is that the concentration of methane in the atmosphere also correlates with temperature and thus $[CO_2]$ ($[CH_4]$ not shown here). This seems at first thought to be consistent with a greenhouse-effect hypothesis, since CH_4 is a very strong greenhouse agent, thus both change the temperature, see **Figure 3(a)**. However, upon second thought this is very enigmatic. If changes of $[CO_2]$ cause temperature variations, and changes of $[CH_4]$ do as well, what is the physical effect that correlates $[CO_2]$ variations to $[CH_4]$ variations? We are opening Pandora's box asking these questions. Once opened, it cannot be closed, and it has far-reaching consequences. We'd allow for a model in which information passes from $[CO_2]$ to $[CH_4]$, or vice versa, which implies that temperature can be a cause rather than an effect of things. There, we said it.

We now have basically two competing hypotheses to explain the observations; they are schematically depicted in **Figure 3**. In the most famous, the Greenhouse Effect (GHE), both CO_2 and CH_4 are changing (causing) the temperature changes (effects), whereas in the model named Henry's Law (HL, name to be explained in a moment), the temperature (cause) changes the concentration of gases in the atmosphere (effect). Which of these two is correct? Or can they

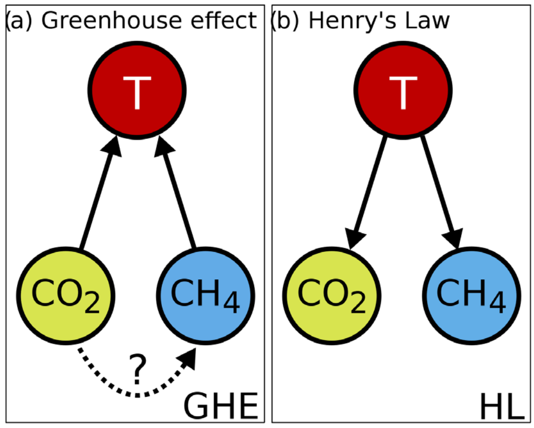

Figure 3. Cause and effect relation between atmospheric gases and the temperature (T). (a) The greenhouse effect of CO_2 and CH_4 both influencing the temperature, but how can then CO_2 correlate to CH_4? (b) Henry's Law (outgassing of oceans) where both CO_2 and CH_4 are caused by temperature changes and thus also correlate with each other.

both be correct? As a first piece of information we see that the observed correlation between $[CO_2]$ and $[CH_4]$ is very difficult to explain in the GHE hypothesis, whereas it is trivial in the HL hypothesis; Whatever the physical phenomenon that causes the temperature to change the concentration of gases in the atmosphere, it is very reasonable to think that both CO_2 and CH_4 are affected simultaneously.

We now come to the magnitude of the signals. We have seen that the data (**Figure 2**) point to a correlation of $\mathrm{d}T/\mathrm{d}[CO_2]$ = 95 mK/ppm, or conversely,

$$(\text{observed:})\quad \frac{\mathrm{d}[CO_2]}{\mathrm{d}T} = 10.5\ \text{ppm/K}. \tag{2}$$

(We invert the notation of the derivative to stress the idea that $[CO_2]$ is a function of T; the two notations are fully interchangeable). It can easily be shown that the total greenhouse effect is 32 degrees, because the equilibrium temperature of an atmosphereless planet can easily be calculated and results in −17˚C, whereas the average temperature of our planet is +15˚C. If the greenhouse effect is solely due to CO_2 which we immediately know it isn't, see the remark about the CH_4 above and is linear, then we get a correlation coefficient of 32 K/350 ppm = 90 mK/ppm and this comes indeed very close to the observed value (Equation (2)). This, however, has immediately two problems. First of all, it'd imply that historically CH_4 had no effect and that methane is not a greenhouse gas. A much more severe problem is denying the effect of water in the atmosphere on the temperature. The best estimation for water is that it is responsible for 95% of the current greenhouse effect. CO_2 has 3.6% contribution [4]. The linear effect of CO_2 is thus estimated to be a factor 30 lower than the above estimate, namely $\mathrm{d}T/\mathrm{d}[CO_2]$ = 3 mK/ppm (doubling of $[CO_2]$ would cause about 1 degree warming). Moreover, it is highly dubious that the effect of CO_2 is linear. That is because the greenhouse effect is governed by absorption of light, a process that is well studied and follows the Beer-Lambert Law of absorption that is sublinear. To put it in layman's terms, placing a second curtain over a window that is already closed with a curtain will have as good as no effect. Absorption according to the Beer-Lambert Law is logarithmic and the IR window of the CO_2-absorption spectrum is already as good as closed; most heat is radiated outwards in the window of 8 μm to 15 μm where CO_2 has no absorption. The effect of CO_2 is at around 20 μm [5] and is tiny. If we take this into account, we can find a small GHE correlation coefficient of

$$(\text{GHE theory:})\quad \frac{\mathrm{d}T}{\mathrm{d}\left[\mathrm{CO_2}\right]} = 1.4\ \mathrm{mK/ppm}, \tag{3}$$

i.e., 500 mK for a doubling of CO_2 in the atmosphere that has moreover been confirmed by measurements [6]. That is a factor 70 below the observations. How it is possible to still maintain the GHE model we will see in a moment, but first let's take a look at the alternative HL hypothesis.

Henry's Law states that the ratio between the partial pressure of a certain gas in an atmosphere above a liquid in which it is also dissolved is constant in equilibrium and this ratio depends on the temperature, and this ratio is called Henry's Constant. In other words, if the system is in equilibrium and has a certain concentration of CO_2 in the oceans and atmosphere above it, when the oceans warm up, the tendency is to outgas the CO_2 from the oceans and the concentration in the atmosphere will increase. Al-Anezi and coworkers have studied this effect in more detail in a laboratory setup under various conditions of salinity and pressure, etc. [7]. For synthetic sea-like water at 1 bar, Al-Anezi *et al.* found a temperature dependence of Henry's Constant that points to a correlation coefficient of about

$$(\text{HL theory:})\quad \frac{\mathrm{d}\left[\mathrm{CO_2}\right]}{\mathrm{d}T} = 10\ \mathrm{ppm/K}, \tag{4}$$

which is remarkably close to the observed value found in reality. We can now conclude that where science consists of rejecting hypotheses, we must conclude that the greenhouse effect hypothesis is rejected and the Henry's Law hypothesis still stands. At least the correlation argument used in most discussions point to a cause-and-effect in which temperature is the cause and CO_2 the effect. See **Figure 4** for a comparison of the GHE model and the HL model with the data.

2.2. Delay

The plot of **Figure 2** showed that contemporary data (there labeled "Humans") fall way outside the confidence intervals in the correlation plot between CO_2 and temperature; the correlation is broken in modern times. Considering the fact that the original plot of Al Gore does not have a high time resolution, the thought might occur that the correlation indeed holds but that there is a delay between the two somehow, so that we are indeed in for a temperature rise of 13

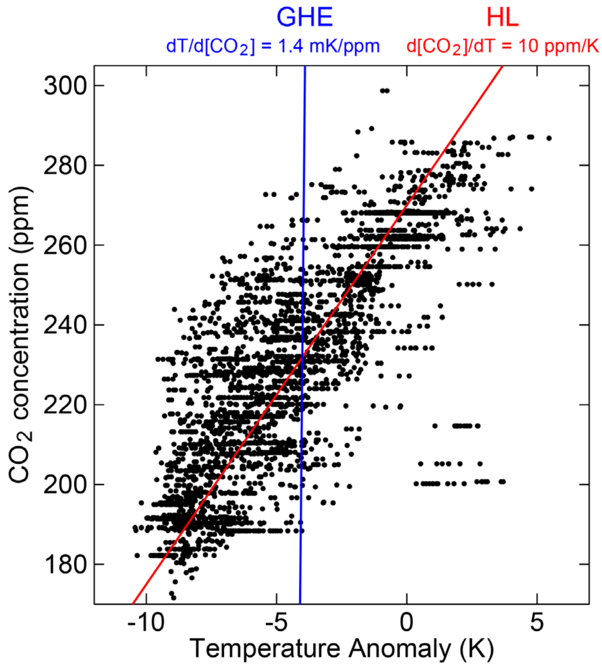

Figure 4. Comparison of the data of **Figure 2** with the models of the greenhouse effect (GHE) of Equation (3) and Henry's Law (HL) of Equation (4) (with the offset chosen to best fit the data). It is obvious that the HL model cannot be rejected and actually works better than the greenhouse-effect model.

degrees in the (near) future. To study the effects of possible delays, we have to analyze in more detail the exact transient behavior of the two signals, [CO_2] and temperature. Plotting the data in the same panel (instead of the rather misleading two-panel format of **Figure 1**) we see that the CO_2 variations seem to be lagging behind the temperature variations. **Figure 5** shows a zoom in on the data around 300 thousand years before present. We have earlier reported on this remarkable fact [8].

Indermühle and coworkers made a full statistical analysis [9] and find a value of 900 yr for the delay and moreover note that "This value is roughly in agreement with findings by Fischer *et al.* who reported a time lag of CO_2 to the Vostok temperature of (600 ± 400) yr during early deglacial changes in the last 3 transitions glacial-interglacial" [10]. Fischer and coworkers attribute the delay to the ocean outgassing effects, *i.e.*, Henry's Law, and even find that at colder times the delay is longer, which is itself consistent with Arrhenius-like behavior of thermally-activated processes, such as most in nature [10].

It is obvious that no delay between temperature and CO_2 can be explained in a greenhouse effect hypothesis. How would nature know the CO_2 is going to change and already starts changing the temperature? Causes have necessarily to come before the effects. That leaves us merely with the question whether the experimentally-found delay between temperature and [CO_2] is reasonable in the framework of Henry's Law.

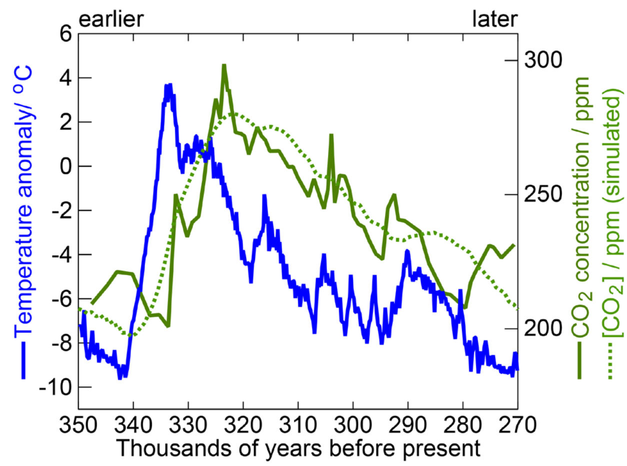

Figure 5. Zoom in of data of **Figure 1** with CO_2 and temperature in the same panel. It shows that the CO_2 lags behind the temperature. The dashed line of CO_2 is a convolution of the temperature data based on a relaxation (time-delay) model. Source: Ref. [8].

First of all, the outgassing and ingassing of carbon dioxide out of and into the oceans and biosphere can easily be determined. As a fortunate side effect of the less-fortunate above-ground nuclear-bomb tests, the residence time of carbon in the atmosphere was accurately determined at some 11 years [11] [12], although more recently also shorter times of about 5 - 6 years were found [13]. That means that if the equilibrium of CO_2 concentrations is disturbed somehow (for instance by artificially injecting CO_2 into the atmosphere by burning of fossil fuels), it will take some decades to reestablish a new equilibrium. This short residence time has serious implications for the validity of the climate-change model based on the greenhouse effect, even if the greenhouse effect were true and seriously climate forcing. A residence time of a decade is too short to make CO_2 have a serious impact on the climate, the same as the orders-of-magnitude larger greenhouse driver water has no impact on the climate because its residence time is even much shorter, about 9 days [14] although voices were heard that wanted to label water a pollutant as well. To overcome this problem, a new term is coined, namely "adjustment time", that is estimated to be much longer than the residence time [15], of the order of 80 years, but this naming trick cannot be explained in chemical kinetics (simple reaction kinetics: if most CO_2 winds up in the ocean, the residence time and adjustment time are very close). Therefore, we take the two to be the same here.

A more important relaxation time in the framework of the Henry's Law hypothesis is the time it takes for the ocean waters to warm up (or cool down) after the atmosphere has warmed up (or cooled down) for whatever reason (other than the greenhouse effect), after which it will take some 11 years to establish the new equilibrium concentrations of gases in the oceans and atmosphere as appropriate to those temperatures. This question is very difficult to answer since it basically depends on the heat-exchange efficiency between atmosphere and ocean and the mixing rate of the heat in the ocean, both not well established. Yet, we can approach it in a different way, to see if we can get an order of magnitude. Imagine that the temperature in the atmosphere is determined by the radiation received from the sun and that for some reason, the radiation balance is disturbed. The advantage is that no, possibly questionable, physics models are involved. We proceed like this: we assume a radiation received from the sun, an albedo (whiteness) of our planet, and a black-body outward radiation of our planet that is required to balance with the incoming radiation to find an equilibrium temperature. We then disturb the radiation to see how that affects the temperature and how fast that will be. Absorbed inward solar radiation is

$$P_{\text{in}} = \pi R^2 \left(1-a\right) W, \tag{5}$$

with R the radius of our planet, a the albedo (33%) and W the solar radiation constant of 1361 W/m^2. The outward black-body radiation is

$$P_{\text{out}} = 4\pi R^2 \sigma T^4, \tag{6}$$

with T the temperature at the surface and σ the constant of Stefan and Boltzmann equal to 5.67×10^{-8} W/(K^{4}m^2). In equilibrium the two are equal and this yields a temperature of T = 251.8 K (note that it does not have an atmosphere). Now we increase the incoming radiation 1 W/m^2, either by changing the albedo or the solar constant. A new temperature will establish that is 69 mK higher. The adjusting of the atmosphere is virtually instantaneous because of its low heat capacity. Now, how long does it take to warm up the oceans 69 mK with this 1 W/m^2? This 1 W/m^2 was through a disk perpendicular to the sunrays. The spherical earth receives 0.25 W/m^2 (the factor 4 comes from the ratio of areas of a disk and a sphere with radius R). 71% of the planet is covered by oceans that are on average 3000 meters deep. The volume of $V = 0.71 \times 4\pi R^2 \times \left(3000\text{ m}\right)$ receives an extra $P = 0.71 \times 4\pi R^2 \times \left(0.25\text{ W/m}^2\right)$ heating power. To raise the temperature of 1 liter of water 1 degree takes 4.2 kJ, the initial heating speed is

$$\frac{\mathrm{d}T}{\mathrm{d}t} = \frac{\mathrm{d}T}{\mathrm{d}U} \cdot \frac{\mathrm{d}U}{\mathrm{d}t} = 2 \times 10^{-11}\text{ K/s}, \tag{7}$$

with U the heat in the ocean, $\mathrm{d}U/\mathrm{d}T = \left(4.2\text{ MJ/m}^3 \cdot \text{K}\right) \times V$, and $\mathrm{d}U/\mathrm{d}t = P$. To establish a new equilibrium thus goes at a time scale of

$$\left(\text{HL theory:}\right) \quad \tau = \left(69\text{ mK}\right) / \left(2 \times 10^{-11}\text{ K/s}\right) = 3.5 \times 10^9\text{ s}. \tag{8}$$

That is 150 years. Plus the 11 years of adjustment time found before makes a response time of about 160 years. This is somewhat low compared to the observed 900 years reported by Indermühle [9] and 600 years by Fischer [10], probably because mixing of oceanic layers is required, taking additional time.

To compare, we could do the same calculation to find out how long it takes to increase the atmospheric temperature when the radiation balance is disturbed, for instance by adding a greenhouse gas to it. It is more difficult to estimate because the heat capacity of the atmosphere is not well known. However, we could get a rough estimate by assuming the atmosphere is equal to 10 meters of water (which gives the same pressure as the atmosphere). That is 300 times less than the oceans and we can thus estimate the temperature adjustment time to be half a year. The real value is probably lower, since water has a much higher specific heat (heat per kg) compared to air. We can even do it a little bit more precisely using daily oscillations. As a rough figure, the temperature drops by about 4 degrees at night in about 8 hours after the sun has set. Assuming that the relaxation upon this step-like solar radiation is a simple exponential and would finish eventually at close to absolute zero (say 10 kelvin), and starts at 290 K (thus a total amplitude of 280 K): 4 degrees in 8 hours, we solve the equation

$$\left(280\ \mathrm{K}\right)\times\exp\left(-\frac{8\ \text{hours}}{\tau}\right)=\left(280-4\right)\mathrm{K}, \tag{9}$$

which yields 23 days a value close to the one of 1.2 months one gets when analyzing the periodic yearly oscillations of summer and winter temperatures that lag behind the solar radiation oscillations by about one month [8]. We thus conclude that the delay between CO_2 disturbances and their effect on the temperature has a relation time of some months,

$$\left(\text{GHE theory:}\right)\quad \tau=-5\times10^{6}\ \mathrm{s}. \tag{10}$$

(Note the minus sign indicating that temperature lags behind). Indeed, on the total time scale this is virtually instantaneous. In conclusion, the experimentally-found delay of some hundreds of years between temperature and $[CO_2]$ fits reasonably well with the Henry's Law, while it even has the wrong sign for the greenhouse-effect hypothesis.

2.3. Feedback and Stability

After having established above what each of the directions of the correlation will be, we can also analyze a system in which both effects occur, both temperature causing $[CO_2]$ changes as well as CO_2 causing temperature changes. This is what is called feedback. In classical signal analysis the system is imagined to be an amplifier with gain A of which a factor β of the output is added "fed back" to the input. The overall effect on the output (for instance $\mathrm{d}T$) of changes at the input (for instance $\mathrm{d}[CO_2]$) can then easily be calculated. For the greenhouse model we get

$$\frac{\mathrm{d}T}{\mathrm{d}\left[CO_2\right]}=\frac{A_{\mathrm{GHE}}}{1-A_{\mathrm{GHE}}\beta_{\mathrm{GHE}}}, \tag{11}$$

with the subscript indicating the hypothesis. See **Figure 6(a)**.

Where the gain of the greenhouse effect could roughly be calculated on physical properties and resulted in an estimated value of $A_{\mathrm{GHE}}=\mathrm{d}T/\mathrm{d}\left[CO_2\right]$ = 1.4 mK/ppm (Equation (3)), the parameter β_{GHE} is not well known and serves mainly as a "fitting parameter". In the simulations on large computers, there may be many such parameters that are adjusted until a good description of the past is

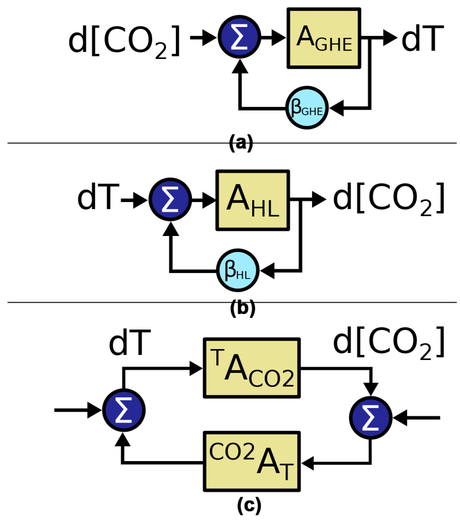

Figure 6. (a) Changes in T, caused by changes in $[CO_2]$ are fed back and cause additional changes in $[CO_2]$. (b) Changes in $[CO_2]$, caused by changes in T are fed back and cause additional changes in T. (c) A symmetric way of representing feedback. Feedback.

found. That is how the subject of the weather is studied and, unfortunately, climate research is mainly done in meteorological calculation centers. The observed sensitivity of 95 mK/ppm (Equation (2)) can "easily" be reproduced with a feedback factor β_{GHE} of 0.70376 ppm/mK. This makes the experimental data coincide with the model (that is, with the calculations based on a model with an adjusting parameter β_{GHE}). The correctness of describing the past data is then often used for validating the simulations and giving them credibility. Yet, literature does nowhere justify the feedback parameters, nor do they actually ever present them in the publications (a fact which actually makes the work deviate from the scientific method [16]). Popular communications mention phenomena, such as the albedo effect of white ice melting and revealing black heat-absorbing ground or water, or permafrost tundras that melt and release large quantities of the greenhouse gas methane, but these are far below the magnitude needed. As an example, the feedback phenomenon could be—and is often managed as such—the relatively huge effect of Henry's Law outgassing of oceans. However, as we have seen, that is a factor 70 too low; 10 ppm/K instead of 700 ppm/K. From scientific journals, on the other hand, we merely get served pictures with results of simulations about how many degrees it will warm up. If the parameter β_{GHE} is simply a fitting parameter, without it having any physical justification, the simulations become nothing more than mere extrapolations of the trend, performed on state-of-the-art supercomputers what could have been done on pocket calculators or done with rulers The circular reasoning is then basically like this. Assuming the observed $[CO_2]$ increments were responsible for the observed temperature changes in the past, further increases of $[CO_2]$ will unavoidably result in more temperature rises.

Note that the found value of β_{GHE} makes the denominator in the above formula close to zero and such systems (and calculations) are very sensitive; small changes of beta can have huge effects on the response. For instance, a slightly larger β_{GHE} of 0.7132 ppm/mK (about 1% larger) will make the response tenfold. It is moreover highly dubious that nature is this close to the critical value that creates a singularity (at $\beta_{\text{GHE}} = 1/A_{\text{GHE}} = 0.7142\ \text{ppm/mK}$). Any feedback factor at or above this critical value will cause an infinite response, $\text{d}T/\text{d}[CO_2] = \infty$. That is the problem with positive-feedback systems. They have huge gain and are unstable when the so-called "open-loop gain" $A_{\text{GHE}}\beta_{\text{GHE}} \geq 1$. For this reason the wording "point of no return" is often used; it hints at the instability of the system (simulated). A run-away scenario is built into the simulations. Imagine that the melting of the ice will increase the "open loop gain" just a little, either through β_{GHE} or A_{GHE}. A catastrophe is envisaged.

That while nature is obviously very stable. It recovers daily from huge temperature oscillations. Similarly it recovers from yearly periodical seasons (with also periodic modulation of the solar flux caused by the ellipticity of Earth's orbit), as well is able to recover from aperiodic fluctuations such as El Niños and La Niñas. This hints at negative feedback ($\beta_{\text{GHE}} < 0$), or small feedback with the open-loop gain much smaller than unity. Such feedback makes the system stable, with the absence of any criticality. Negative feedback even attenuates the overall gain of the system. As an example, the value of β_{GHE} of −0.70376 ppm/mK above would about halve the overall gain to 0.71 mK/ppm, as Equation (11) easily shows.

On the other hand, the model based on Henry's Law does not need feedback, let alone critical feedback. The gain of the system is A_{HL} = 10 ppm/K, and a small feedback (which might be the greenhouse effect, thus $\beta_{\text{HL}} = A_{\text{GHE}} = 1.4\ \text{mK/ppm}$) does not change this value appreciably (only about 1%).

$$\frac{\text{d}[CO_2]}{\text{d}T} = \frac{A_{\text{HL}}}{1 - A_{\text{HL}}\beta_{\text{HL}}}, \tag{12}$$

See **Figure 6(b)**.

In the above we talked about "gain" since this is classic jargon of the signal processing field. However, gain is only defined if the input and output quantities are in the same domain. In our case we have two different domains, T and $[CO_2]$. A better picture is shown in **Figure 6(c)**. It has two transfer functions ${}^{CO_2}A_{\text{T}}$ and ${}^{\text{T}}A_{CO_2}$ modeling the response to changes in $[CO_2]$ upon changes of T and changes of T upon changes of $[CO_2]$, respectively. Where either one can be seen as "gain" or "feedback"; to translate the circuit in **Figure 6(c)** to the one in **Figure 6(b)**, we substitute $A_{\text{HL}} = {}^{CO_2}A_{\text{T}}$ and $\beta_{\text{HL}} = {}^{\text{T}}A_{CO_2}$, and to translate the circuit in **Figure 6(c)** to the one in **Figure 6(a)**, we substitute $A_{\text{GHE}} = {}^{\text{T}}A_{CO_2}$ and $\beta_{\text{GHE}} = {}^{CO_2}A_{\text{T}}$. If we plug the derived sensitivities (Equation (3) and Equation (4), resp.) into this system and feed it the $[CO_2]$ data on the right side, it does not reproduce the temperature data, whereas when we feed it the temperature data on the left, it does reproduce the $[CO_2]$ data. Note that we have eliminated the fitting parameter β from the equation—no fitting parameter is left whatsoever—and yet, it fully reproduces the observed data. The inevitable conclusion is that the temperature variations were the source of the [CO_2] variations and not the other way around.

Note that the loop gain equals, ${}^{\mathrm{T}}A_{\mathrm{CO_2}} \times {}^{\mathrm{CO_2}}A_{\mathrm{T}} = (10.5\ \mathrm{ppm/K}) \times (1.4\ \mathrm{mK/ppm}) = 1.47 \times 10^{-3}$, and, while positive, this is far away from instability. The climate system, while chaotic and unpredictable, is stable on the long run.

Feedback analysis can also make statements about the stability as a function of frequency—periodicity of the driving force. The gain and feedback—transfer functions in general—may depend on frequency and a system may start to oscillate without external driving signals at those frequencies where the open-loop gain is positive and larger than unity. Apart from a loop gain, Aβ also introduces a phase shift, and the two are normally presented in a so-called Nyquist plot. In phasor terminology we define an amplitude and a phase: $A(\omega)\beta(\omega) = |A(\omega)\beta(\omega)|\exp(i\phi)$, where ω is the (radial) frequency and ϕ the phase, and plot the real and imaginary part of this product, see **Figure 7**. The point of perfect oscillation (open-loop gain unity and phase zero) is called the Barkhausen Criterion (BC). Inside the circle indicating a unity gain, no oscillation takes place, whereas outside it oscillation can take place if the phase is correct. (Note that an "oscillation" at zero hertz is simply the run-away scenario described before). **Figure 7** summarizes this for our models. We saw that a process of Henry's Law outgassing has a characteristic time of τ = 600 year and such a relaxation process causes an attenuation of the response for higher frequencies as well as a phase shift tending towards −90˚, *i.e.*, one quarter period lagging behind. In the Nyquist plot this is a semicircle (see the zoom in at the bottom left; the bottom of the semicircle occurs at $\omega = 1/\tau$), the phase shift which has been observed [8]. This means that for higher frequencies the system, even though the feedback does not become negative, becomes ever more stable. For the greenhouse effect, the delay of CO_2 having effect on the temperature is about a month, as we have discussed above, but other effects that are not simple first-order (relaxation) behavior might make the system enter into the unstable behavior, which is often mentioned in popular press, since it is critically stable; there must then be especially high-frequency oscillations in both temperature and [CO_2].

3. Summary and Conclusions

The greenhouse effect cannot explain the experimental data because it does not manage to reproduce the correlation coefficient between temperature variations and carbon-dioxide concentration variations, unless a feedback is added to the system. This feedback factor is then coincidentally very near the critical value, which would turn the climate system marginally stable with real risk for catastrophic climate scenarios. Moreover, this feedback factor must be really huge; ($\beta_{\mathrm{GHE}} = 703.76\ \mathrm{ppm/K}$ is a factor 70 larger than the simple Henry's Law, $A_{\mathrm{HL}} = 10.5\ \mathrm{ppm/K}$). While feedback is recently more often used as an explanation

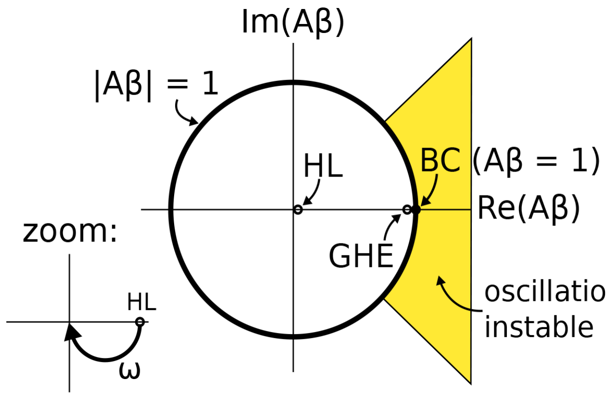

Figure 7. Feedback and stability. The open-loop gain of feedback represented in a Nyquist plot. The Henry's Law system is stable and feedback makes it more stable at higher frequencies (see zoom in at bottom left). The system controlled by the greenhouse effect is marginally stable, but any perturbation can make it unstable, which is not observed in nature that is always recovering easily from disturbances such as seasonal oscillations and El Niño and La Niña events.

for the observed data, there do not seem to be any physical phenomena that might explain such large feedback factors. An outgassing of tundra's or the albedo effect is too small.

What is more, the greenhouse hypothesis does not have an explanation for the simultaneously occurring correlation with methane in the atmosphere. Moreover, the delay between the temperature and the [CO_2] variations demonstrate that the temperature cannot be the effect of [CO_2] variations but rather must be their cause.

On the other hand, Henry's Law hypothesis can explain the correlation between temperature and carbon dioxide in the atmosphere flawlessly, both the correlation coefficient, as well as the time delay. Moreover, it also explains the correlation with methane. It does not need any feedback, but adding a greenhouse effect as feedback to the system does not alter the behavior significantly (only by about 1%).

We therefore come to the conclusions that the model as presented in **Figure 8** is correct, where the values of the parameters are based on experimental behavior instead of our calculations. It leads in signal analysis to a response function equal to

$$\mathrm{d}\left[\mathrm{CO_2}\right](t) = \left(10.5\ \mathrm{ppm/K}\right)\cdot\int_0^\infty \mathrm{d}T\left(t-r\right)\exp\left(-r/\left[600\ \mathrm{year}\right]\right)\mathrm{d}r. \tag{13}$$

This technique was used in a simulation of **Figure 5** [8].

Table 1 summarizes the comparison of the two hypotheses, the greenhouse effect on one side and Henry's Law on the other side. On basis of our analysis presented here, we tend to reject the greenhouse-effect hypothesis while the data seem consistent with the hypothesis based on Henry's Law.

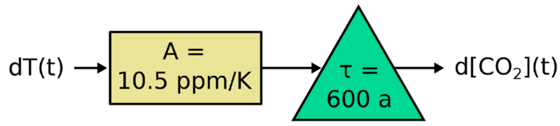

Figure 8. Final model including an outgassing of oceans that has an adjustment time of 600 years and a response of 10.5 ppm/K.

Table 1. Comparison of the two models of greenhouse effect and Henry's Law describing the observed phenomena. ✓: good. ❑: reasonable. ×: problematic.

Phenomenon	Greenhouse	Henry's Law
Correlation T-[CO_2]	✓	✓
Correlation T-[CH_4]	×	✓
Correlation coefficient T-[CO_2]	×	✓
Delay magnitude	no sense	❑
Feedback	×	not needed

Disclosure of Interests

The author declares not to have any conflict of interests. This research was paid by no grant. It received no funding whatsoever, apart from the salary at the university where he works. Nor is he member of any climate committees (political or other) or is he linked to companies or NGOs, financially or otherwise. He is not member of any political party or movement. This is an independent work that does not necessarily represent the opinion of his university or of his government. The author wishes to thank Prof. Khmelinskii for valuable discussions.

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