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Atmospheric CO₂: Exploring the Role of Sea Surface Temperatures and the Influence of Anthropogenic CO₂

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Abstract

Close examination of the small perturbations within the atmospheric CO₂ trend, as measured at Mauna Loa, reveals a strong correlation with variations in sea surface temperatures (SSTs), most notably with those in the tropics. The temperature-dependent process of CO₂ degassing and absorption via sea surfaces is well-documented, and changes in SSTs will also coincide with changes in terrestrial temperatures, and temperature-dependent changes in the marine and terrestrial biospheres with their associated carbon cycles. Using SST and Mauna Loa datasets, three methods of analysis are presented that seek to identify and estimate the anthropogenic and, by default, natural components of recent increases in atmospheric CO₂, an assumption being that changes in SSTs coincide with changes in nature's influence, as a whole, on atmospheric CO₂ levels. The findings of the analyses suggest that an anthropogenic component is likely to be around 20 %, or less, of the total increase since the start of the industrial revolution. The inference is that around 80 % or more of those increases are of natural origin, and indeed the findings suggest that nature is continually working to maintain an atmospheric/surface CO₂ balance, which is itself dependent on temperature. A further pointer to this balance may come from chemical measurements that indicate a brief peak in atmospheric CO₂ levels centred around the 1940s, and that coincided with a peak in global SSTs.

Keywords: Atmospheric CO₂; Sea Surface Temperatures; Anthropogenic CO₂

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1. Introduction

Research into the influence SSTs have on changes in atmospheric CO₂ includes the work by Humlum et al. (2013). When examining phase relationships, they found a maximum correlation for changes in atmospheric CO₂ lagging 11-12 months behind those of global SSTs [1]. A paper by the late Fred Goldberg (2008) noted their correlation by examining El Niño events [2]. He also considered Henry's law [3] in relation to SSTs, i.e. a temperature-dependent equilibrium between atmospheric CO₂ and its solubility in seawater. Spencer (2008) also noted similarities between surface temperature variations with changes in atmospheric CO₂ [4].

For the oceans specifically, areas of surface CO₂ absorption and degassing are shown in maps provided by NOAA [5] and ESA [6] for example. These maps show that colder sea surfaces towards the poles are net absorbers of CO₂ whilst the warmer surface waters of the tropics are net emitters. An analogy often cited is the greater ability of carbonated drinks to retain CO₂ at cooler temperatures; this ability drops as the drinks get warmer.

A strong correlation between changes in atmospheric CO₂ and SSTs can be readily discerned from the relevant datasets. To illustrate, the upper graph in Fig. 1 plots atmospheric CO₂ in parts per million (ppm) as measured at Mauna Loa, Hawaii, since 1982. The data [7] has been 'deseasonalised' by NOAA to remove natural annual CO₂ cycles.

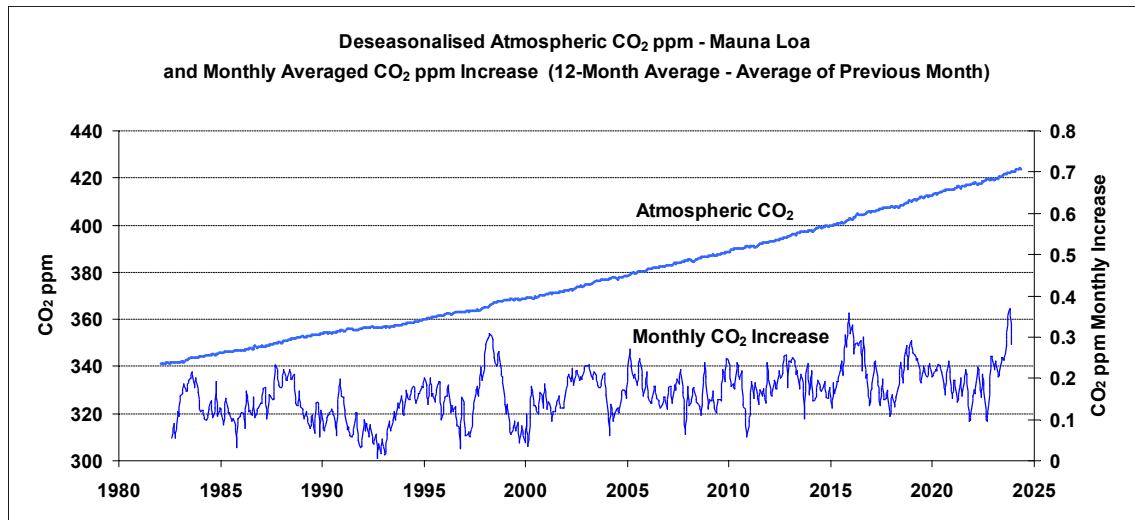


Figure 1: Deseasonalised atmospheric CO₂ data (Mauna Loa).

It can be seen that the graph's general trend exhibits small perturbations. These can be magnified by plotting the monthly CO₂ ppm increases with time, and the lower graph in the figure shows averaged monthly ppm increases over the same time period. Averaging removes some of the 'noise' from the trace. Distinct peaks and troughs are now apparent in the data. If global tropic SSTs [8] are overlaid onto the lower graph, a strong correlation is observed, Fig. 2.

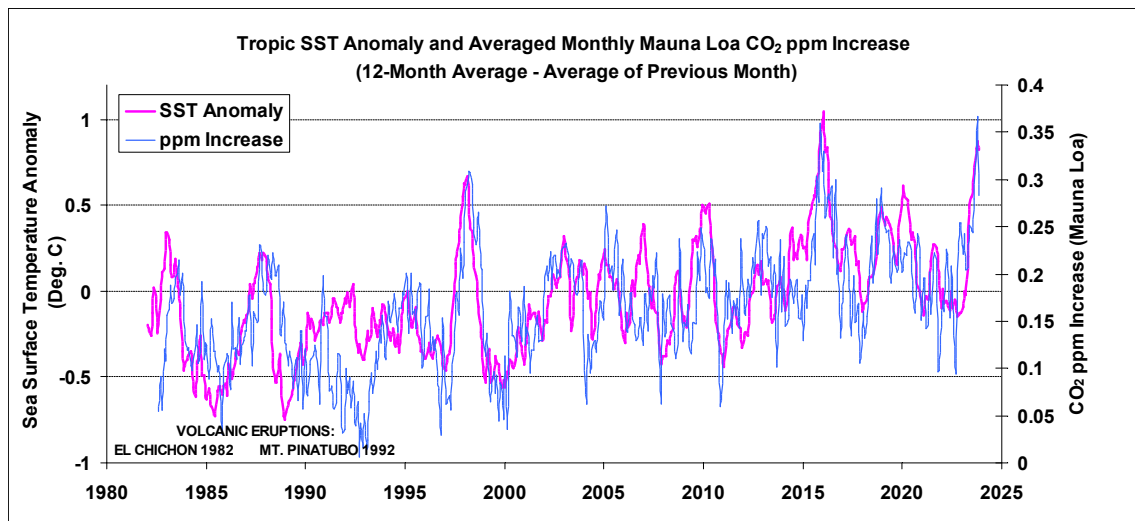


Figure 2: Global tropic SSTs overlaid onto monthly atmospheric CO₂ increases (Mauna Loa)

The similarity between the two traces is striking: short-term fluctuations in CO₂ readings at Mauna Loa appear particularly sensitive to tropic conditions (if tropic SSTs are substituted for global SSTs in Fig. 2, the correlation is less strong). Warm tropical seas, with surface temperatures typically around 25-30 °C, cover almost one third of the earth's surface. The most prominent peaks in the figure coincide with strong El Niño events. Taken at face value, and ignoring any influence from anthropogenic emissions, Fig. 2 suggests that if the tropic SST anomaly dropped to around -1 °C (with related drops globally) then the concentration of CO₂ in the atmosphere, as measured at Mauna Loa, would level off.

An important point is that changes in SSTs will coincide with those of terrestrial temperatures, temperature-dependent changes to both terrestrial and marine carbon cycles and, taking into consideration the research by Humlum et al. (2013) who found that changes in atmospheric CO₂ followed changes in SSTs, an assumption in the work presented here is that nature's influence on atmospheric CO₂ levels, as a whole, follows on from changes in SSTs.

The basis behind such an assumption is examined in more detail as follows:

In a 2022 article, Schrijver [9] summarises his interpretation of recent events regarding atmospheric CO₂, writing: *“The... increase in the average global temperature has resulted in a higher annual natural emission from land and sea... The increase in both natural and anthropogenic emissions has led to more CO₂ in the atmosphere...The higher concentration results in a greater down-flux to both sea and land...The increase in concentration in the atmosphere is the result of a combination of increased temperature and human emissions.”*

For the oceans, and considering Henry’s law, Schrijver describes how both atmospheric CO₂ concentrations and water temperature influences the exchange of CO₂ at the sea surface: higher atmospheric concentrations result in an increased CO₂ absorption, whereas a higher water temperature results in reduced CO₂ retention. The implication is that some ‘re-balancing’ of seawater CO₂ concentrations takes place.

For the land, Schrijver says: *“About half of the CO₂ that plants absorb through photosynthesis disappears almost immediately into the atmosphere in the form of plant respiration. The other half is converted into biomass (leaves, wood, roots, etc.) that ends up on or in the ground.”* He also discusses the temperature-dependency of soil respiration. On this subject, Harde (2023) [10] concluded: *“Particularly soil respiration in the tropics and mid-latitudes can be identified as the main natural source of CO₂ emissions.”*

Regarding the significance of the tropics in relation to atmospheric CO₂ increases, Harde and Salby (2021) [11] say in their abstract: *“Thermally-induced emission, especially from tropical land surface, is found to represent much of the observed evolution of net CO₂ emission”* and they conclude: *“Net emission of CO₂, which is the resultant of all contributions, is concentrated at tropical latitudes”*.

It might be suggested that it is increases in anthropogenic CO₂ that are driving SSTs in Fig. 2. However, by way of example, referring to the prominent 1998 peak in the figure, the CO₂ increase in 1998 was three times that in 1999. If this was a result of human emissions then these would have been three times as much in 1998 as ‘99. Data supplied by the GCB website [12] suggest these were about 24.9 Gt in 1998 and 25.4 Gt in 1999: very similar. The 1998 CO₂ peak therefore points to a natural origin and corresponds to a strong El Niño event with its associated warmer SSTs.

2. Materials and Methods

The observations described above serve as a starting point for the data analyses presented here, which first seek to identify and estimate an anthropogenic CO₂ signature from within this apparent natural atmospheric CO₂/SST relationship. Microsoft® Excel® is used throughout for data processing, graphics (except Fig. 9), linear regression trend lines and curve-fitting.

2.1 Analysis 1: Using a Short Time Window

Using the data presented in Fig. 2, the first analysis method uses the relationship between the prominent short-term fluctuation in SSTs at the time of the 1998 El Niño event, and atmospheric CO₂ increases over the same time period, to try to discern, and roughly-quantify, a human component within the CO₂ trend of the last few decades. Data prior to 1995 is excluded due to the 1982 El Chichon & 1992 Mt. Pinatubo volcanic eruptions that served to suppress atmospheric CO₂ levels. GCB data [12] suggests roughly half of all anthropogenic CO₂ emissions have occurred since 1995 with annual emissions increasing by about 60 % since then.

The analysis procedure is as follows:

Using only the data from within the green inset box, Fig. 3, the time of the 1998 El Niño event, establish the relationship between monthly CO₂ ppm increase and SST anomaly, Fig. 4. This event incorporates a broad range of SST values which helps optimise the accuracy of the analysis. The event’s short time frame (~2.5 years) means that this relationship is, essentially, independent

of any longer-term ppm increase resulting from the rise in human emissions.

Now apply the relationship derived in Fig. 4 to the whole SST dataset of Fig. 3 i.e. calculate from each monthly SST value the CO₂ ppm increase for every month starting in 1995. Then sum all these monthly increases to produce a calculated total value (CTV) of ppm increase.

The measured CO₂ increase since 1995 was 62 ppm (Fig.1). If the CTV is less than this measured increase, then this could suggest the difference is a possible human component. For example, if the CTV is 52 ppm, then the 10 ppm difference might be attributed to the increase in human emissions of CO₂ since the mid-1990s. If the CTV is about the same as the measured increase, then this points to a non-discernible human component of CO₂.

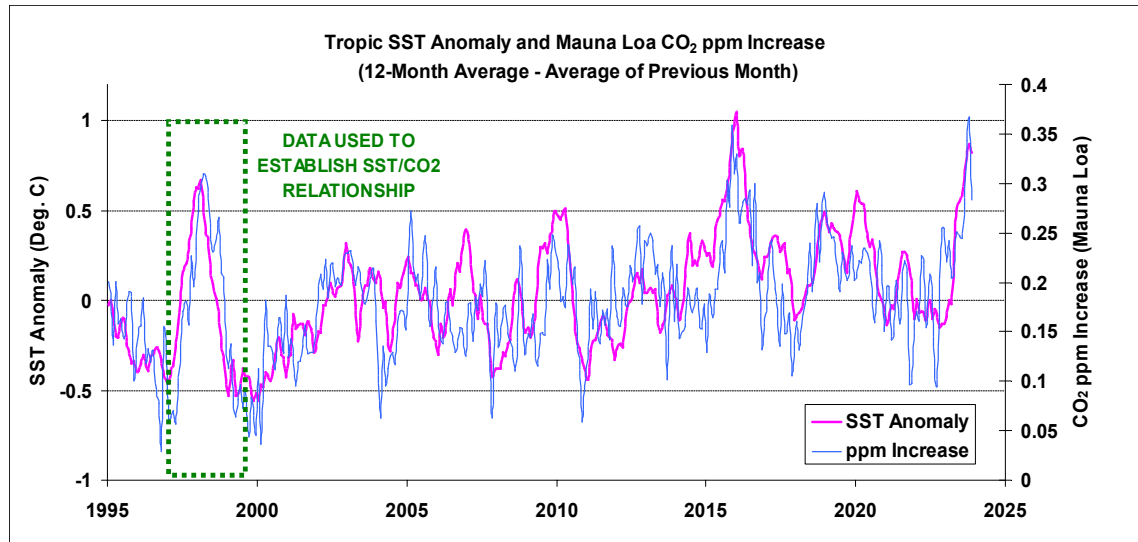


Figure 3: The 1998 El Niño data 'Window' (Green Inset Box) used to establish the CO₂/SST data relationship shown in Fig. 4.

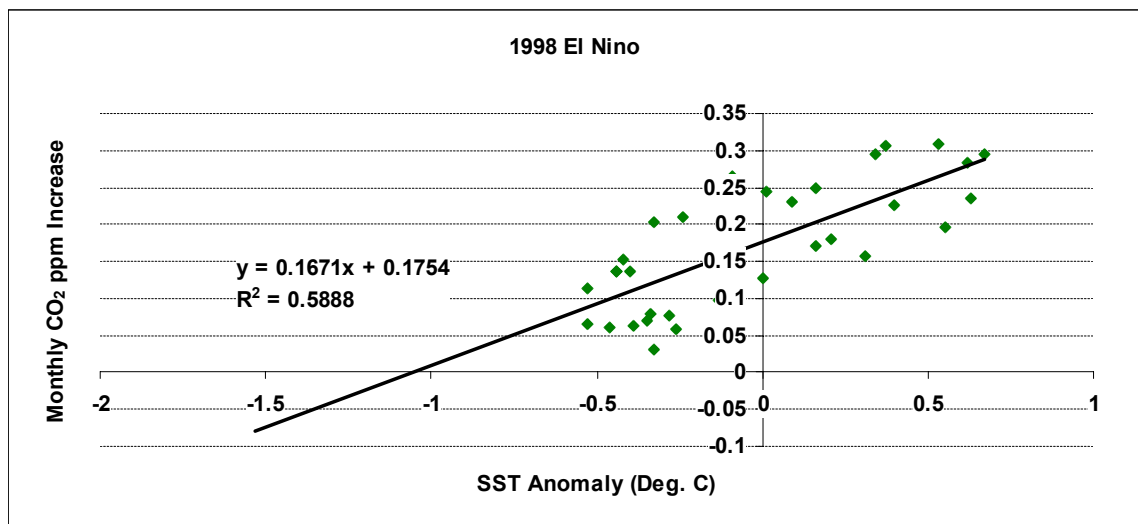


Figure 4: Using only the data from within Fig. 3's inset box, values of SST and monthly CO₂ increase with the same time stamp are plotted as x-y values, together with a fitted linear trend line and associated equation. This equation ($y = \text{the monthly CO}_2 \text{ ppm increase as a function of SST } (x)$) is then applied to every month of the whole SST dataset (1995 onwards) to calculate the final CTV.

Fig. 5 now plots cumulative monthly CO₂ increases calculated from the SST data using Fig. 4's equation, starting at 360 ppm and ending at (360 + CTV) ppm. Measured values are also shown.

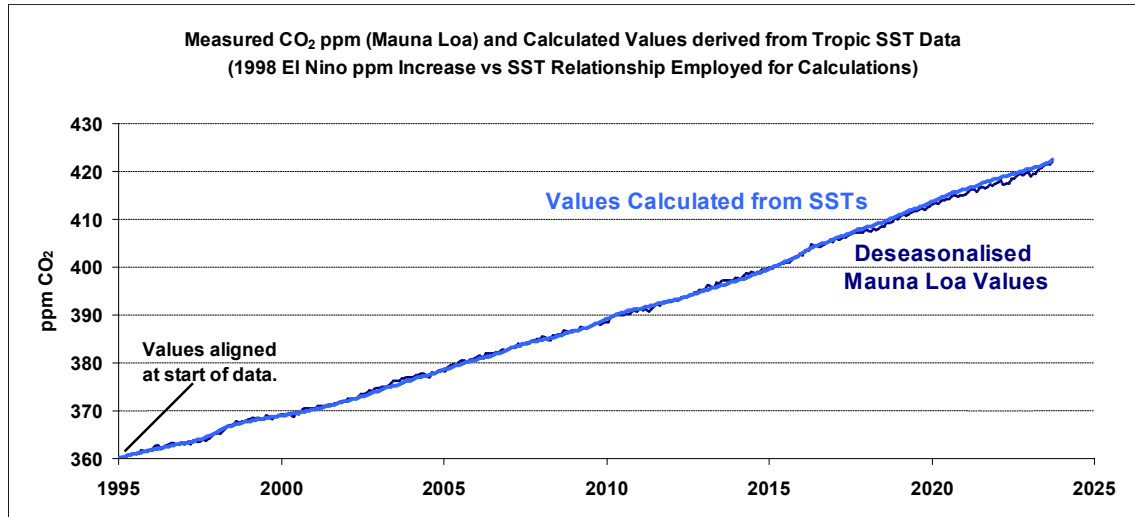


Figure 5: Calculated monthly CO₂ ppm values since 1995, based on SSTs, and Mauna Loa values. The final CTV and measured increase are both 62 ppm i.e. a human component is not discernible.

2.2 Analysis 2: Using a Moving SST Window

With the same aim as Analysis 1, this method uses the same data sets. Again, the years prior to 1995 have been excluded to avoid possible biasing of the results due to the 1982 & 1992 volcanic eruptions. This method takes ‘slices’ through the data at different SSTs, Fig. 6.

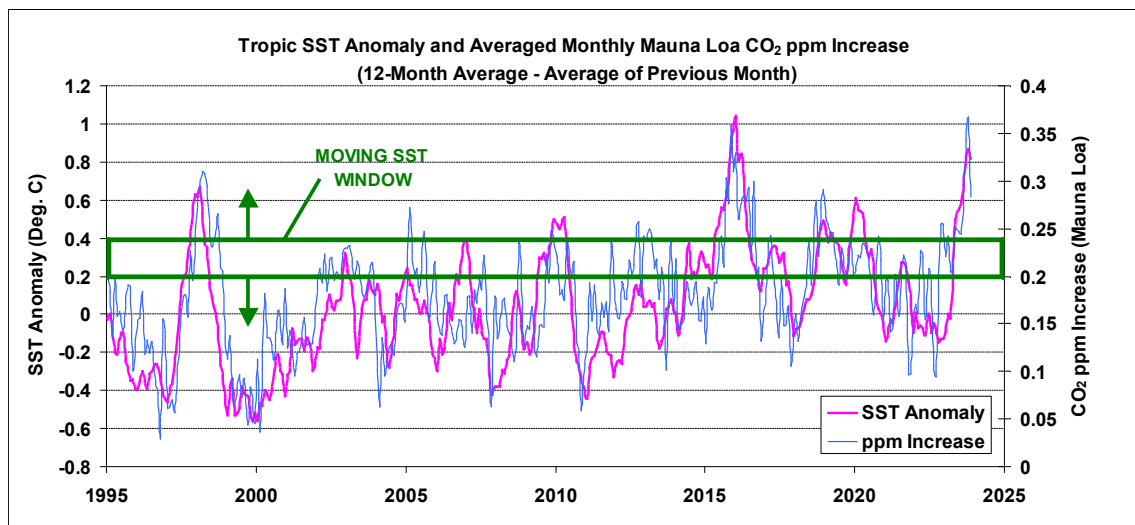


Figure 6: A typical ‘Slice’ or ‘Window’ for a 0.2 °C range of SSTs (1995 onwards)

This method analyses SST data that is only within the chosen ‘slice’ or ‘window’. Monthly CO₂ increases, with the same timestamp as the SST data, are plotted as a function of time. An assumption when using this method is that, if there is no influence from anthropogenic emissions, then there should be no upward trend in these increases as time progresses. However, if increasing annual anthropogenic emissions are contributing to those increases (GCB data suggests they have increased by about 60 % since 1995), then this may show up in the resulting trends.

Fig. 7f shows the trend in monthly ppm increases from the window identified in Fig. 6. The fitted trend line shows a very slight positive gradient resulting in a change in monthly increase of 0.0084 ppm since 1995, as calculated from the trend line’s gradient. This exercise is performed as the window moves between -0.3 and 0.6 °C in steps of 0.1 °C, resulting in the trend lines, with equations, in Figs. 7(a-h). The highest and lowest SSTs are excluded from the analysis due to there being insufficient data points.

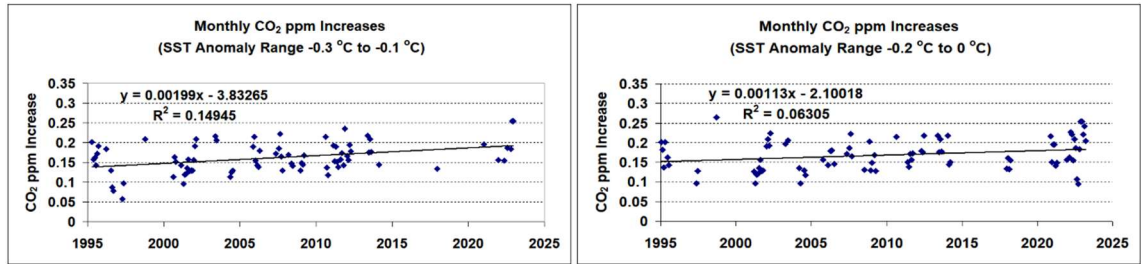


Figure 7 (a & b): Monthly CO₂ ppm increases for SST anomaly windows -0.3 to -0.1 & -0.2 to 0 °C.

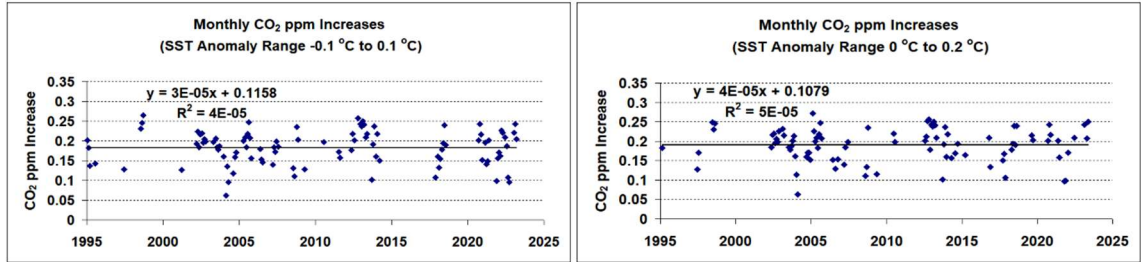


Figure 7 (c & d): Monthly CO₂ ppm increases for SST anomaly windows -0.1 to 0.1 & 0 to 0.2 °C.

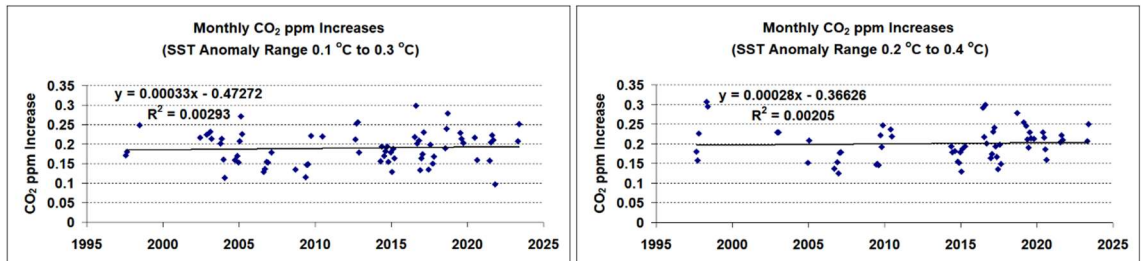


Figure 7 (e & f): Monthly CO₂ ppm increases for SST anomaly windows 0.1 to 0.3 & 0.2 to 0.4 °C.

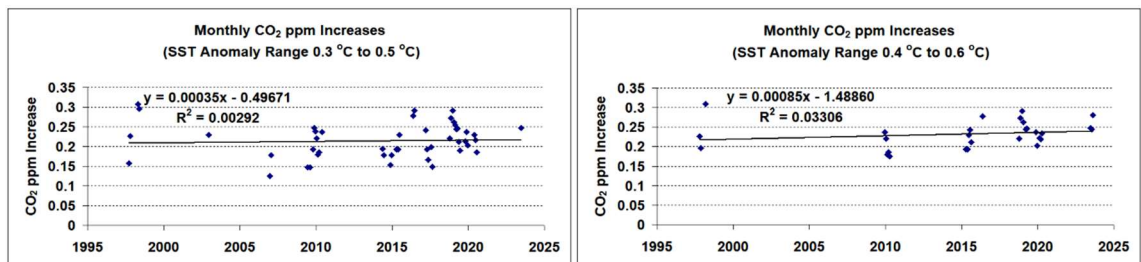


Figure 7 (g & h): Monthly CO₂ ppm increases for SST anomaly windows 0.3 to 0.5 & 0.4 to 0.6 °C.

The average trend line gradient from all eight ‘windows’ or ‘slices’ is +0.000625 ppm change in the monthly increase, per year. At the end of the ~28-year period this equates to a change of +0.0175 ppm/month (this figure can be approximately derived by visually examining the change in trend line end point values for each graph, and then averaging). Assuming that this change could be attributed to increasing anthropogenic emissions, an estimate can be made of the percentage contribution of these emissions to the total atmospheric CO₂ increase as follows:

Assuming a linear increase in annual anthropogenic emissions since 1995 (see Fig. 8) calculate the change in ppm increase for each month, based on the 0.0175 ppm end-point figure. So, for example, the monthly change halfway through the period would be half of that value. Then for all 336 months over the 28-year period, sum each incremental monthly change with respect to the start of 1995, starting at 0 ppm and ending at 0.0175 ppm, as illustrated in Fig. 9. The cumulative sum of all 336 incremental changes in monthly ppm increases comes to almost 3 ppm.

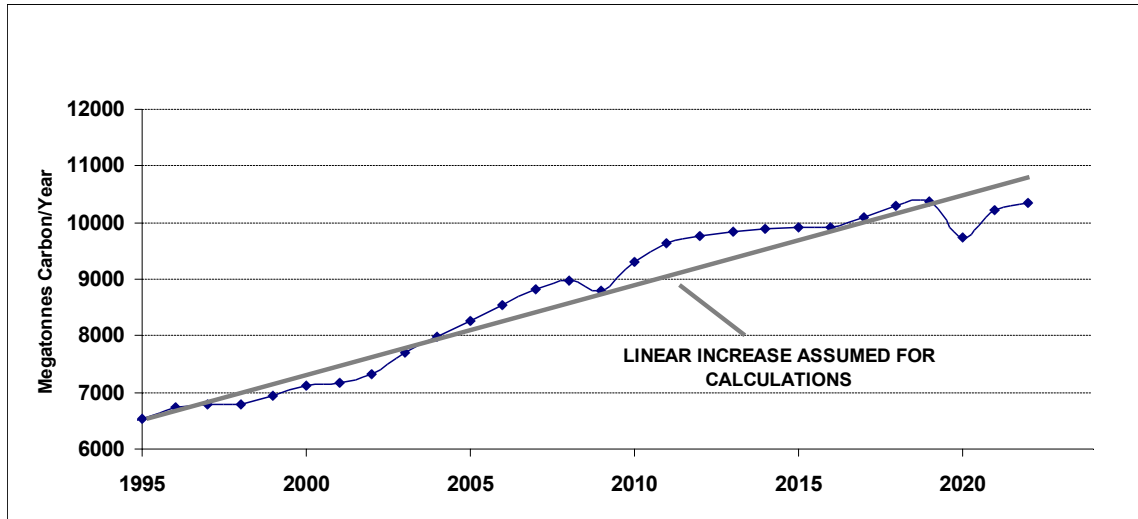


Figure 8: Annual anthropogenic carbon emissions (GCB data – Blue Trace). A linear rise in emissions (Grey Line) is assumed for the final summed calculation (Fig. 9)

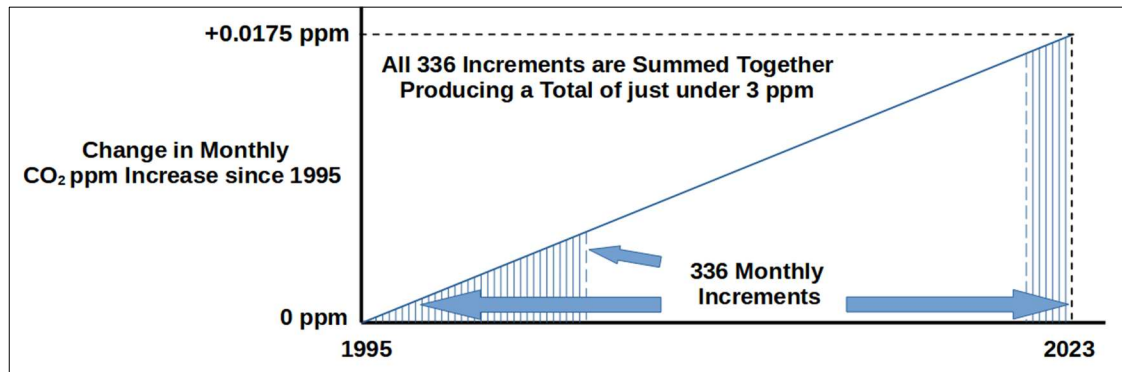


Figure 9: Assuming a linear rise in annual anthropogenic emissions from 1995 (see Fig. 8), the cumulative sum of all 336 incremental changes in monthly ppm increases comes to almost 3 ppm.

3. Results (Analyses 1 & 2)

For Analysis 1, the calculated CO₂ ppm increase (from SSTs) and the measured increase, since 1995, are in close agreement at about 62 ppm i.e. a human contribution cannot be discerned. This suggests that any increase due to human activity is, as a minimum, likely to be a minor component relative to the total increase.

For Analysis 2, the cumulative sum of all 336 incremental changes in monthly ppm increases comes to 2.94 ppm. The method used was repeated for seven thinner 0.1 °C ‘slices’ or windows in steps of 0.1 °C over the SST anomaly range of -0.2 to 0.4 °C. This repeated exercise suggested a possible human contribution of 3.85 ppm, resulting in a combined average of 3.4 ppm.

For the final step of Analysis 2, the figure of 3.4 ppm is assumed to be a consequence of the total increase in human emissions over and above the 1995 level of emissions (see Fig. 8). This increase was 61,030 MtC, whilst the total emissions since 1850 comes to 491,910 MtC, according to GCB data. Using simple linear extrapolation, the ppm from the total of all human emissions comes to $(491,900 / 61,030) * 3.4 = 27.4$ ppm. Using an assumed figure of 143 ppm increase in atmospheric CO₂ since 1850, this represents 19.2 % of the total increase in atmospheric CO₂.

The two analysis methods just described produce approximate results and so are useful for estimation only. Broadly-speaking, they suggest a quantifiable atmospheric CO₂ increase, possibly attributed to human emissions, of about 20 %, or less, of the total over the last three decades, thus inferring around 80 % or more is of natural origin.

4. Analysis 3: Longer-Term Data Trends

Using a broadly similar technique to that described by the late Lance Endersbee (2008) [13], this third analysis method plots atmospheric CO₂ against longer-term trends in SSTs.

To do this, the spreadsheet software applies a second-degree polynomial curve fit to tropic and global SST datasets, essentially acting as a low-pass filter that smooths out the peaks and troughs that are principally a consequence of El Niño and La Niña events.

4.1 3a. Global Tropic SSTs since 1982

Fig. 10 shows a second-degree polynomial curve fit to the global tropic SST data of Fig. 2 together with the associated equation.

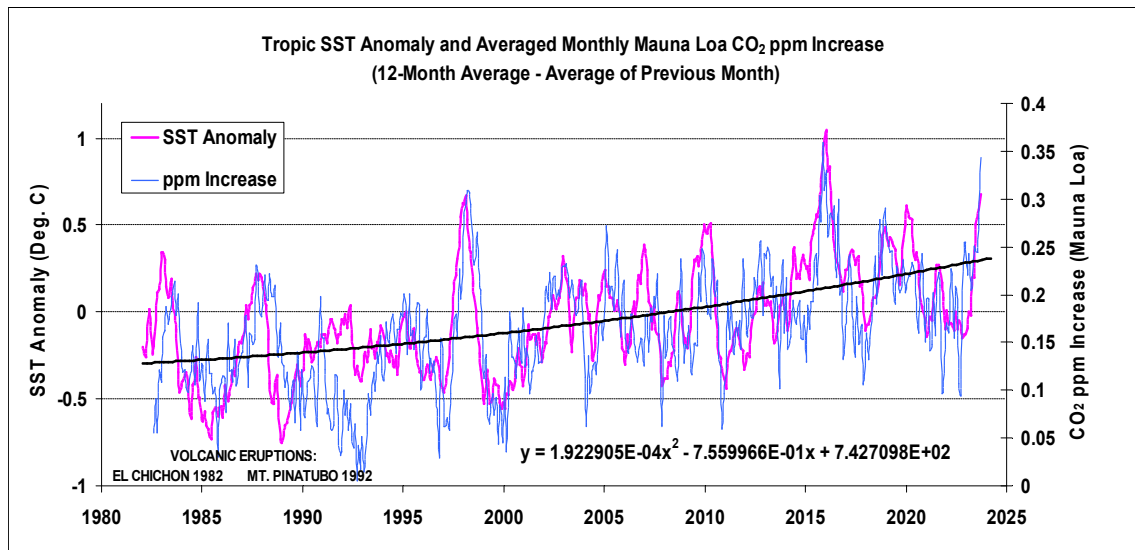


Figure 10: Polynomial curve fit to global tropic SSTs since 1982

The equation for this curve fit is then used to plot the trend of atmospheric CO₂ as a function of the ‘smoothed’ tropic SST data, both parameters possessing the same timestamp for each data point, Fig. 11. A fitted linear trend line (with associated equation) is superimposed. Date stamps are shown at selected CO₂ ppm levels.

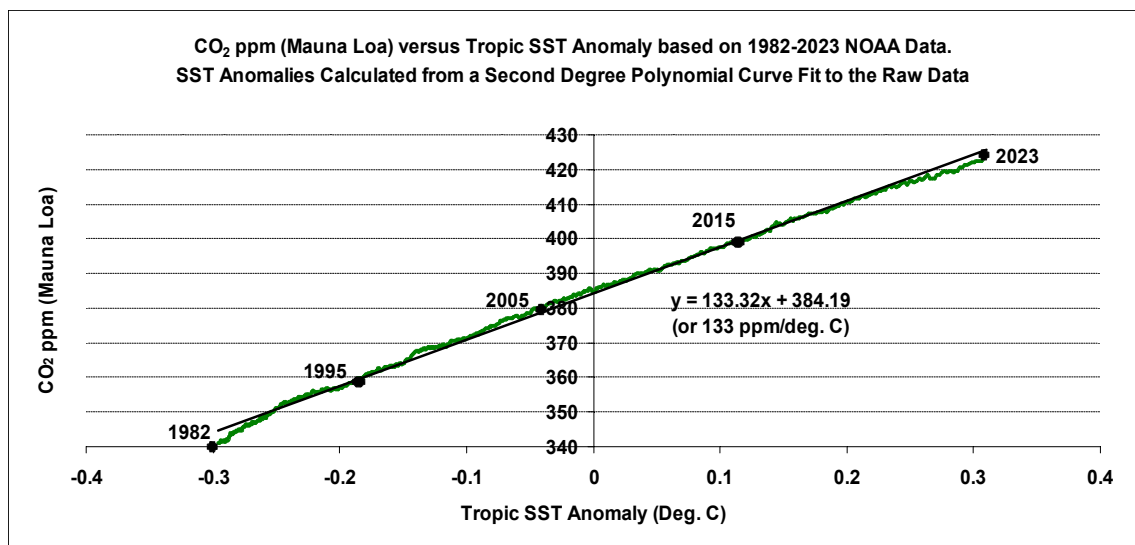


Figure 11: Atmospheric CO₂ as a function of the global tropic SST trend since 1982

4.2 3b. East Pacific Tropic SSTs (81W-179W, 27S-27N) Since 1951

This data [14] goes back to 1950. Again, the spreadsheet software applies a second degree polynomial curve fit to the data, Fig. 12. Note that the SST anomalies for this dataset are assumed to be in degrees Fahrenheit, and not Celsius as was stated on the website that the data was downloaded from.

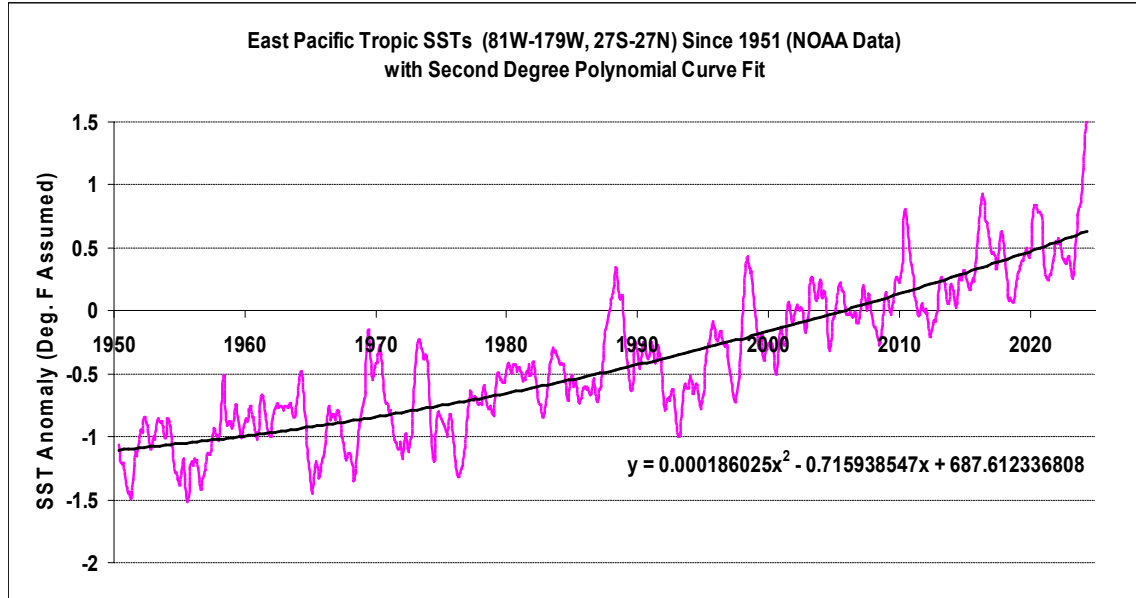


Figure 12: East Pacific tropic SSTs since 1950 (degrees Fahrenheit assumed)

The SST anomaly is the difference from a chosen baseline, or zero reference point. This reference point is normally a mean SST value averaged between two earlier dates.

Using the data from the smoothed SST curve fit, above, the resulting trend of atmospheric CO₂ as a function of SST is shown in Fig. 13, together with fitted linear trend line and equation.

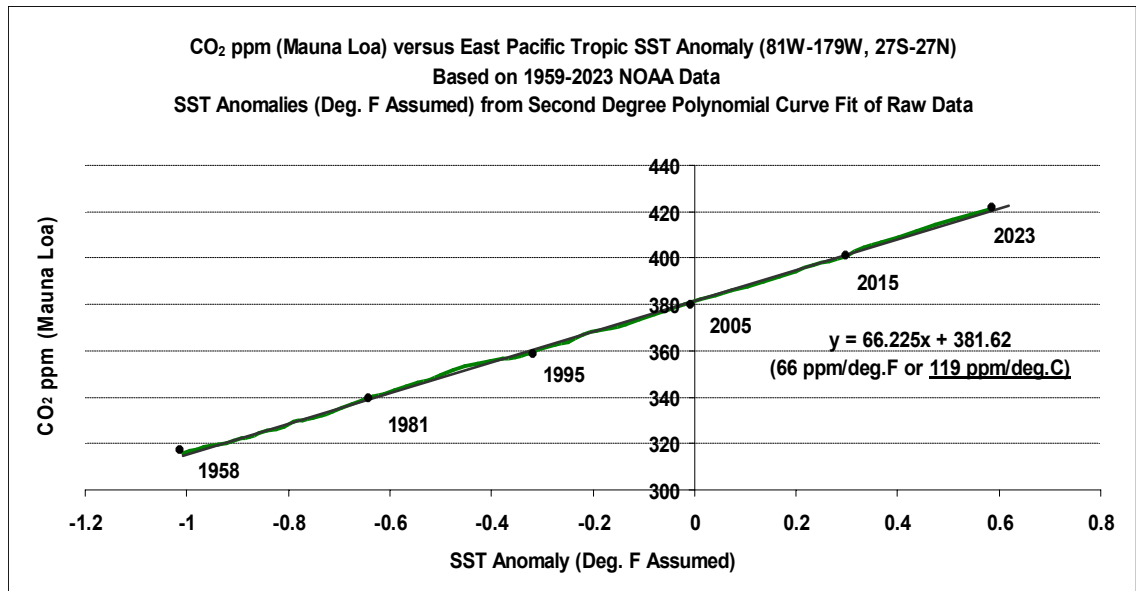


Figure 13: Atmospheric CO₂ as a function of East Pacific Tropic SST trend since 1958.

As a point of reference, GCB data suggests more than 80 % of human CO₂ emissions have occurred since 1958.

4.3 3c. Global SSTs Since 1958

The exercise is repeated here using global SST data [15] as compared to tropic SST data. A second-degree polynomial curve is once again fitted using the spreadsheet software, producing the equation shown in Fig. 14.

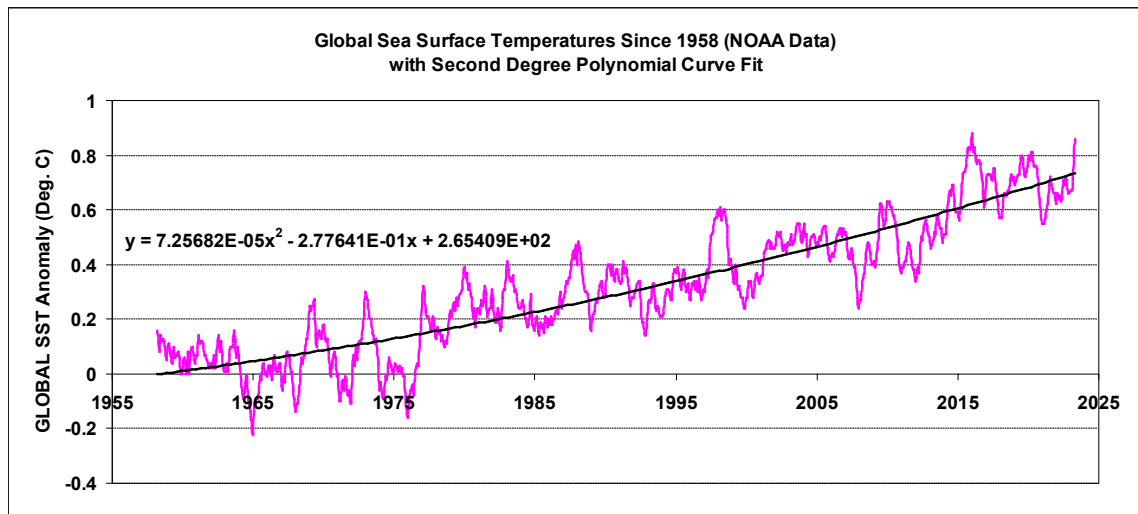


Figure 14: Global SSTs since 1958

Using the data from the smoothed SST curve fit, above, the resulting trend of atmospheric CO₂ as a function of global SST is shown in Fig. 15, together with fitted linear trend line and associated equation.

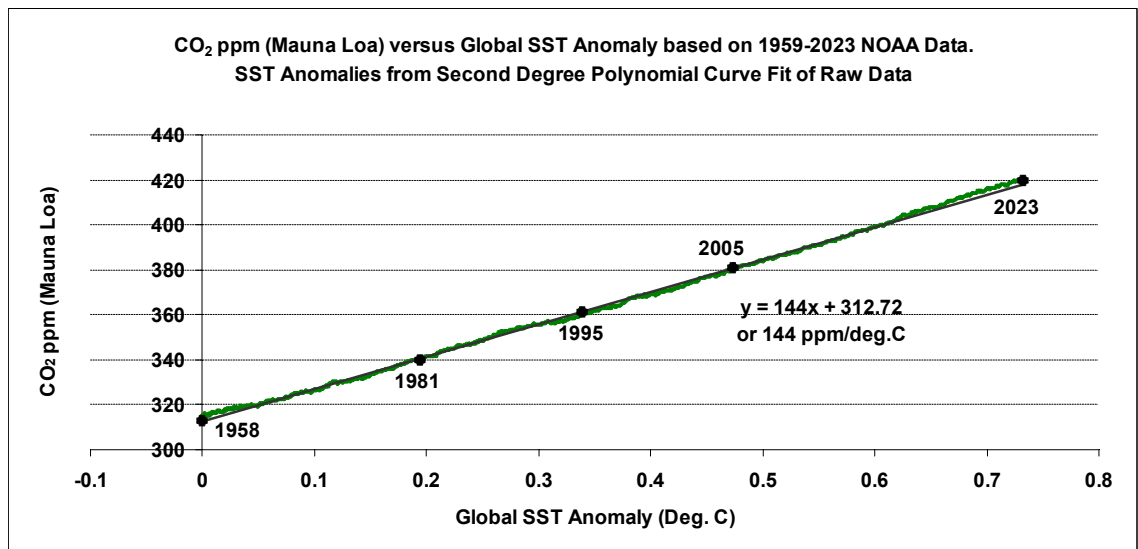


Figure 15: Atmospheric CO₂ as a function of global SST trend since 1958

5. Results (Analysis 3)

Approximate linear trends are apparent for all three graphs in Figs. 11, 13 and 15, with fitted trend line gradients of:

- 133 ppm/ °C for global tropic SSTs since 1982.
- 119 ppm/ °C for East Pacific tropic SSTs since 1958 (it's interesting to note that the trend line almost hides the graph due to the graph's linearity).
- 144 ppm/ °C for global SSTs since 1958.

6. Discussion

The techniques used in Analyses 1 and 2, aimed at discerning and estimating the human contribution to recent increases in atmospheric CO₂, are based on processing of monthly data from both SST and atmospheric CO₂ datasets.

Using the technique described in Analysis 1, no contribution from human emissions to the measured increases in atmospheric CO₂ since 1995, was discerned. Given an approximate 60 % increase in annual human emissions since 1995 this suggests, by itself, that any human contribution to the measured increases is likely to be relatively small compared to nature's contribution.

For the technique described in Analysis 2, a figure of ~27 ppm was estimated for a possible human contribution out of a total increase of 143 ppm since 1850, equating to around 19 % of the total increase in atmospheric CO₂ since the start of the industrial revolution.

Thus the results of these two analyses, taken together, suggest that nature appears to account for around 80 % or more of increases in atmospheric CO₂ since 1995.

The technique described in Analysis 3 examines the relationship between longer-term trends in SST datasets and atmospheric CO₂ measurements. This data analysis goes as far back as the late 1950s, when the ongoing acquisition of atmospheric CO₂ measurements began at Mauna Loa. The resulting three graphs show an apparent almost-linear long-term relationship between SSTs and atmospheric CO₂. Linear trend lines fitted to these graphs produce gradients of between ~120 and ~145 ppm/ °C for the three SST datasets examined.

As for anthropogenic CO₂, published figures (e.g. GCB data) suggest a roughly linear relationship between cumulative anthropogenic emissions as a function of time, and atmospheric CO₂ measurements from Mauna Loa. If it's reasoned that this mostly accounts for the linear trends as calculated in Analysis 3, , this reasoning would not fit with the findings of the first two analysis methods that suggest 80 % or more of recent atmospheric CO₂ increases are of natural origin.

6.1 Comparison with Other Recent Publications

A number of recent papers and articles put forward a case for recent increases in atmospheric CO₂ being mostly natural. Conclusions are drawn from several different lines of reasoning, and the approaches used are different to those presented above. Here are some examples (excerpts are from abstracts unless otherwise stated):

Humlum et al. (2013) [1] based on analysis of several well-known datasets (this excerpt is from their Section 8): *“Summing up, our analysis suggests that changes in atmospheric CO₂ appear to occur largely independently of changes in anthropogenic emissions... by this we have not demonstrated that CO₂ released by burning fossil fuels is without influence on the amount of atmospheric CO₂, but merely that the effect is small compared to the effect of other processes.”*

Skrable et al. (2022) [16] by examining 14C: *“We determined that in 2018, atmospheric anthropogenic fossil CO₂ represented 23% of the total emissions since 1750...”*

Schroder (2022) [17]: *“Over the industrial era, the natural emission increased three times as much as the man-made. The result is that only about 25 percent of the increase in atmospheric CO₂ is man-made”*

Salby & Harde (2022) [18] conclude: *“Thermally-induced emission in the tropics closely tracks observed net emission of CO₂. It thus accounts for the preponderance of CO₂ net emission, which in turn determines anomalous CO₂. For this reason, the thermally-induced response to observed warming in the tropics represents nearly all of the observed increase of atmospheric CO₂.”*

Berry (2023) [19]: *“UN data show human carbon emissions have added only 33 ppm to atmospheric CO₂... This predicted human-caused increase of 33 ppm is 8% of the total carbon in the atmosphere as of 2020... Also, $\delta^{14}C$ data prove nature is the overwhelming cause of the CO₂*

increase since 1750, and lower the 8% of human carbon in the atmosphere calculated from the UN data to less than 4 percent.”

Harde (2023) [20]: “We present own calculations based on the Conservation Law, which reproduce all details of the measured atmospheric CO₂ concentration over the Mauna Loa Era. From the calculations we derive an anthropogenic contribution to the observed increase of CO₂ over the Industrial Era of only 15%.”

Koutsoyiannis (2024) [21]: “Examining isotopic data in four important observation sites, we show that the standard metric $\delta^{13}\text{C}$ is consistent with an input isotopic signature that is stable over the entire period of observations (>40 years), i.e. not affected by increases in human CO₂ emissions. In addition, proxy data covering the period after 1500 AD also show stable behaviour. These findings confirm the major role of the biosphere in the carbon cycle and a non-discernible signature of humans.”

Ato (2024) [22]: “this study is the first to use multiple regression analysis to demonstrate that the independent determinant of the annual increase in atmospheric CO₂ concentration was SST” and concludes: “The global SST has been the main determinant of annual increases in atmospheric CO₂ concentrations since 1959. No human impact was observed.”

Shelley (2024) [23] says in a recent on-line article: “... I propose that the observed ocean warming since 1905... has resulted in the release of oceanic CO₂, which is the main reason why atmospheric CO₂ has increased by 140 ppm.”

Schrijver (2024) [24] concludes: “Due to the dominant role of natural changes in the biosphere under the influence of higher temperatures, one can conclude that the present CO₂ concentration can be regarded as a ‘natural’ level.”... “With a single residence time for all carbon dioxide in the atmosphere the human contribution based on fossil fuels is approximately 4.3%...”

Summarising the above figures for human contributions to atmospheric CO₂ since the start of the industrial revolution, these are: 25 % (Schroder), 23 % to 2018 (Skrable et al.), 15 % (Harde), 13 %* (Schrijver) and <12 %* (Berry) (*estimated from % of total atmospheric CO₂). Both Ato and Koutsoyiannis suggest no discernible human contribution.

By comparison, the estimated figure from Analysis 2 in this paper is ~19 % total human contribution to atmospheric CO₂ since the start of the industrial revolution: aligning reasonably well with the above figures.

With regards to the ppm/ °C trend line gradients derived in Analysis 3 of this paper, these gradients (averaging ~130 ppm/ °C) are broadly-similar to the gradient of the graph in Fig. 3 of Harde’s 2017 paper [25], for surface temperatures of the last fifty years or so.

Referring again to the findings of Analyses 1-3 in this paper, factors that may explain these findings are now considered (note that the majority of these factors are discussed by the aforementioned authors).

6.2 A Natural CO₂ Surface/Atmosphere Balance?

The idea of a natural CO₂ surface/atmosphere balance is nothing new. In his 2008 paper, Goldberg, for example, considered Henry’s law as a fundamental contributor to such a balance. This states that the amount of gas dissolved in a liquid is directly proportional to the gas’s partial pressure above the liquid. The law applies to any water exposed to the atmosphere, from ocean surfaces to cloud droplets, and the associated temperature-dependency means that cold water is able to retain more CO₂ than warm water.

When considering the oceans, most of the absorbed CO₂ undergoes chemical dissociation, or ionisation: the vast majority seemingly ‘prefers’ to take the form of bicarbonate and carbonate ions. When CO₂ is released from the oceans, the chemistry works in the reverse direction. Henry’s law applies to CO₂ as a gas only, not to its associated ionic species, and simple calculations suggest

that this law, when used in isolation from any other chemistry, results in a CO₂ ppm/ °C figure that's about an order of magnitude smaller than the >100 ppm/ °C values derived in Analysis 3. If that's the case (and some hypothesising is required here) then perhaps the reversible chemical changes taking place during ocean absorption and degassing might serve to 'enhance' the Henry's law effect: the suggestion being that most of the CO₂, upon absorption, is essentially removed from the balance determined by this law, through the process of ionisation, so allowing more CO₂ to be absorbed; the reverse taking place for CO₂ degassing.

CO₂ solubility in water is also pressure-dependent: water at 100m depth, for example, can retain about seven times more CO₂ than at the surface [26]. Perhaps water mixing between different depths, or general upwelling of deep CO₂-rich waters, might also be factors that enhance CO₂ exchange between the ocean and atmosphere.

Returning to the wider picture, it is again assumed that changes in the terrestrial and marine biospheres, and associated carbon cycles, would coincide with changes in SSTs, much as others have concluded. All are interlinked through global temperature changes and associated changes to weather patterns, and all would have a part to play in any temperature/CO₂ relationship. As Humlum et al. noted, changes in both air temperature and naturally-sourced atmospheric CO₂ follow changes in SSTs and my assumption is that nature's carbon cycle as a whole adjusts to changes in climate, which in turn are initiated by changes in SSTs.

6.3 CO₂ and a Colder Climate

Taken at face value, the observed >100 ppm/ °C relationship implies that, if surface temperatures were a few degrees cooler, atmospheric CO₂ levels would drop to the point where terrestrial plant life wouldn't survive: the threshold for plant survival is often quoted as ~150 ppm.

Clearly, atmospheric CO₂ must have remained above this threshold and this might partly be explained if the ppm/ °C relationship diminishes in magnitude as the biosphere becomes less active in cooler conditions. Also, a minimum level of atmospheric CO₂ may always be present due to emissions from volcanoes, other fissures within the earth's surface, wildfires and weathering of carbonate rocks. Aquatic CO₂ would still be in abundance and phytoplankton, that synthesise CO₂, are the start of the aquatic food chain, supporting marine life that respire CO₂.

Harde (2017) discusses atmospheric CO₂ levels in cooler climates in some detail [25].

6.4 Coincident Peaks Centred Around the 1940s

Temperature records show a peak in SSTs centred around the 1940s. If a natural surface/CO₂ balance holds true, is there any evidence of a coincident increase in atmospheric CO₂ at that time? Mauna Loa data did not come on stream until 1958, but there are numerous data sets of atmospheric CO₂ concentration, measured using chemical methods, going back to the early 1800s. These are described in a paper by the late Ernst-Georg Beck (2008) [27].

Atmospheric CO₂ measurements vary depending on factors such as location, time of day and season, and the measurements of the early 1800s were likely to be less accurate than more recent ones. These factors would account for some of the scatter in the data presented in the paper. However, within the collated measurements are several datasets indicating a peak in CO₂ levels in the 1930s-40s. Often-shown 'CO₂ hockey stick' graphs, partly based on ice core derived data, do not show any such peak of course, something which Beck is critical of in his paper¹.

In Fig. 16 a graph is constructed that combines the direct chemical measurement CO₂ trend from a later, more extensive paper by Beck (2010) [29]² (see his Table 11) with Mauna Loa data. A

¹ Beck mentions "the unreliability of ice core reconstructions" and cites the work of the late Zbigniew Jaworowski who wrote several publications on this matter, for example Jaworowski et al. (1992) [28].

² Beck's 2010 paper contains more refined data analysis compared to his earlier 2008 paper.

graph of global SST trends from 1880 onward [30] is shown above the CO₂ trend.

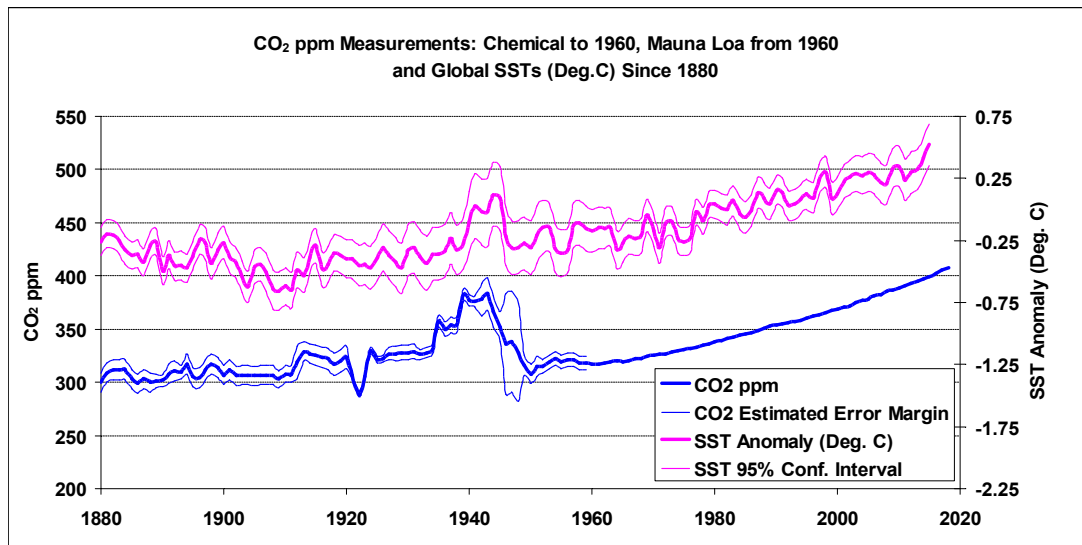


Figure 16: Atmospheric CO₂ measurements, shown in Blue (chemical measurements to 1960 and Mauna Loa measurements from 1960) and global SSTs (shown in Violet). The error margins and confidence intervals are as supplied with the chemical CO₂ and SST datasets.

The figure shows broadly-coincident peaks centred around the 1940s³. The CO₂ peak's transience would imply a short atmospheric residence time: opinions on this range from less than five years upwards. The peak in global temperatures is documented in both SST and terrestrial records.

Despite Beck's best efforts in analysing the collated chemical measurements, the presence (and perhaps magnitude) of a CO₂ peak centred around the 1940s is still the subject of debate⁴. Should the CO₂ profile in this figure be a fair representation of reality, then the coincidence of the two peaks is again suggestive of nature working to maintain a surface/ CO₂ balance.

6.5 Further Considerations

Earth's continually-changing climate has warmer interludes, such as the relatively-recent Medieval, Roman and Minoan warm periods (the present milder climate is sometimes named the Modern Warm Period)⁵. Given these warmer periods and consideration of a natural temperature-dependent surface/CO₂ balance, it seems logical to question whether the present levels of atmospheric CO₂ are anything unusual. As for CO₂ as a greenhouse gas, at the levels we currently experience, it has already done all the warming it can easily do because of the 'saturation effect'.⁶

³ Beck also plotted coincident SST and CO₂ peaks in his 2010 paper [29]. His Fig. 26 shows more precise peak alignment and he describes the cross correlation of the traces as having "a lag of 1 year for CO₂ after global SST".

⁴ For example, see Harde's explanation of the 1940's peak in chemical CO₂ measurements (2023) [10] and Engelbeen's criticism of the same measurements (2023) [31].

⁵ The fact that these warmer interludes are roughly 1000 years apart is almost certainly no coincidence. There are multiple climate cycles spanning decadal to millennial time scales, each of different phase and amplitude and contributing to a complex pattern of warming and cooling trends. There is considerable recent research on this topic e.g. Ludecke et al. (2017) [32].

⁶ The CO₂ 'saturation effect', the physics of which the IPCC doesn't dispute, is explained eloquently by physicist Will Happer in his many presentations and articles.

7. Conclusions

Analyses of SST and atmospheric CO₂ data, acquired since 1995, produce an estimated atmospheric CO₂ increase, possibly attributed to human emissions, of around 20 %, or less, of the total increase since the industrial revolution, thus inferring that around 80 % or more of the increase is of natural origin.

Further data examination points to an almost linear longer-term relationship between SSTs and atmospheric CO₂ since at least the late 1950s, and is suggestive of nature working to maintain a temperature-dependent atmosphere/surface CO₂ balance. Recent historical evidence of such a balance may come from chemical measurements that indicate a brief peak in atmospheric CO₂ levels centred around the 1940s, and that coincided with a peak in global SSTs.

Human emissions of CO₂ are about 1/20-th of the natural turnover, and the findings of the analyses presented here suggest that this relatively-small human contribution is being readily incorporated into nature's carbon cycles as they continually adjust to our constantly-changing climate.

As for surface temperatures, the research by Humlum et al. concluded that changes in atmospheric temperature are an 'effect' of changes in SSTs and not a 'cause' as some might advocate. And Humlum's 'take home' message from a recent presentation was: 'What controls the ocean surface temperature, controls the global climate' [33]. He suggests the sun would be a good candidate, modulated with the cloud cover.

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