I. MAN AND BIOSPHERE

INVESTIGATING THE HISTORICAL CORRELATION BETWEEN ATMOSPHERIC CARBON DIOXIDE CONCENTRATION AND GLOBAL TEMPERATURE CHANGE

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Abstract. Understanding the fundamental relationship between atmospheric carbon dioxide concentration and temperature rise is essential for tackling the problem of climate change that faces us today. Misconceptions regarding the relationship are widespread due to media and political influences. This investigation aims to address the popular misconception that CO₂ concentration *directly* and *naturally* leads to global temperature rise. While anthropogenic CO₂ emissions seem to affect the rising global atmospheric temperature with a confidence of 95%, it falters when the historical relationship using ice core data is studied. This investigation uses two statistical approaches to determine an accurate range and direction for this important relationship. Through a combined approach, it was found that historically CO₂ concentration in the last 650 000 years lags global temperature rise by 1020-1080 years with a maximum correlation coefficient of 0.8371-0.8372. This result is important for the investigation of climate change.

Keywords: environment; temperature rise; global warming; carbon dioxide emissions.

INTRODUCTION

Climate change is an issue at the forefront of science and technology. Rising global temperatures has put humankind on a crossroad. If we continue our current path of using the primary energy resources, wildlife will suffer, ecosystems may collapse, and agriculture will suffer serious consequences, all affecting our entire society [1]–[3]. These effects would be reflected in our modern society through food and freshwater shortages, macroeconomic deficiencies, and increased human aggression [1], [4]–[6].

While these impacts have been quantified and empirically determined, the mechanisms by which the global temperature rises is not 100% known. The most important world-wide study of global warming, performed by the Intergovernmental Panel on Climate Change estimated that the probability for the increase in the CO₂ emissions to the atmosphere causing the increase the atmospheric temperature, is 95% [7]. A widely held assumption is that temperature rise is the *direct result* of increased carbon dioxide (CO₂) emissions [8], [9]. While climate models show that CO₂ is a gas that perpetuates the greenhouse effect in Earth's atmosphere, there is no sufficient historical analysis to presume a natural relationship between greenhouse gases such as CO₂ and *global temperature rise*. The greenhouse gas effect is limited to recent data extending only to the period of industrial revolution. The industrial revolution marked the beginning of incredible human influence on the global environment and more specifically, the atmosphere.

Much of this misconception can be credited to inaccurate portrayals of climate change data fueled by prominent politicians and media corporations. Historical temperature and CO₂ concentration data follow extremely similar graphical paths, giving way to simplifications that are simply scientific and statistical misinterpretations. Furthermore, the time-axis, or x-axis, for this data is massive, making a visual correlation fruitless.

The documentary *An Inconvenient Truth*, featuring prominent American politicians, is an example of exaggeration of this inaccurate visual correlation. The film uses ice core data extending 650,000 years into the past and relates it to the impacts caused by humans in approximately 0.03% of that time period [10]. Furthermore, less than a year after the release of this film, the British High Court ruled that the film infringed on the Education Act 1996 and found the filmmakers guilty of political indoctrination. This ruling identified 11 inaccuracies in the film that must be highlighted by instructors prior to showing the film to a student audience. One such inaccuracy, the assertion that 650,000 years of ice core data *proved* that rising CO₂ emissions caused rising global temperatures, had a significant impact on the scientific community [11]. The British High Court showed, on the basis of the comparison of the peaks of temperature and CO₂ concentration data, that actually, the change in temperature caused the change in carbon dioxide concentration, and not vice-versa. This relationship is investigated mathematically using correlation analysis in this paper.

This investigation aims to provide a mathematical analysis of ice core data from the Vostok Arctic station. An accurate correlation between atmospheric CO₂ concentration and global temperature is determined via two distinct methods. Mathematical quantitative analysis is used for this investigation. Therefore, the results may serve as a basis for future scientific investigation of carbon dioxide concentration and global temperature. Most importantly, this analysis aims to show that it is in fact temperature rise that has led to CO₂ concentration throughout the past several hundred thousand years.

LITERATURE REVIEW

Investigation of the historic relationship between atmospheric CO₂ concentration and global temperature has led to varied conclusions. Petit et. al, prominent early (1999) investigators of the 420,000-year history from the Vostok ice core data, made some interesting logical leaps in their discussion [12]. The authors identified that CO₂ concentration lags global temperature in time, the hypothesis that this investigation aims to provide statistical reference for. However, their assertion that the lag is of several thousand years is inconsistent with the statistical results provided herein [12]. Furthermore, they ignored this lagging relationship in making the assertion “that CO₂... may have contributed to the glacial-interglacial changes over this entire period by amplifying the orbital forcing along with albedo, and possibly other changes” [12, p. 433].

The effect of orbital and radiative forcing was investigated in detail by Raynaud et. al, and Lorius et. al [13], [14]. In simplified terms, radiative forcing is the method by which the Earth comes into radiative equilibrium with space. It is strongly related with the albedo effect, and greenhouse gas entrapment is proposed as a motivator for changes in this equilibrium. It is theorized that this change in equilibrium causes orbital forcing, which is a change in the tilt of the Earth's axis and solar orbits to account for the new radiative equilibrium [6], [13]. This equilibrium can take many millennia to reach and is a result of fast and slow feedback processes. This is an assertion that increases in greenhouse gas emissions may cause temperature rise. Lorius et. al claim that to investigate fast feedback processes such as water vapour, clouds, and sea ice, it is unnecessary to understand the lead or lag relationship between CO₂ concentration and temperature [13]. Interestingly, like ice sheets, the impact of greenhouse gases on temperature is a slow feedback process. So although they say the relationship is unimportant for fast

feedback, they derive conclusions on slow feedback processes where the lead-lag relationship is of utmost importance [13].

As climate models have matured, they have become more reliable. However, like investigations in the early 1990s, only fast feedback processes were considered [13]–[15]. Even as slow feedback processes have been implemented into modern models, the error within increases because of inconsistencies in fast and slow feedback processes [16]. Conversely, ice-core data has already accounted for fast and slow feedback processes. This gives way to the simple conclusion that ice-core data reveals the most accurate depiction of natural climate fluctuations through history. Further, the relationship between CO₂ and global temperature can be accurately depicted by the simple correlations of ice-core data. Again, this does not consider human activity, and therefore neither ice-core data nor general climate models can accurately predict future outcomes. However, it can be said that past investigations, such as those reviewed above, claiming CO₂ concentration used to lead temperature rise may be inherently flawed.

METHODS

Data from the Vostok Arctic station was used for this investigation. In total, 3311 points of raw data corresponding to 422,766 years were provided for temperature change and CO₂ concentration respectively [12]. This presented two distinct opportunities for statistical analysis. The first method involved interpolating the data to the year. The alternate approach was to simply align the data points.

Each method involved normalization of the data followed by simple cross-correlative methods using MATLAB. The resulting maximum correlation coefficient (R-value) reflected a time value for the delay between the similarly trending data of temperature change and CO₂ concentration. A positive value denoted a leading relationship for CO₂ concentration as proposed by politically fueled information such as *An Inconvenient Truth*. Meanwhile a negative value reflected a lagging relationship, such as is proposed in this paper. In other words, a positive value would show that CO₂ concentration leads to temperature rise. A negative value reflects CO₂ concentration rise follows global temperature rise. The first approach involved simple interpolation of the data. The ice core data for CO₂ contains 594 distinct data points, compared to 3310 for temperature deviation. In this first method, interpolation was done to the year value.

The second method aimed to match the CO₂ dataset up to the bigger data point range of temperature

deviation. As such, rather than interpolating to the year, interpolation was done to 3310 data points for the CO₂ history. The method for statistical analysis was identical to the first method beyond this change in interpolative approach. This secondary method provides less interpolated data noise but does not deliver as much time precision as the first method. The resulting correlational coefficient is then a reflection of data point shift instead of year shift. The final step in this method is converting the R-value back to a time value in years.

RESULTS

The analysis begun with import and visualization of CO₂ concentration in parts per million (PPM) and temperature deviation in degrees Kelvin (K) as a function of ice age in years. Fig. 1 illustrates the similarity between these two curves. It should be noted that the year represented as zero for this analysis is 2001 [12]. That is, reading the graph from left to right represents going back in time.

Fig. 1. CO₂ Concentration & Temperature Deviation as a Function of Ice Age

Fig. 2. Normalized and Interpolated CO₂ Concentration & Temperature Deviation as a Function of Ice Age

The x-axis of the graphs in Fig. 1 represent a time-scale of 422,766 years. This massive scale makes simple correlation difficult and unprecise. Instead, the data must first be interpolated along the x-axis, and normalized along the y-axis as shown in Fig. 2. This step was unique to the primary method employed.

This figure shows that normalization of the CO₂ concentration data is inaccurate beyond a certain

point. This is seen as the large step near the end of the first graph in Fig. 2. This data is beyond the 422,766 years of data, as temperature data extended beyond this value. As such, the misaligned data was ignored.

Fig. 3, or Graph 5, is a stacked visualization of the similarities between the data. Again, no leading or lagging relationship can be derived visually from this interpolated and normalized data.

Fig. 3. Normalized CO₂ Concentration & Normalized Temperature Deviation as a Function of Ice Age

Numerical methods tools within the MATLAB environment were used to compare these trends using correlation coefficients. The maximum correlation, or peak of **Error! Reference source not**

found., represents the strongest relationship. This graph has been zoomed in on the absolute maximum of the trend.

Fig. 4. Correlation Coefficient as a Function of Delay

From the figure above, the delay lays at approximately -1000 years. This is represented by a maximum coefficient of correlation of 0.8372. The true value was determined to be -1080 years, as found by the absolute maximum, and confirmed by the MATLAB toolbox function *finddelay*.

This result was highly precise but may suffer from interpolation noise. To further confirm this value, a second approach was used. The primary data was presented in-line with the primary method as seen in Fig. 5, or Graphs 7 & 8.

Fig. 5. CO₂ Concentration & Temperature Deviation as a Function of Ice Age

Contrary to the first method, this approach simply relied on aligning data points and normalizing the y-axis.

Fig. 6. Normalized CO₂ Concentration & Temperature Deviation as a Function of Ice Age

Once again, limits of the CO₂ concentration data ignored for the purposes of calculating the correlation coefficients for the trends seen in Fig. 7.

Fig. 7. Normalized and Interpolated CO₂ Concentration & Normalized Temperature Deviation as a Function of Ice Age

Finally, the maximum correlation coefficient is derived from the absolute maximum of **Error! Reference source not found.** and confirmed by the *finddelay* function.

Fig. 8: Correlation Coefficient as a Function of Delay

The maximum peak represents a *data point delay* of -8, with a maximum correlation coefficient of 0.8371. This does not correspond to a year value and must be converted to determine a year delay for the second method.

DATA ANALYSIS

The two approaches for statistically determining the correlation between CO₂ concentration and temperature deviation allow for comparison of a highly precise value with high interpolation noise, to a value with lower precision and decreased interpolation noise. The first approach provides the result of -1080 years. The negative value confirms the hypothesis of this investigation: temperature rise leads to CO₂ concentration rise. The value of 1080 years is promising, as it entails a very short delay in relation to the timescale. In other words, this small time shift would not be visually identifiable as seen in Fig. 3 and

Fig. 7. A maximum correlation coefficient of 0.8372 is representative of the high similarity between the two trends.

The interpolation of this data provides a large amount of noise, as the step between each data point is approximately 128 years. Statistically, this provides an inaccurate answer. To confirm the accuracy, a secondary approach was employed. This involved aligning the data to 3311 data points instead of 422,766. The y-axis was normalized, as with the primary method, to accurately compare the graphs along the x-axis only. The delay was -8 using this method. By multiplying this value by the step between each data point of ~128, a time delay value of -1020 years was determined. The negative value once again confirms the hypothesis. The time value of 1020 years is close to the primary value of 1080 years. Furthermore, this method granted a maximum correlation coefficient of 0.8371. This value was extremely close to the value provided by method one ($R_1 = 0.8372$). Taken together, we can assert that CO₂ concentration lags temperature rise by between 1020 and 1080 years. This range is statistically accurate with a strong correlation (0.8371-0.8372).

CONCLUSIONS

Ultimately this investigation serves to provide a scientific basis for the *natural* relationship between CO₂ concentration and atmospheric temperature change. For many years, an unbased and inaccurate assertion taught in primary and secondary scientific curricula has served as a fundamental truth in scientific investigation [8], [9], [11], [17]. Prior,

limited models ignored the simple correlations shown in historical data to make basis for complex and potentially flawed theories [12]–[16]. The results from many of these investigations have provided direction for modern society to tackle climate change. The theories, such as those underlying orbital and radiative forcing, are strong and *may* maintain truth with adjustment of the fundamental assumptions. Nevertheless, it is essential that these theories be hypothesized with accurate and precise assumptions to overcome excessive errors [15].

This investigation proves that the CO₂ concentration change does not have a history of naturally causing atmospheric temperature change. In fact, the opposite is true: CO₂ concentration lags temperature rise by approximately 1000 years. Importantly, no conclusion can be drawn about human activity impact on temperature rise from this data.

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APPENDICES

Appendix A - MatLab Script w/ Interpolation to the Year

```

%% Problem statement: Use MatLab or similar correlation software to model the
relationship between
%% CO2 concentration and temperature deviation from ice core data. The
correlation lag should be between
%% 0-5000 years (literature indicates that CO2 should be trailing by ~1000
years)

%*** PLEASE NOTE: THIS FUNCTION INTERPOLATES DATA DOWN TO THE YEAR ***%

%% DATA EXTRACTION

data_CO2 = xlsread('raw_data.xlsx', 'CO2');
data_temp = xlsread('raw_data.xlsx', 'Temp');

%% PLOT OF RAW DATA

figure(1);

subplot(2,1,1);
plot(data_CO2(:,1), data_CO2(:,2));
title('Graph 1: CO_2 Concentration as a Function of Ice Age');
xlabel('Ice Age (yrs)')
ylabel('[CO_2] (PPM)')

subplot(2,1,2);
plot(data_temp(:,2), data_temp(:,4));
title('Graph 2: Temperature Deviation as a Function of Ice Age');
xlabel('Ice Age (yrs)');
ylabel('Temp. Dev. WRT Mean Recent Time Value (K)') ;

%% INTERPOLATION OF DATA IN X-AXIS (TIME) AND NORMALIZATION OF Y-AXIS DATA
([CO2] & TEMP DEVIATION)

t_INT = linspace(1,422766,422766)';
data_CO2_INT = interp1(data_CO2(:,1), data_CO2(:,2), t_INT);

data_CO2_norm = normalize(data_CO2_INT);
data_CO2_norm(isnan(data_CO2_norm)) = [0];
data_temp_INT = interp1(data_temp(:,2), data_temp(:,4), t_INT);
data_temp_INT(isnan(data_temp_INT)) = [];
data_temp_norm = normalize(data_temp_INT);

[m,n] = size(data_CO2_INT);
t_INT_CO2 = linspace(1, m, m);

%% GRAPH OF NORMALIZED AND INTERPOLATED DATA
figure(2);

subplot(2,1,1);
plot(t_INT_CO2, data_CO2_norm);
title('Graph 3: Normalized & Interpolated CO_2 Concentration as a Function of
Ice Age');
xlabel('Ice Age (yrs)')
ylabel('[CO_2] (norm)')

subplot(2,1,2);
plot(t_INT, data_temp_norm);

```

```

title('Graph 4: Normalized & Interpolated Temperature Deviation as a Function of
Ice Age');
xlabel('Ice Age (yrs)');
ylabel('Temp. Dev. WRT Mean Recent Time Value (norm)') ;

figure(3);

plot(t_INT_CO2, data_CO2_norm, 'r', t_INT, data_temp_norm, 'b');
title('Graph 5: Normalized CO2 Concentration & Normalized Temperature Deviation
as a Function of Ice Age');
xlabel('Ice Age (yrs)')
ylabel('[CO2] & Temp. Dev. (norm)')

%% CROSS CORRELATION MANUAL CHECK
maxLag = 5000;
[r, lag] = xcorr(data_CO2_norm, data_temp_norm, maxLag, 'normalized');

[M, I] = max(abs(r));
lagDiff = lag(I)

%% CORRELATION FINDER
yearsDelay = finddelay(data_CO2_norm, data_temp_norm) %% (Debugging attempt)

%% PLOT OF 'R' vs delay
figure(4);

plot(lag,r);
title('Graph 6: Correlation Coefficient as a Function of Lag OR Delay in
Years');
xlabel('Lag [Yrs]')
ylabel('Correlation Coefficient [ ]');

```

Appendix B - MatLab Script w/ Interpolation to the Year

```

%% Problem statement: Use MatLab or similar correlation software to model the
relationship between
%% CO2 concentration and temperature deviation from ice core data. The
correlation lag should be between
%% 0-5000 years (literature indicates that CO2 should be trailing by ~1000
years)

%*** PLEASE NOTE: THIS FUNCTION INTERPOLATES DATA TO MATCH DATA POINTS (3311)
***%

%% DATA EXTRACTION

data_CO2 = xlsread('raw_data.xlsx', 'CO2');
data_temp = xlsread('raw_data.xlsx', 'Temp');

%% PLOT OF RAW DATA

figure(5);

subplot(2,1,1);
plot(data_CO2(:,1), data_CO2(:,2));
title('Graph 7: CO_2 Concentration as a Function of Ice Age');
xlabel('Ice Age (yrs)')
ylabel('[CO_2] (PPM)')

subplot(2,1,2);
plot(data_temp(:,2), data_temp(:,4));
title('Graph 8: Temperature Deviation as a Function of Ice Age');
xlabel('Ice Age (yrs)');
ylabel('Temp. Dev. WRT Mean Recent Time Value (K)') ;

%% INTERPOLATION OF DATA IN X-AXIS (TIME) AND NORMALIZATION OF Y-AXIS DATA
([CO2] & TEMP DEVIATION)

t_INT = linspace(1, 422766, 3311)';
data_CO2_INT = interp1(data_CO2(:,1), data_CO2(:,2), t_INT);

data_CO2_norm = normalize(data_CO2_INT);
data_CO2_norm(isnan(data_CO2_norm)) = [0];
data_temp_INT = interp1(data_temp(:,2), data_temp(:,4), t_INT);
data_temp_INT(isnan(data_temp_INT)) = [];
data_temp_norm = normalize(data_temp_INT);

%% GRAPH OF NORMALIZED AND INTERPOLATED DATA

figure(6);

subplot(2,1,1);
plot(t_INT, data_CO2_norm);
title('Graph 9: Normalized CO_2 Concentration as a Function of Ice Age');
xlabel('Ice Age (yrs)')
ylabel('[CO_2] (norm)')

subplot(2,1,2);
plot(t_INT, data_temp_norm);
title('Graph 10: Normalized Temperature Deviation as a Function of Ice Age');
xlabel('Ice Age (yrs)');
ylabel('Temp. Dev. WRT Mean Recent Time Value (norm)') ;

```

```

figure(7);

plot(t_INT, data_CO2_norm, 'r', t_INT, data_temp_norm, 'b');
title('Graph 11: Normalized CO2 Concentration & Normalized Temperature  
Deviation as a Function of Ice Age');
xlabel('Ice Age (yrs)')
ylabel('[CO2] & Temp. Dev. (norm)')

%% CROSS CORRELATION MANUAL CHECK
maxLag = 5000;
[r, lag] = xcorr(data_CO2_norm, data_temp_norm, 'normalized');

[M, I] = max(abs(r));
lagDiff = lag(I)

%% CORRELATION DETERMINATION
delay = finddelay(data_CO2_norm, data_temp_norm)

%% CONVERSION TO YEARS
y = (422766/3311)*delay;
yearsDelay = round(y)

%% PLOT OF 'R' vs delay
figure(8);

plot(lag,r);
title('Graph 12: Correlation Coefficient as a Function of Lag');
xlabel('Lag [data point]')
ylabel('Correlation Coefficient [ ]');

```

Appendix C - MatLab Output

```

>> Code1
lagDiff =
    -1077
yearsDelay =
    1077
>> Code2
lagDiff =
    -8
delay =
     8
yearsDelay =
    1021

```