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Difficulties in Reducing Atmospheric CO_2 Concentrations during the Modern Warm Period

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Abstract

According to the IPCC, when anthropogenic CO_2 emissions increase, the atmospheric CO_2 concentration increases, and the temperature increases due to the greenhouse effect of CO_2. In the mechanism derived in our recent papers, the rise in temperature during the modern warm period increases CO_2 emissions due to an increase in soil respiration (*Rs control process*). The CO_2 emitted due to an increase in temperature can be considered thermally induced CO_2. Therefore, although there is a correlation between temperature and CO_2 concentration, there is a temperature-leading time lag due to the *Rs* control process. In this work, we analyzed the relationships between temperature changes and CO_2 concentration changes in detail. As a result, we found that even if anthropogenic CO_2 decreases, it is difficult to reduce the atmospheric CO_2 concentration because of the large *Rs* control process during the modern warm period. One of the main reasons is that the *Rs* control process in mid-latitude forests is significantly affected by temperature changes, which also means that the increase in anthropogenic CO_2 since the Industrial Revolution has had only a small effect on the change in global CO_2 concentrations.

Keywords

Global Warming, Global CO_2, Anthropogenic CO_2, Thermally Induced CO_2, Soil Respiration, Cross-Correlation, Time Lag, El Niño

1. Introduction

The global temperature started to rise after the *Little Ice Age* of the 19th century [1]. Compared with the Little Ice Age, the present day may be called a *modern warm period*. Additionally, atmospheric CO_2 has risen simultaneously, although direct measurements of CO_2 were limited before 1958 [2]. There is a relationship between the change rate of the CO_2 concentration ($\mathrm{d}rco_2/\mathrm{d}t$, where rco_2 = CO_2 concentration, t = time) and the change in global temperature (ΔT), as shown in Equation (1), but with a temperature-leading time lag [3].

$$\mathrm{d}rco_2/\mathrm{d}t = \gamma \Delta T \; (\gamma\text{: a constant}) \quad (1)$$

The time lag is approximately 0.5 - 1 year.

The relationship between the global temperature and CO_2 concentration has been investigated [3]-[6]. On the basis of Equation (1), a cross-correlation between $\mathrm{d}rco_2/\mathrm{d}t$ and ΔT with a temperature-leading time lag was found [6], where a correlation coefficient r can be defined as follows ($x = \mathrm{d}rco_2/\mathrm{d}t$ and $y = \Delta T$):

$$r = \frac{\frac{1}{n}\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\frac{1}{n}\sum_{i=1}^{n}(x_i - \bar{x})^2}\sqrt{\frac{1}{n}\sum_{i=1}^{n}(y_i - \bar{y})^2}} \quad (2)$$

The satellite-based 13-month average of the temperature anomaly and the annual average of the rate of CO_2 increase corresponding to Equation (1) are correlated over 40 years, as reported in a previous paper [3]. Its correlation coefficient, r, was 0.73, and the correlation was relatively good [6]. A detailed analysis indicated that the temperature-leading time lag was 5 months [6].

An increase in global temperature, an increase in soil respiration (*Rs*), and a subsequent increase in global CO_2 emissions were recognized in our papers [4] [5]. In other words, as the temperature increases, *thermally induced* CO_2 is emitted, and the CO_2 concentration increases [5]. This natural process can be clearly detected during periods of increasing temperature, specifically during El Niño events. **Figure 1** summarizes the *Rs control process* for global warming. In the mechanism based on the *Rs* control process, the increase in temperature during the modern warm period increases CO_2 emissions because of an increase in *Rs*. The emitted CO_2 can be considered thermally induced CO_2 [5]. As a result, the CO_2 concentration in the atmosphere increases. Although there is a cross-correlation between temperature and CO_2 concentration, a temperature-leading time lag is observed because it is a process mediated by *Rs*. However, according to the Intergovernmental Panel on Climate Change (IPCC) under the United Nations, as anthropogenic CO_2 emissions increase, the CO_2 concentration in the atmosphere increases, and the atmospheric temperature increases due to the greenhouse effect of CO_2 [7], even though anthropogenic CO_2 is a minor constituent of global CO_2. The IPCC model may predict a CO_2-leading time lag if there is a cross-correlation between the CO_2 concentration and temperature. Therefore, our recent results cast strong doubts that anthropogenic CO_2 is the cause of global warming.

Tropical rainforests account for 6% - 7% of the Earth's land surface, whereas temperate rainforests account for only 0.2% - 0.3%. However, deciduous and coniferous forests each occupy more than 10% of the Earth's land surface, and if forests in subtropical regions are included, these forests account for approximately 30% of the Earth's land area [8] [9]. Since the temperature in midlatitude

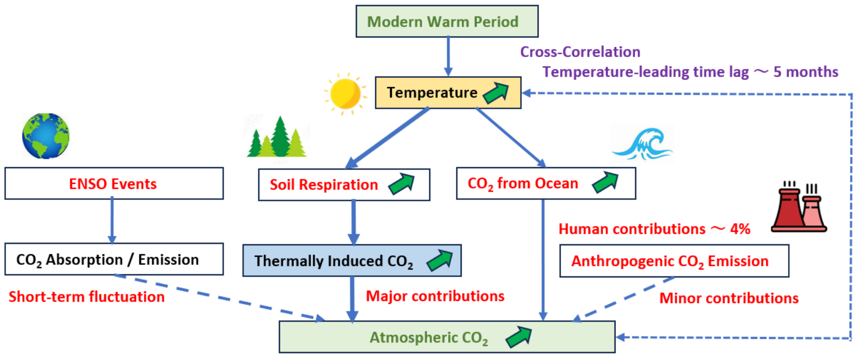


Figure 1. *Rs* controls the increase in atmospheric CO_2 during the modern warm period.

forests changes seasonally in contrast to the temperature in tropical rainforests, soil respiration in midlatitude forests changes seasonally depending on changes in the annual temperature. Additionally, an increase in global temperature affects the degree of soil respiration in midlatitude forests rather than in tropical rainforests. Soil respiration emits a large amount of CO_2 that exceeds anthropogenic CO_2 emissions, and an increase in CO_2 emissions due to an increase in temperature during the modern warm period must be significant.

For these reasons, soil respiration in midlatitude forests is highly dependent on temperature changes during the modern warm period and may play a significant role in controlling atmospheric CO_2 concentrations. Compared with that in the tropics, the rate of change in the CO_2 concentration at midlatitudes (≒ 50 N) significantly responds to temperature changes [4]. The temperature difference between land and sea areas is greater in the north (20 N - 90 N) than in the south (20S - 90S) [4]. These results support the critical role of soil respiration in midlatitude forests. For example, the Pacific temperate rainforest is located between No. California and S. Alaska along the Pacific Ocean. The region of Olympic National Park has approximately 3500 mm/year of precipitation (see Figure 2). CO_2 emission by soil respiration from forests is significant.

Figure 2. Temperate forests in Olympic National Park, WA (USA) (photographed by the author, March 4, 2025).

The United Nations and each government have begun to take the initiative to reduce anthropogenic CO_2 emissions to prevent global warming. This raises the question of whether reducing anthropogenic CO_2 emissions actually decrease the global CO_2 concentration. This question is investigated in this paper.

2. Global Data

Atmospheric CO_2 concentrations are reported by the National Oceanic and Atmospheric Administration (NOAA). Further details are available on their website [10]. The annual emission of anthropogenic carbon was determined according to Boden *et al.* [11]. The global carbon budget of the IPCC [12] was also used.

The temperature datasets were obtained from the University of Alabama in Huntsville (UAH), and the 13-month average of the lower troposphere anomaly values was used [13].

3. Results and Discussion

The change rate of the CO_2 concentration has been the focus of our previous papers [3]-[6]. In this paper, temporal changes in global CO_2 concentrations are the focus. **Figure 3** shows the changes in atmospheric CO_2 and satellite-based temperature anomalies between 1979 and 2023. The CO_2 concentrations in **Figure 3** are de-seasonalized values representing the long-term trend reported by NOAA [10]. The atmospheric CO_2 concentrations and global temperature anomalies are correlated, with $r = 0.81$. Notably, the small inflection points, *a*-*j*, in the temporal change in CO_2 concentrations correspond to ENSO events [3]. The changes in CO_2 concentrations around the inflection points are small for La Niña events, whereas the changes in CO_2 concentrations are greater for El Niño events. **Figure 4** shows examples of inflection points, *c* and *d*, which represent changes in CO_2 concentrations. The inflection point *c* corresponds to La Niña, and the CO_2 concentration shows a small change, whereas the inflection point *d* corresponds to El Niño, and the CO_2 concentration shows a great change.

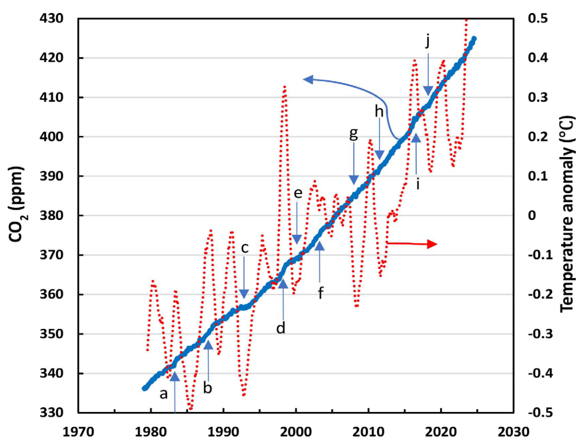
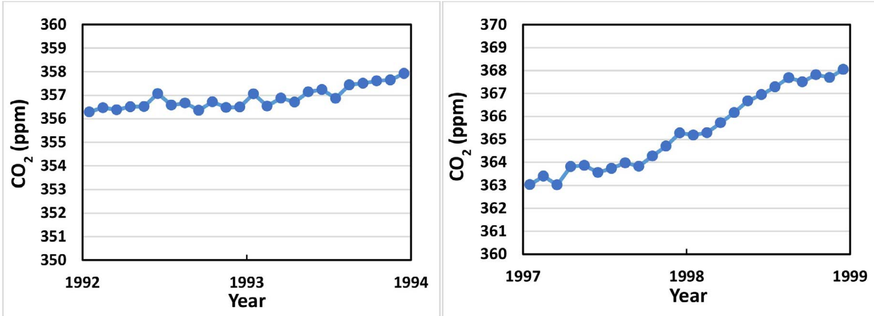


Figure 3. Temporal changes in atmospheric CO_2 and temperature anomalies (*a*-*j* on the CO_2 curve denote inflection points, correlation coefficient $r = 0.8148$, CO_2 data: [10], temperature data: [13]).



(a) (b)

Figure 4. Changes in atmospheric CO_2 around inflection points *c* and *d* in **Figure 3**.

In the *Rs* control process summarized in **Figure 1**, the increase in temperature due to the modern warm period increases CO_2 emissions because of an increase in *Rs*. The emitted CO_2 can be considered thermally induced CO_2. As a result, the CO_2 concentration in the atmosphere increases. For a short period, similar natural processes can be detected during El Niño and La Niña events. The inflection points of temporal changes in CO_2 concentrations demonstrate that ENSO events change temperature, followed by changes in CO_2 [3] [4].

The same temporal changes in atmospheric CO_2 and satellite-based temperature anomalies are shown in **Figure 5** to compare the rates of acceleration between the two. The red solid line represents a linear regression of the temperature anomaly, (temperature) = 0.01438 × (year) − 28.83. The regression line indicates that the rate of increase in temperature is 0.1438˚C/decade. Notably, the atmospheric CO_2 concentration increases with time, but the rate of increase is greater than the rate of increase in temperature. Next, the change rate of the CO_2 concentration over 10 years was analyzed to determine the trend of changes in CO_2 over a long time range. **Figure 6** shows the averages of increased annual CO_2 over ten years between 1970 and 2020, for example, (a value of CO_2 concentration in 1970 − a value of CO_2 concentration in 1960)/10. The increase in annual CO_2 over ten years is not constant but rather has increased over time or accelerated. If atmospheric CO_2 concentrations increase, followed by an increase in the global temperature, the global temperature may show a similar change to the accelerated increase in CO_2. However, the global temperature increases as a linear function, and no acceleration is observed.

The acceleration of the increase in CO_2 concentration is critical in predicting future CO_2 during the modern warm period. As described later, anthropogenic CO_2 is a small proportion of the total carbon cycle budget, so even if a small portion of anthropogenic CO_2 is partially reduced, the decrease in CO_2 concentration may be difficult because of this acceleration of the CO_2 concentration.

Figure 7 shows the annual emissions of anthropogenic carbon [11]. The emission increases approximately linearly and shows no acceleration. Additionally, the global CO_2 in **Figure 3** has no effect on the CO_2 corresponding to inflection points *a*, *b*, and *c* in **Figure 7**. The annual emission of anthropogenic carbon from 1960 and 2020 was 2 - 10 PgC (or GtC). The unit conversion from PgC (or GtC) to *ppm* can be calculated via Equation (3) [14]:

$$(x_1 \text{ GtC} \times 3.67/44)/(5135 \text{ Eg}/28.9) = x_2 \text{ ppm} \quad (3)$$

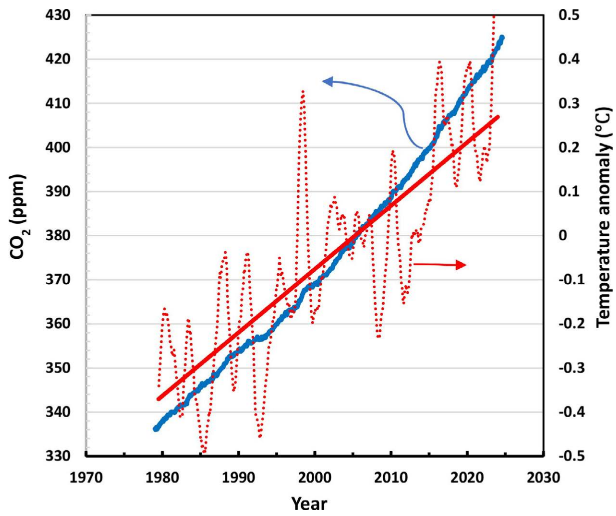


Figure 5. Comparison of rate accelerations between temporal changes in atmospheric CO_2 and temperature anomalies. The red solid line shows a linear regression of the temperature anomaly ((temperature) = 0.01438 × (year) − 28.83, which corresponds to an increasing rate of temperature = 0.1438˚C/decade).

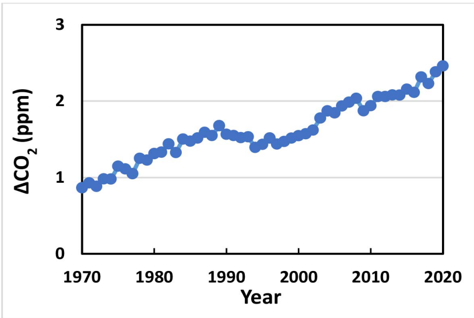


Figure 6. The average increase in annual CO_2 over ten years between 1970 and 2020.

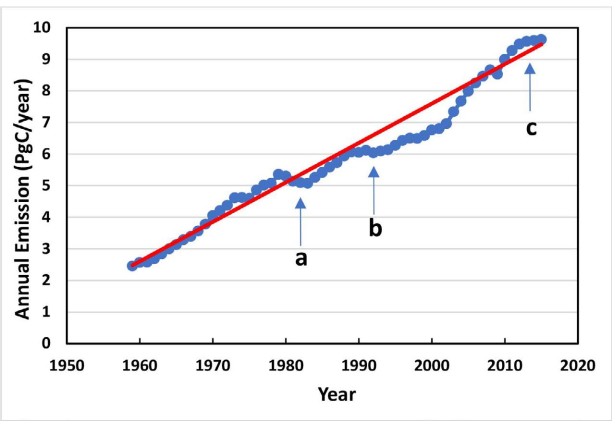


Figure 7. Annual emission of anthropogenic carbon (Carbon = 0.1248 × (year) − 242 [11]).

x_1 and x_2: variables, 3.67: a conversion factor from carbon to CO_2, 44: molecular mass of CO_2, 28.9: molecular mass of air, 5135 Eg: air mass on earth.

Therefore, 2 - 10 PgC/year is equivalent to 1 - 5 ppm/year. Additionally, according to the IPCC carbon cycle, CO_2 emissions from fossil fuels are 7.8 GtC (or 3.9 ppm) [12]. These CO_2 amounts are too small compared with the change in atmospheric CO_2 concentrations (330 - 430 ppm) shown in **Figure 5**. Since the residence time of atmospheric CO_2 can be estimated to be 3 - 4 years [4] [14], anthropogenic CO_2 does not accumulate in the atmosphere for a long period of time. For these reasons, anthropogenic CO_2 does not significantly affect global CO_2 concentrations.

Since *Rs* increases exponentially with temperature [15], it is assumed that CO_2 thermally induced via *Rs* follows a first-order reaction rate, as shown in Equation (4).

$$k = \alpha \cdot \exp(-\beta/\mathrm{T}) \quad (4)$$

k: reaction rate constant, T: temperature, α and β: constants.

Figure 8 shows a hypothetical chart showing the temperature (or time) dependence of atmospheric CO_2. As shown in **Figure 5**, the temperature changes linearly with time, so the x-axis can be replaced with time. The hypothetical chart is similar to the change in CO_2 with time in **Figure 5**. This assumption may explain the accelerated increase in CO_2 concentrations during the modern warm period.

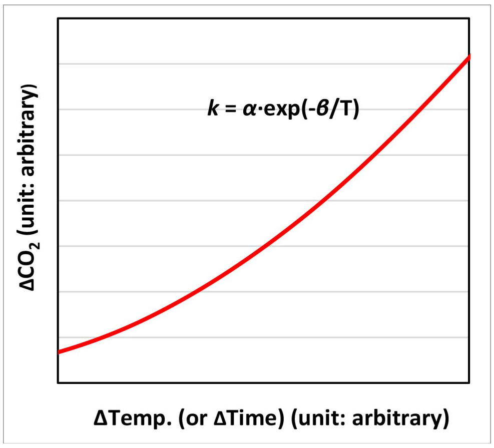


Figure 8. A hypothetical chart showing the temperature (or time) dependence of the temporal change in atmospheric CO_2, assuming a first-order reaction rate for *Rs*. Compared with **Figure 3** and **Figure 5**.

As shown in Equation (1), there is a relationship between the change rate of the CO_2 concentration ($\mathrm{d}rco_2/\mathrm{d}t$) and the change in global temperature (ΔT). To examine the response of the change rate of the CO_2 concentration to temperature changes at various latitudes, two variables were compared between 1979 and 2022 in the tropics, at northern latitudes, and at southern latitudes, as reported in a previous paper [3]. Although ΔT in the tropics strongly responds to El Niño, $\mathrm{d}rco_2/\mathrm{d}t$ at northern latitudes responds more strongly to ΔT than does that in the tropics. Therefore, the temperature dependence of the temporal change in atmospheric CO_2 may be greater at northern latitudes than in the tropics. In other words, changes in *Rs* with temperature at northern latitudes are more important than those in the tropics in controlling atmospheric CO_2.

Anthropogenic CO_2 emissions constitute only ~4% of the global CO_2 cycles, as discussed above. The anthropogenic CO_2 emissions and other CO_2 origins of the global CO_2 cycle budget are shown in **Figure 9**. Notably, anthropogenic CO_2 emissions contribute too little to affecting the global CO_2 concentration. Furthermore, no sign of a reduction in atmospheric CO_2 concentrations is observed, regardless of an effort to reduce anthropogenic CO_2 emissions, as shown in **Figure 5**. Additionally, this means that an increase in anthropogenic CO_2 since the Industrial Revolution has contributed too little to affect the global CO_2 concentration.

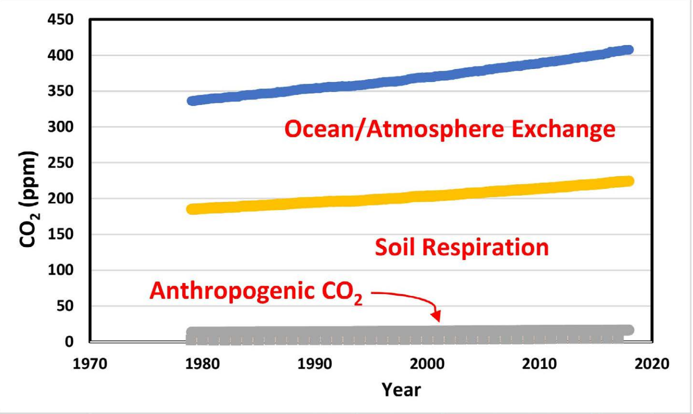


Figure 9. Ratios of CO_2 origins in atmospheric CO_2 based on the global carbon budget by the IPCC [12].

The plants that abound on Earth are produced through photosynthesis. The amount on Earth is enormous, and according to IPCC assessments, *Rs* is estimated to be involved in approximately half of the carbon cycle on Earth, as shown in **Figure 9**. When the global CO_2 or carbon cycle is in balance, the same number of plants synthesized are decomposed through "soil respiration" and returned to CO_2. Therefore, the quantitative role of "soil respiration" in the carbon cycle on Earth far exceeds that of anthropogenic CO_2 emissions [4].

As described in the introduction, midlatitude forests cover approximately 30% of the Earth's land area [8] [9]. Because the temperature of midlatitude forests varies seasonally, in contrast to that of tropical rainforests, soil respiration in midlatitude forests varies seasonally in response to changes in annual temperature. Thus, increasing global temperatures affect the extent of soil respiration in midlatitude forests more than they do in tropical rainforests. Therefore, the global Rs control process is highly dependent on temperature, and during the modern warm period, atmospheric CO_2 concentrations continue to increase and are difficult to reduce. Even if anthropogenic CO_2 is changed by human activities, atmospheric CO_2 will not change significantly.

The Little Ice Age lasted until the mid-18th century [1]. The Mendenhall Glacier near Juneau, AK, is an example of a receding glacier after the Little Ice Age. The Glacier started retreating in the mid-1700s before the rapid development of the Industrial Revolution [16]. The amount of thermally induced CO_2 may have started to increase before the Industrial Revolution. It is doubtful that anthropogenic CO_2 increased at the beginning of the Industrial Revolution, after which the global temperature simultaneously increased.

Hermann Harde [17] reported that the increase in CO_2 over recent years can be explained well by a single balance equation, which considers the total atmospheric CO_2 cycle. It comprises temperature-dependent natural emissions and uptake processes and human activities. This uptake is characterized by a single time scale, with a residence time of approximately 3 years. For a conservative assessment, he reported that the anthropogenic contribution to the observed CO_2 increase over the Industrial Era was significantly less than the natural influence. On average, between 2007 and 2016, anthropogenic emissions contributed no more than 4.3% to the total concentration. He noted that not anthropogenic emissions but rather natural processes, particularly temperature, have to be considered the dominant impacts for the observed CO_2 increase over the last 270 years. His analysis correlates well with our results in this paper.

To consider how to control the concentration of CO_2 in the atmosphere, our recent results [3]-[6] and the results from this work are summarized here.

1) Changes in temperature and CO_2 are correlated, but temperature leads to CO_2.

2) Thermally induced CO_2 is overwhelmingly larger than anthropogenic CO_2.

3) Thermally induced CO_2 plays a critical role in the atmospheric CO_2 balance during the modern warm period.

4) The temperature linearly increased, whereas atmospheric CO_2 did not linearly change but accelerated with time.

5) Atmospheric CO_2 significantly changes during El Niño events but does not change much during La Niña events.

6) There is no correlation between the atmospheric CO_2 concentration and anthropogenic CO_2 emissions.

As a result, anthropogenic CO_2 emissions constitute a small part of the overall CO_2 balance, and the total amount of CO_2 is controlled by thermally induced CO_2 and not by anthropogenic CO_2. After the Little Ice Age ended, the modern warm period began in the mid-18th century, and the amount of thermally induced CO_2 increased. Therefore, even if anthropogenic CO_2 emissions are reduced, the total CO_2 concentration will continue to increase during the modern warm period.

4. Conclusion

Figure 1 summarizes the *Rs* control process derived from our work on global warming. According to the IPCC, as anthropogenic CO_2 emissions increase, the CO_2 concentration in the atmosphere increases, and the atmospheric temperature increases due to the greenhouse effect of CO_2. In the *Rs* control process, the increase in temperature due to the modern warm period increases CO_2 emissions due to increased *Rs*. One of the main factors is that the *Rs* control process in the midlatitude forest zone changes significantly due to temperature changes. The emitted CO_2 can be considered thermally induced CO_2. As a result, the CO_2 concentration in the atmosphere increases. Therefore, although there is a cross-correlation between temperature and CO_2 concentration, a temperature-leading time lag is observed because it is a process mediated by *Rs*. Even though anthropogenic CO_2 has decreased, reducing total atmospheric CO_2 concentrations during the modern warm period is difficult. Additionally, this means that an increase in anthropogenic CO_2 since the Industrial Revolution has contributed too little to affect the global CO_2 concentration.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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Abbreviations

ENSO Index:	El Niño-Southern Oscillation Index
IPCC:	Intergovernmental Panel on Climate Change (the United Nations body)
NOAA:	National Oceanic and Atmospheric Administration
UAH:	University of Alabama in Huntsville
$\mathrm{d}rco_2/\mathrm{d}t$:	The change rate of the CO_2 concentration or CO_2 growth rate
Rs:	Soil respiration
ΔT:	Temperature change
r:	correlation coefficient