

# Cross-Correlation between Global Temperature and Atmospheric CO<sub>2</sub> with a Temperature-Leading Time Lag

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## Abstract

The temperature change and rate of CO<sub>2</sub> change are correlated with a time lag, as reported in a previous paper. The correlation was investigated by calculating a correlation coefficient  $r$  of these changes for selected ENSO events in this study. Annual periodical increases and decreases in the CO<sub>2</sub> concentration were considered, with a regular pattern of minimum values in August and maximum values in May each year. An increased deviation in CO<sub>2</sub> and temperature was found in response to the occurrence of El Niño, but the increase in CO<sub>2</sub> lagged behind the change in temperature by 5 months. This pattern was not observed for La Niña events. An increase in global CO<sub>2</sub> emissions and a subsequent increase in global temperature proposed by IPCC were not observed, but an increase in global temperature, an increase in soil respiration, and a subsequent increase in global CO<sub>2</sub> emissions were noticed. This natural process can be clearly detected during periods of increasing temperature specifically during El Niño events. The results cast strong doubts that anthropogenic CO<sub>2</sub> is the cause of global warming.

## Keywords

Global Warming, Thermally-Induced CO<sub>2</sub>, Soil Respiration, Cross-Correlation Coefficient, Time Lag, El Niño

## 1. Introduction

Murry Salby analyzed the change in temperature ( $\Delta T$ ) and the change rate of the CO<sub>2</sub> concentration ( $rco_2$ ) and suggested that the change rate of the CO<sub>2</sub> concentration ( $drco_2/dt$ ) can be expressed as Equation (1) [1] [2]:

$$drco_2/dt = \gamma\Delta T \quad (1)$$

where  $\gamma$  is a constant, or Equation (1) is also expressed by Equation (2):

$$r_{CO_2} = \gamma \int_0^t \Delta T dt \quad (2)$$

The major natural functions affecting  $dr_{CO_2}/dt$  are (1) plant photosynthesis, (2) CO<sub>2</sub> solubilization into the ocean, and (3) plant decomposition or respiration [3]. For a small temperature range,  $dr_{CO_2}/dt$  may be considered to be approximately proportional to the temperature change [4]:

$$\begin{aligned} dr_{CO_2}/dt & \\ & \equiv \text{rate of photosynthesis} + \text{solubilization rate into sea} \\ & \quad + \text{plant decomposition rate} \\ & \equiv \gamma \Delta T \end{aligned} \quad (3)$$

Recent direct observations of CO<sub>2</sub> concentrations have shown that the CO<sub>2</sub> concentration steadily increases every year [5]. The change rate of the CO<sub>2</sub> concentration,  $dr_{CO_2}/dt$ , is the change in the CO<sub>2</sub> concentration during a predetermined time and can be expressed as an annual CO<sub>2</sub> growth rate, “ppm/year”.

The annual mean CO<sub>2</sub> growth rates are reported by the National Oceanic and Atmospheric Administration (NOAA) [6]. Since 1979, NOAA satellites have been carrying instruments that measure natural microwave thermal emissions from oxygen in the atmosphere [7]. Every month, the University of Alabama in Huntsville (UAH) updates global temperature datasets from different satellites. Satellite-based temperatures, the 13-month average of lower troposphere anomaly values, and CO<sub>2</sub> growth rates were compared to evaluate Equation (1) during 1979-2022, which revealed that temperature changes and the CO<sub>2</sub> growth rate are correlated over 40 years. Therefore, Equation (1) is supported by the observed results [8].

For a short period of time, Equation (1) may be expressed as Equation (4),

$$\Delta r_{CO_2} \propto \Delta T \quad (4)$$

( $\Delta r_{CO_2}$ : a change in CO<sub>2</sub> concentration).

In other words, the CO<sub>2</sub> concentration is determined by temperature changes, and generally, the higher the temperature is, the higher the CO<sub>2</sub> concentration, which may be called “*thermally induced CO<sub>2</sub>*” [1] [2]. As temperatures change due to seasons and weather events, CO<sub>2</sub> can also change with temperature [8]. This was confirmed by ENSO events, which drive temperature changes that lag behind a change in an ENSO index by approximately one year. Furthermore, the rates of CO<sub>2</sub> absorption and emission vary with temperature changes during ENSO events, and CO<sub>2</sub> changes lag behind temperature changes by approximately 0.5 - 1 year [8]:

$$\Delta T \rightarrow (0.5-1 \text{ year}) \rightarrow \Delta r_{CO_2} \quad (5)$$

CO<sub>2</sub> emissions during El Niño events were interpreted as an increase in plant respiration (decomposition) due to increased temperatures, as reported in previous papers [9]-[11]. The proposed process for strong El Niño events is shown in



## 2. Global Data

Since 1979, the UAH has updated global temperature datasets that represent the piecing together of temperature data from a total of fifteen instruments flying on different satellites over the years. Further details are available [7]. Temperatures here were obtained from the datasets, and monthly data and the 13-month average of lower troposphere anomaly values were used.

The annual mean growth rate of CO<sub>2</sub> in a given year is the difference in concentration between the end of December and the start of January of that year reported by NOAA. Further details are available on their website [6]. Because of the seasonal changes in CO<sub>2</sub> concentrations, the annual means and the monthly data are compared.

These datasets can be downloaded on the websites [6] [7], and only two datasets, temperatures and CO<sub>2</sub> concentrations, are analyzed in this paper.

## 3. Results and Discussion

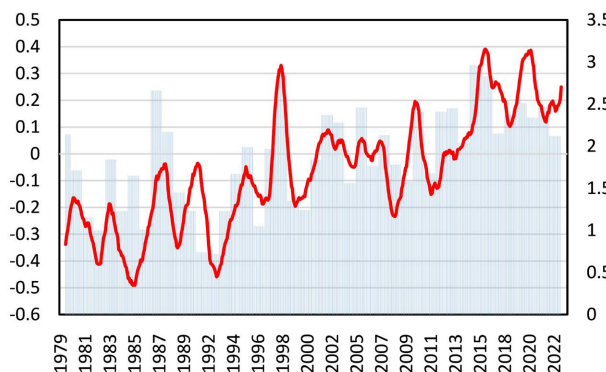
On the basis of Equation (1), a cross correlation between  $dr_{CO_2}/dt$  and  $\Delta T$  with a time lag may be considered, where a correlation coefficient  $r$  can be defined as follows ( $x = dr_{CO_2}/dt$  and  $y = \Delta T$ ):

$$r = \frac{\frac{1}{n} \sum_{i=1}^n (xi - \bar{x})(yi - \bar{y})}{\sqrt{\frac{1}{n} \sum_{i=1}^n (xi - \bar{x})^2} \sqrt{\frac{1}{n} \sum_{i=1}^n (yi - \bar{y})^2}} \quad (7)$$

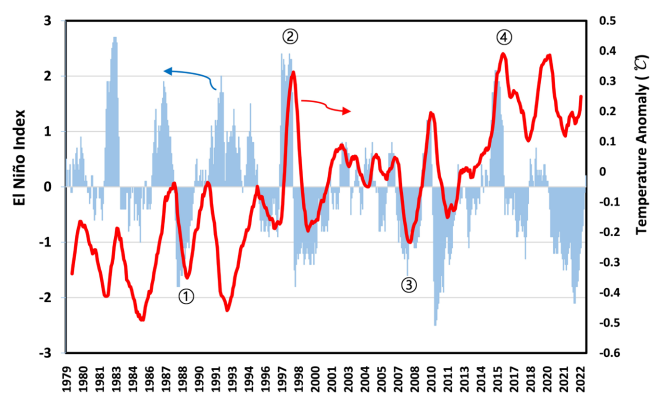
It has been reported that temperature change and the rate of CO<sub>2</sub> increase are correlated over 40 years, as shown in **Figure 2** from a previous paper [8]. Its correlation coefficient  $r$  can be calculated via Equation (7). The value of  $r$  is 0.73, and the correlation is relatively good, where optionally, the calculation can be easily performed via Excel's built-in function. Since the 13-month average of temperature change and the annual average of the rate of CO<sub>2</sub> increase are used in **Figure 2**, a time lag within 12 months between  $dr_{CO_2}/dt$  and  $\Delta T$  cannot be effectively analyzed.

In this paper, time lags for selected ENSO events, ①-④, shown in **Figure 3** [8], were analyzed in detail. **Figure 4** shows the changes in CO<sub>2</sub> and temperature anomalies between 2014 and 2018, corresponding to the El Niño ④ events in **Figure 3**. The CO<sub>2</sub> concentration is increasing, but it increases and decreases periodically each year, showing a regular pattern of minimum values in August and maximum values in May each year. Therefore, for each year, we consider the change in CO<sub>2</sub> over the course of a year starting from September as increased CO<sub>2</sub> ( $\Delta CO_2$ ), as shown in **Figure 5**. Temperatures rise in response to the occurrence of El Niño. CO<sub>2</sub> concentrations also increase in response to temperature increases. This is shown as a larger  $\Delta CO_2$  from 2015-2016 in **Figure 5**. Here, we consider the deviation of  $\Delta CO_2$  between 2015-2016 and 2014-2015 in **Figure 5**. The deviations in  $\Delta CO_2$  and  $\Delta T$  between 2015-2016 and 2014-2015 are plotted in **Figure 6(a)**. The same data are plotted in **Figure 6(b)**, but  $\Delta T$  is shifted to the right by five months. The correlation coefficient  $r$  is improved from "0.47" to "0.94" by

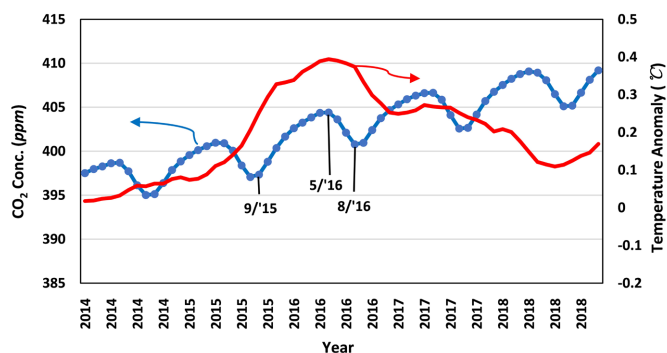
shifting. This means that the CO<sub>2</sub> concentration is determined by temperature changes but with a 5-month time lag. The results prove Equations (4)-(5).



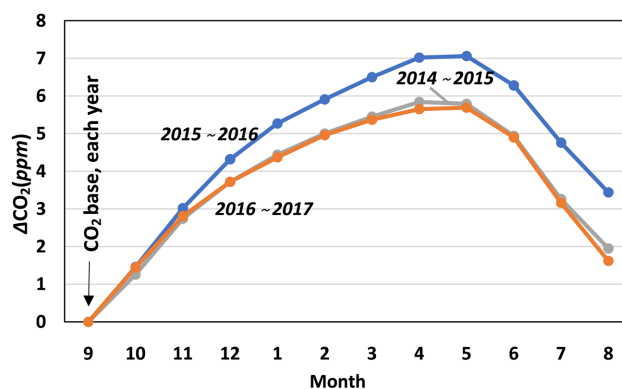
**Figure 2.** Correlations between temperature and CO<sub>2</sub> changes during 1979-2022. Temperature (°C, red line): 13-month average of lower troposphere anomaly values by UAH with scales on the left. CO<sub>2</sub> (ppm/year, blue vertical lines): difference from the previous year in annual averages by NOAA with scales on the right (a correlation coefficient  $r = 0.73$ ).



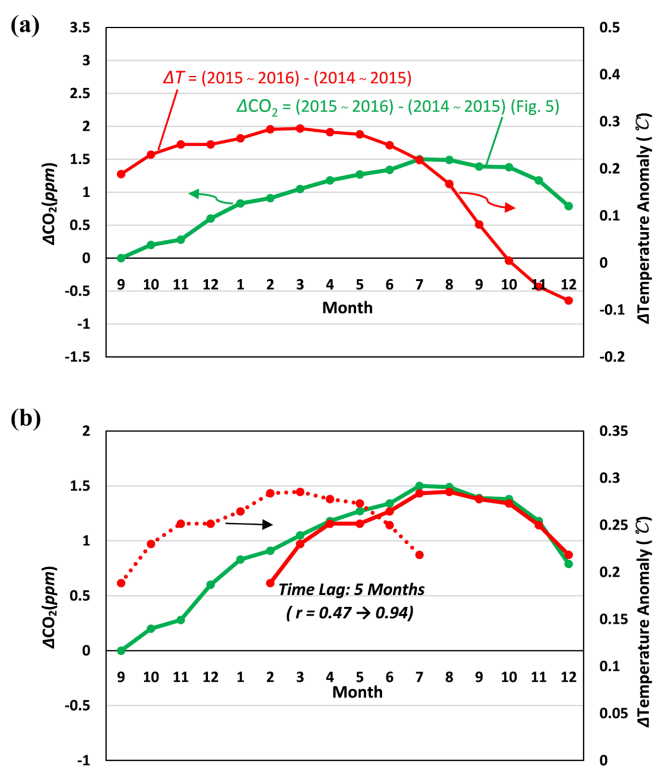
**Figure 3.** Correlation between temperature and the ENSO index during 1979-2022. Temperature (°C, red line): 13-month average of lower troposphere anomaly values by UAH with scales on the right. ENSO index (blue vertical lines): two-month average by NOAA with scales on the left [8].



**Figure 4.** Seasonal change in global CO<sub>2</sub> (blue dots; scale: left axis; unit: ppm) between 2014 and 2018. The red curve shows satellite-based temperatures (scale: right axis, unit: °C) during the same period: 13-month average lower troposphere anomaly values by the UAH.



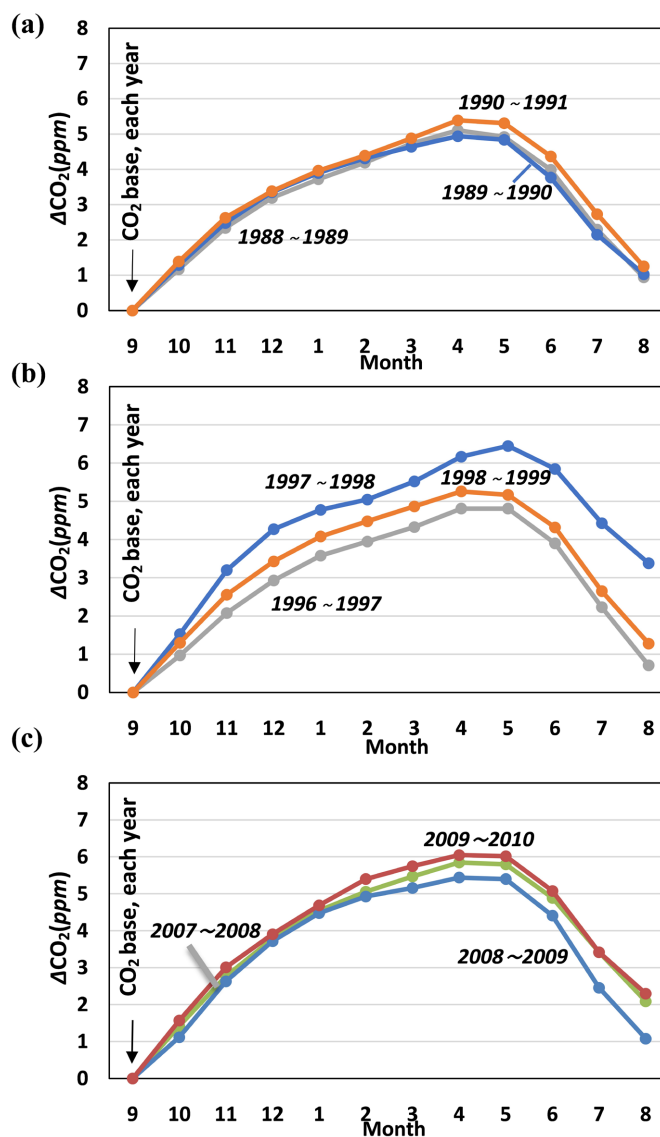
**Figure 5.** Changes in the annual CO<sub>2</sub> concentration (*ppm*) from September 2014, 2015, or 2016 to August 2015, 2016, or 2017.



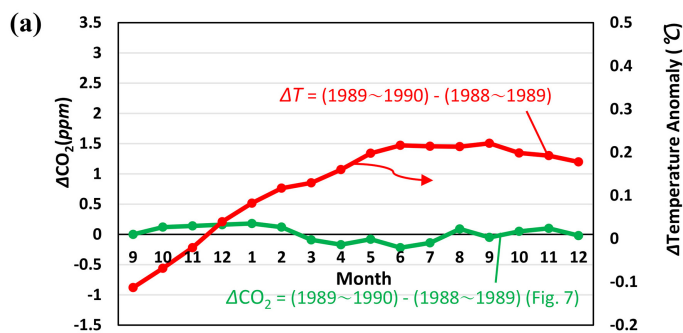
**Figure 6.** (a) The deviations of  $\Delta\text{CO}_2$  and  $\Delta T$  between 2015-2016 and 2014-2015 in **Figure 5**, and (b) the same data are plotted, but  $\Delta T$  is shifted to the right by five months. The correlation coefficient  $r$  is improved from “0.47” to “0.94” by shifting.

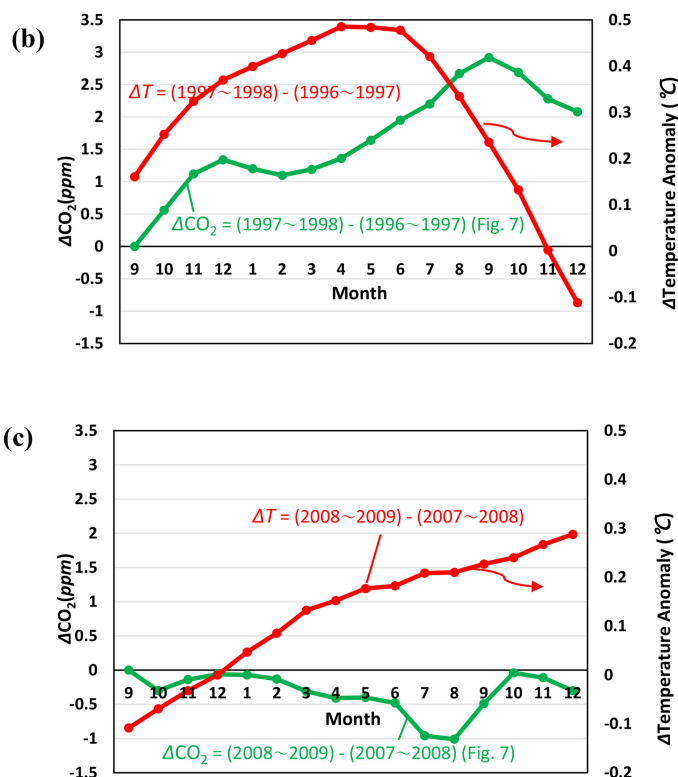
Next, other ENSO events, ①-③, were similarly analyzed. Larger deviations in  $\Delta\text{CO}_2$  were not found for La Niña events ① and ③ but were again found for El Niño events ②, as shown in **Figure 7**. The deviations in  $\Delta\text{CO}_2$  and  $\Delta T$  are plotted in **Figure 8**, similar to **Figure 6(a)**. The correlation coefficient  $r$  for El Niño ② in **Figure 8(b)** also improved from “0.21” to “0.92” when  $\Delta T$  was shifted to the right by five months. This means that the CO<sub>2</sub> concentration is determined by temperature changes but with a 5-month time lag. The results also prove

equations (4)-(5).



**Figure 7.** Changes in the annual CO<sub>2</sub> concentration (ppm) from September each year during other ENSO periods: (a) La Niña event ① in Figure 3, (b) El Niño event ② in Figure 3, and (c) La Niña event ③ in Figure 3.





**Figure 8.** Deviations in  $\Delta\text{CO}_2$  and  $\Delta T$  for ①-③ in Figure 7.

The global CO<sub>2</sub> residence time can be estimated to be 4 years by the IPCC CO<sub>2</sub> cycle budget [3] [11], as shown in Equation (8):

$$\begin{aligned}
 & \text{CO}_2 \text{ residence time} \\
 & = (\text{CO}_2 \text{ in the atmosphere}) / (\text{fossil fuel combustion} \\
 & \quad + \text{respiration and decomposition} + \text{ocean-atmosphere exchange}) \quad (8) \\
 & \cong 829 / (7.8 + 107.2 + 79.2) \text{ (unit : GtC)} \\
 & \cong 4
 \end{aligned}$$

The major natural functions affecting  $\Delta\text{CO}_2$  are (1) plant photosynthesis, (2) CO<sub>2</sub> solubilization into the ocean, and (3) plant decomposition or respiration, as described in the introduction. The periodical annual change in  $\Delta\text{CO}_2$  is dependent on these functions. Therefore, a time lag for the cross correlation between  $dr_{\text{CO}_2}/dt$  (or  $\Delta\text{CO}_2$ ) and  $\Delta T$  may be determined by natural functions and the residence time. Although the detailed physical process determining the time lag is not known at this time, our analysis reveals a “5-month” time lag when the temperature leads to a change in CO<sub>2</sub>. It has been considered that temperature and CO<sub>2</sub> simultaneously change or that a change in CO<sub>2</sub> leads to a change in temperature [12]. However, a cross-correlation between the global temperature and atmospheric CO<sub>2</sub> with a temperature leading to a “5-month” time lag is noticeable.

Significant deviations in  $\Delta\text{CO}_2$  were not found for La Niña events ① and ③, as shown in Figure 7. The deviations in  $\Delta\text{CO}_2$  and  $\Delta T$  are plotted in Figure 8(a) and Figure 8(c), similar to Figure 8(b). A correlation between  $\Delta\text{CO}_2$  and  $\Delta T$  is not

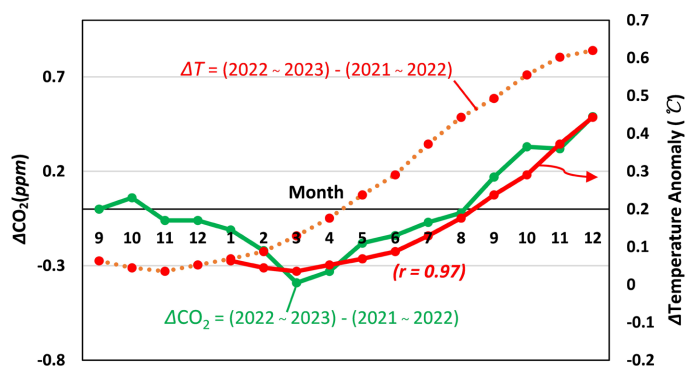
observed, unlike El Niño ②. A time lag within 12 months between  $dr_{CO_2}/dt$  and  $\Delta T$  cannot be effectively analyzed under regular climate periods as shown in **Figure 2**. However, the 5-month time lag was clearly recognized by the analysis during El Niño events, while it was difficult to analyze a time lag during La Niña events.

Since temperature changes affect plant decomposition and soil respiration ( $R_s$ ), followed by a change in  $CO_2$  generation, the change rate of soil respiration ( $dR_s/dt$ ) may be expressed as Equation (9), similar to Equation (1) [11]:

$$dR_s/dt \equiv \gamma' \Delta T \quad (R_s : \text{soil respiration}, \gamma' : \text{constant}) \quad (9)$$

Since the average satellite-based global temperature has changed by  $0.16^\circ C/\text{decade}$  [7], soil respiration ( $R_s$ ) is also expected to increase annually. The temporal increase,  $dR_s/dt$ , again confirms this proposition, as reported in a previous paper [11]. We need more data to calculate a correlation coefficient  $r$  between  $dR_s/dt$  and temperature because the determination of  $R_s$  is not straightforward, and only approximate values are available [13]-[15].

If the cross-correlation between global temperature and atmospheric  $CO_2$  with a temperature leading time lag is applied for a current temperature and  $CO_2$  trend, a near-future trend of temperature and  $CO_2$  may be predicted. The El Niño event that started in 2022 is not over at this time (September 2024). The same analysis as that for El Niño ④ events shown in **Figure 3** was conducted for 2022 and 2023 on the basis of the durations of 2021 and 2022. The results are shown in **Figure 9**. The improved correlation coefficient  $r$  between  $\Delta CO_2$  and  $\Delta T$  was “0.94” after shifting to 4 months. Although it is a demonstrative example at this time, the estimation of an approximate  $\Delta CO_2$  in the near future may be possible.



**Figure 9.** The deviation of  $\Delta CO_2$  and  $\Delta T$  between 2022-2023 and 2021-2022 and  $\Delta T$  shifted to the right by four months. The correlation coefficient  $r$  is improved to “0.97” by shifting.

## 4. Conclusion

The temperature change and rate of  $CO_2$  change are correlated but with a time lag, as reported in a previous paper. The correlation was investigated by calculating a correlation coefficient  $r$  of these changes for selected ENSO events. Annual periodical increases and decreases in the  $CO_2$  concentration were considered, with

a regular pattern of minimum values in August and maximum values in May each year. An increased deviation in CO<sub>2</sub> and temperature was found in response to the occurrence of El Niño, but the increase in CO<sub>2</sub> lagged behind the change in temperature by 5 months. This pattern was not observed for La Niña events. An increase in global CO<sub>2</sub> emissions and a subsequent increase in global temperature proposed by IPCC were not observed, but an increase in global temperature, an increase in soil respiration, and a subsequent increase in global CO<sub>2</sub> emissions were noticed. This natural process can be clearly detected during periods of increasing temperature at El Niño events. The results support Equation (1) or Equation (4) and Equation (5) and cast strong doubts that anthropogenic CO<sub>2</sub> is the cause of global warming.

### 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
$dr_{CO_2}/dt$	The change rate of the CO <sub>2</sub> concentration or CO <sub>2</sub> growth rate
$R_s$	Soil respiration
$\Delta T$	Temperature change
$r$	correlation coefficient