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Commentary

Changes in Temperature and CO_2 Concentration Induced by El Niño

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ABSTRACT

We compared satellite-based UAH Earth surface temperature, NOAA ENSO index, and Earth-surface CO_2 change rate in detail. These three variables were well correlated over the observed 40 years. The temperature changed approximately one year after the ENSO index changed, and the CO_2 change rate followed the temperature change by several months. CO_2 emission and absorption at the Earth's surface responded to temperature changes. It was like Earth's breathing. CO_2 emission due to higher temperature was related to plant respiration or decomposition processes.

Keywords: Carbon cycles; Atmospheric CO_2 concentration; Anthropogenic emissions; El Niño; Plant Respiration; Plant decomposition

ABBREVIATIONS

IPCC: The Intergovernmental Panel on Climate Change (the United Nations body); NOAA: The National Oceanic and Atmospheric Administration; NASA: The National Aeronautics and Space Administration; OCO-2: Orbiting Carbon Observatory-2; ENSO Index: El Niño-Southern Oscillation Index; UAH: The University of Alabama in Huntsville

INTRODUCTION

CO_2 is emitted into the atmosphere by both anthropogenic and natural processes. Anthropogenic CO_2 emissions are, however, only a small fraction of total processes. They are only 4-5% based on the IPCC carbon cycle estimate [1]. Unlike anthropogenic processes, natural processes also absorb CO_2 from the atmosphere that is emitted by anthropogenic and natural processes. For these reasons, the carbon cycle may be mainly controlled by natural processes, and CO_2 emission and absorption processes by natural cycles resemble the Earth's "breathing" [2].

NASA's Orbiting Carbon Observatory-2 (OCO-2) mission was launched in July 2014 and has been gathering data on patterns of carbon exchange between the land and the atmosphere [3]. The project observes CO_2 emissions and absorption processes, or the Earth's "breathing", how the planet's carbon flux changes seasonally and with weather events such as El Niño [4].

Murry Salby analyzed a change in temperature and the change rate of CO_2 concentration and suggested that the change rate of a CO_2 concentration, rCO_2, is shown by eq. (1) [5,6],

$$\frac{dr_{CO2}}{dt} = \gamma(T - T_0) \qquad (1)$$

where γ is a constant, and $(T\text{-}T_0)$ is a change in the temperature, or eq. (1) is expressed by eq. (2),

$$r_{CO2} = \gamma \int_0^t (T - T_0)dt \qquad (2)$$

In other words, the CO_2 concentration is determined by temperature changes, and generally, the higher the temperature is, the higher the CO_2 concentration. As temperatures change due to seasons and weather events, CO_2 can also change with temperature. These changes could be significantly observed during El Niño periods.

In this paper, we consider the correlation between temperature change and the rate of change of CO_2 concentration based on available data sets. Understanding the Earth's "breathing", the process of CO_2 emissions and absorption, could help us better understand the processes of climate change.

Atmospheric Data

Since 1979, NOAA (National Oceanic and Atmospheric Administration) satellites have been carrying instruments that measure the natural microwave thermal emissions from oxygen in the atmosphere [7]. Every month, UAH (The University of Alabama in Huntsville) updates global temperature datasets that represent the piecing together of the 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 the 13-month average of lower troposphere anomaly values was used.

The annual mean rate of growth of CO_2 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 [8]. Because of the seasonal change in CO_2 concentrations, the annual mean is compared.

Multivariate ENSO Index Version 2 (MEI.v2) by NOAA was used as the ENSO index [9]. Further details are available on their website.

RESULTS AND DISCUSSION

Figure 1 shows the correlation between temperature and the ENSO index from 1979 to 2022. El Niño and temperature changes are clearly correlated over 40 years, except for 1991-93. Mount Pinatubo in the Philippines erupted on June 15, 1991, and it was the second-largest terrestrial eruption of the 20th century. Global temperatures dropped by approximately 0.5°C in 1991–1993 due to the eruption [10]. This may explain the lack of correlation between El Niño and temperature changes from 1991 to 1993. ENSO primarily causes temperature changes, but the changes lag ENSO by approximately one year, as shown in Figure 1.

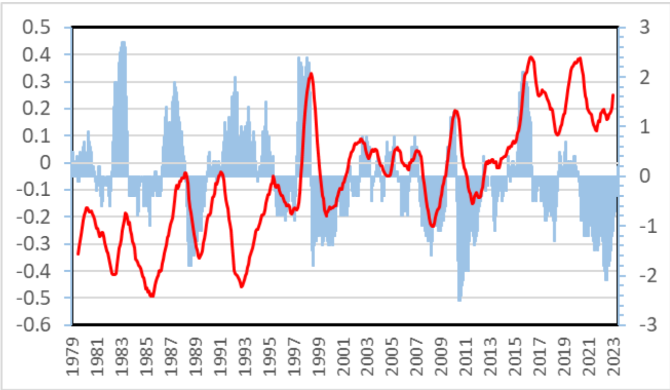

Figure 1: Correlation between temperature and ENSO index during 1979-2022. Temperature (°C, red line): 13-month average of lower troposphere anomaly values by UAH with scales on the left. ENSO index (blue vertical lines): two-month average by NOAA with scales on the right.

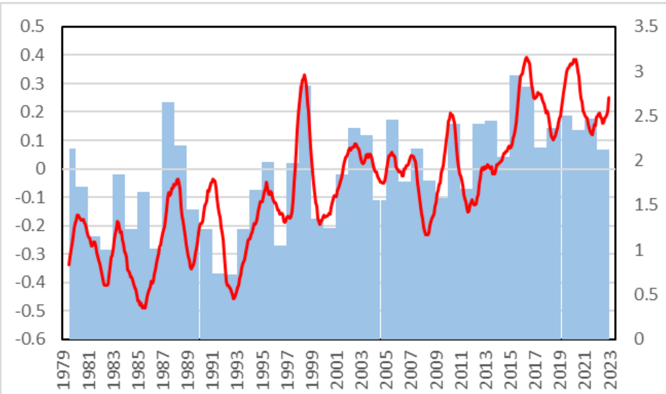

Figure 2: Correlation between temperature and CO_2 changes during 1979-2022. Temperature (°C, red line): 13-month average of lower troposphere anomaly values by UAH with scales on the left. CO_2 (ppm/year, blue vertical lines): difference from the previous year in annual averages by NOAA with scales on the right.

Figure 2 shows temperature changes and CO_2 growth rates from 1979 to 2022. It is worth noting that temperature change and the rate of CO_2 increase are correlated over 40 years. The CO_2 increase rate shows the average value for one year because the monthly CO_2 concentration varies greatly in an annual cycle due to changes in activities such as photosynthesis and respiration of plants. Since the CO_2 growth rate is an annual average, temperature changes first, followed by the CO_2 growth rate, but no significant difference in the correlation between temperature and CO_2 is apparent. To investigate this, the monthly correlations of temperature and CO_2 during the 2015-2016 El Niño period were examined, as shown in Figure 3. There was a difference of approximately 5 months in the correlation between temperature and CO_2. The change in temperature changed the rate of CO_2 growth after 5 months. Humlum et al. [11] compared changes in CO_2 concentration and land-sea surface temperature over the period from January 1980 to December 2011, during which time they examined the phase relationship between CO_2 and temperature, and found that changes in CO_2 always lag changes in temperature by 10 to 12 months. Our case is consistent with the results of Humlum et al.

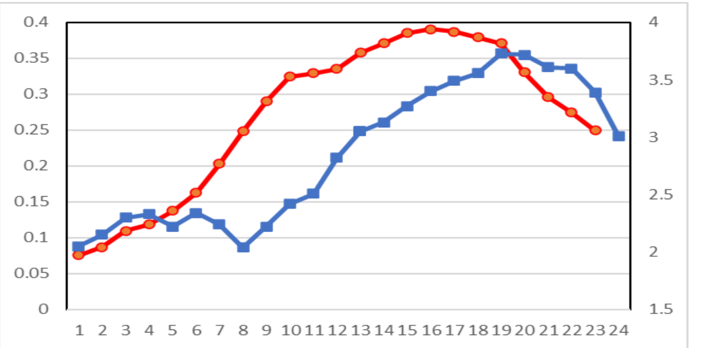

Figure 3: Change in temperatures and CO_2 concentrations during El Nino in 2015-2016 (horizontal line: months starting January 2015), (red: UAH lower troposphere 13-month average temperature (°C) with left side scale, blue: monthly CO_2 growth rate (ppm/year) reported by NOAA with right side scale).

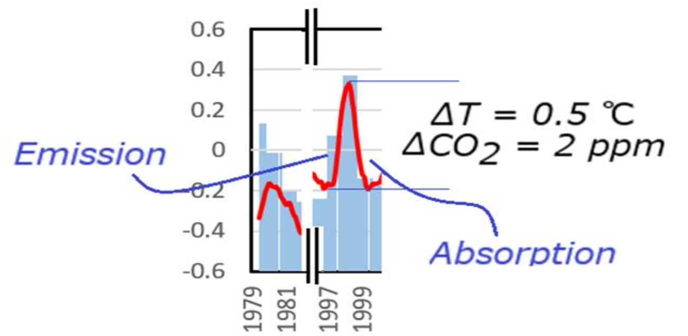

Figure 4: Changes in global temperatures and CO_2 concentration growth rate from Figure 2 during El Niño in 1997-99.

CO_2 increased by 2 ppm during the large El Niño of 1997. This CO_2 approximately corresponds to 4 GtC of emissions (see Figure 4). A unit conversion can be calculated by the following equation[12]:

$$(x_1\ GtC \times 3.67/44)/(5{,}135\ Eg / 28.9) = x_2\ ppm \qquad (3)$$

(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, 5,135 Eg: air mass on earth) The amount of change in CO_2 was comparable to the normal average annual increase in CO_2. Since CO_2 emissions from fossil fuels are 7.8 GtC in the IPCC carbon cycle [1], anthropogenic CO_2 emissions do not significantly affect the CO_2 absorption/emission rate during El Niño.

CO_2 emissions during El Niño are influenced by various factors, including plant respiration (or decomposition), which may increase due to a temperature rise. There are four lines of evidence to support that plant respiration is one of the factors that affect CO_2 emissions during El Niño.

Photosynthesis converts CO_2 into organic compounds, which later break down and release CO_2 back into the air. This breakdown, also known as soil respiration, occurs mostly underground and involves both autotrophs and heterotrophs. The main heterotrophic process is microbial decomposition, which is the largest carbon cycle process on earth, as shown in Figure 5 with carbon equivalent estimates from the IPCC report [1]. Soil respiration emits approximately 70 GtC/year of CO_2 globally, and this rate increases with higher temperature and precipitation [13].

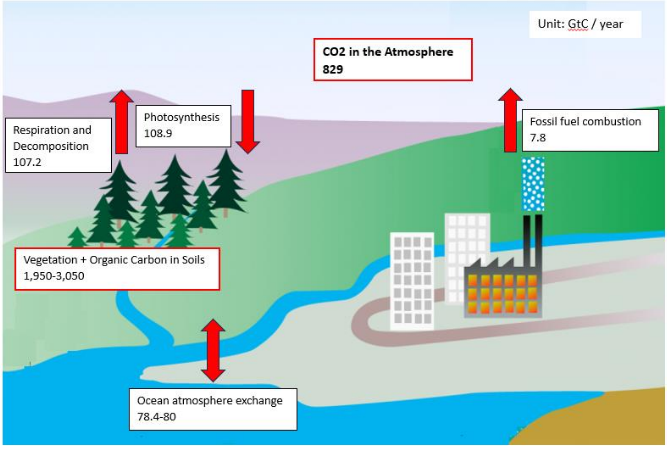

Figure 5: Simplified carbon cycles and carbon equivalent estimates (unit: GtC) obtained from the IPCC report [1].

Figure 5 shows that respiration and decomposition emit 110 GtC of CO_2, while fossil fuels only emit 8 GtC, which is a small part of the global CO_2 emissions. There is also 2,000-3,000 GtC of organic carbon in plants and soil that can release CO_2 through respiration under certain environmental conditions. This could explain why the natural respiration process dominates over human-related processes.

Seasonal changes affect CO_2 concentration. Natural CO_2 production and consumption depend on photosynthesis and plant decomposition. According to NOAA's figure [14], the CO_2 concentration varies less in Antarctica than in the north. This is because the Southern Hemisphere has less land and forests than the Northern Hemisphere. Moreover, high latitudes have larger temperature swings than the tropics. Thus, plant decomposition rates change more in the Northern Hemisphere and the north throughout the year.

Plants use more $^{12}CO_2$ than $^{13}CO_2$ in photosynthesis, as ^{13}C is only 1.1% of natural carbon. When plants break down and emit CO_2, they increase the ratio of $^{12}CO_2$ to $^{13}CO_2$ in the air. NOAA's graphic [15] shows that plant decomposition is a major source of atmospheric CO_2 based on carbon isotope variations.

Changes in temperature affect microbial soil respiration processes (decomposition of plants) and alter CO_2 emissions. This process is the maximum carbon cycle, as shown in the IPCC carbon cycle above. Since the decomposition of plants is a biological process, it does not change immediately when the temperature changes, and there is some time lag. In this paper, a time lag of 5 months was obtained between changes in global temperature and the rate of CO_2 increase, while a time lag of 10-12 months was also reported for changes in temperature and CO_2 concentration by Humlum et al. [11].

CONCLUSION

Finally, we can summarize the following points (see Figure 6):

1. El Niño, temperature, and CO2 changes are correlated over 40 years.
2. ENSO mainly drives temperature changes, which lag behind ENSO by approximately one year.
3. The rate of CO_2 absorption and emission varies with temperature changes. CO_2 changes lag behind temperature by approximately 5 months.
4. The strong El Niño events of 1997 and 2015 caused a 0.5°C increase in temperature and a 2-ppm increase in CO_2, or 4 GtC of CO_2 emissions. The CO_2 change was comparable to the normal average annual CO_2 increase.
5. CO_2 emissions from fossil fuels are approximately 8 GtC, and do not significantly affect the CO2 emission rate by El Niño.
6. CO_2 emissions during El Niño can be interpreted as an increase in plant respiration (decomposition) due to higher temperatures.

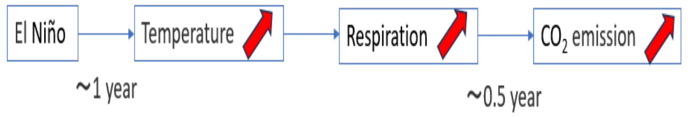

Figure 6: Derived processes for El Niño, global temperature, plant respiration (or decomposition), and subsequent global CO_2 emissions.

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