Where has the CO_2 we released gone?

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Climate change has already begun, and we are now in the unfortunate position that we cannot prevent it from happening. But at least we can aim to prevent the change from accelerating, giving us more time to find accurate long-term solutions. Carbon dioxide (CO2) is one of the most famous greenhouse gases on Earth. But how is it emitted and absorbed; a set of processes known as the carbon cycle? Thus far, the basics of this crucial cycle remain mysterious. Revealing and understanding the Earth's carbon cycle might hold the key to avoiding accelerating levels of greenhouse gases.

The carbon cycle describes the movement of carbon, consisted of sources and sinks. The main reservoirs of CO2 called sinks in the Earth are the atmosphere, land, and ocean, in which the ocean is the largest one since it occupies 70% of the Earth's surface. A source is any process to release CO2 into the atmosphere, such as the burning of fossil fuel, volcanic eruption, plant and animal decay, and breathing. Although we often heard that we humans accelerate global warming, the fraction of the CO2 emission by fossil fuel combustion and other human activities are surprisingly only 4% compared with the natural process. Contrary to the small percentage, human activity contributes only to emitting CO2 into the atmosphere, although biological processes absorb as well as emit CO2.

Since our planet and its atmosphere is a closed environment, the total amount of carbon should be maintained. Actually, the sources and sinks related to the natural process are well balanced. A simple question arises here, where has carbon dioxide we release gone? Observations show about half stays in the atmosphere, and theoretical models estimate about 30% is thought to be absorbed by the ocean. Then, 20% of carbon dioxide should be absorbed somewhere, but the sink has been unclear [1]. This problem sometimes is called "the missing CO2" or "the missing sink".

Since the 1980s, modeling construction and observations in the ocean and the atmosphere have attacked the missing sink problem. It is doubtful that an unknown reservoir exists, suggesting two hypotheses; the ocean can reserve more carbon, or the "net" CO2 emission from the biosphere is much smaller. Some support the latter by proposing the rise of CO2 in the atmosphere can encourage photosynthesis [2], which is the process that plants transform light energy, water, and CO2 into chemical energy. In contrast, others suggest that the amount of absorption by lands and the ocean can vary in time, and the sink could be changed depending on the year [3]. These studies made the missing CO2 no more missing but still mysterious.

Why the missing CO2 or the revealing of the carbon cycle is essential? Let's imagine that the efficiency of the mysterious sink decreases in the future. Can we predict the amount of CO2 build-up? Suppose we have no clue about the sink. Then, we cannot expect how our environment, such as temperature or precipitation, changes. To predict our future more precisely, an understanding of the carbon cycle is necessary.

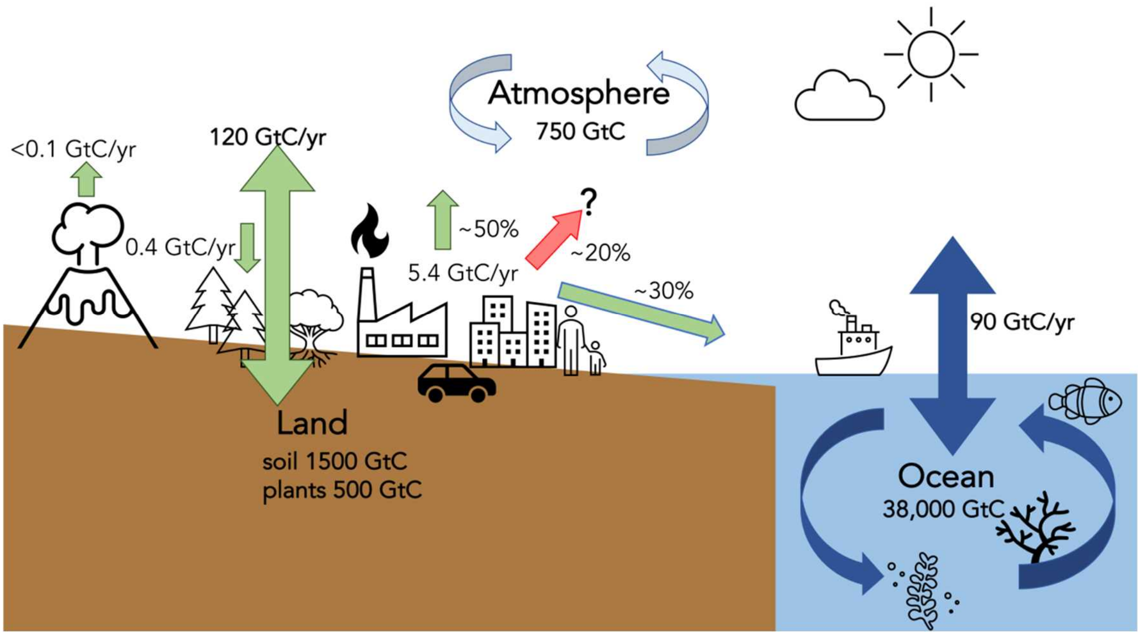
The predictions of temperature rise, for example, are based on analytical models and observations of CO2 flux. I want to introduce two recent scientific progress in model prediction and observations. One example is the contribution of climate-carbon feedback in analytical models. Since both the direct effects and the effects of climate change due to CO2 change affects the ocean and land, the contribution of the feedback cannot be negligible. C4MIP (Coupled Climate-Carbon Cycle Model Intercomparison Project) reported that the CO2 rise due to human activity and the following climate change could decrease the potential for ocean and land to absorb CO2 [4]. To consider the feedback results in the amplification of temperature rise. This result implies the importance of the feedback [5].

Another example is an observation satellite, the Orbiting Carbon Observatory 2 (OCO-2). It was launched to address the complete understanding of the carbon cycle or the mystery of the missing CO2. Using the OCO-2 data from 2014 to 2019 for five years, Z. Chan et al. studied the year-to-year differences in the release of carbon dioxide in some regions of various climates [6]. They revealed the significant contribution of tropics for grasslands, savannah, and agriculture as forested areas comparable to tropical forests. Tropical forests have been considered to play a dominant role because the land has 2.7 times more reservoirs of CO2 than the atmosphere, in which 2/3 occupies the forest ecosystem. Still, this finding emphasizes the importance of monitoring other areas in the tropics [7]. Based on such long-term observations in various regions, models should be reconstructed with smaller uncertainty to predict more precisely. María Fernanda Espinosa Garcés, President of the United Nations General Assembly at the COP 24, said, "If you can't measure it, you can't manage it".

It is time to attack the question, where has carbon dioxide we release gone.

Following the OCO-2 satellite, OCO-3 was launched on 4 May 2019. It will monitor the geographic distribution of CO2 sources and sinks, quantify their variability, and provide accurate data with superb spatial resolution. The expected product obtained in OCO-3 would be a global dataset that accomplishes the science objectives and high precision of the amount of carbon dioxide. Besides, in 2022, the Sixth Assessment Report (AR6) will be produced by the Intergovernmental Panel on Climate Change (IPCC) to summarize its sixth assessment cycle. They will tell us the current climate change situation, including the CO2 amount and the carbon cycle.

Recent progress in observations and more realistic analytical models will reveal more precisely the carbon cycle and the variation of CO2 from year to year in regions with a different climate. These are necessary information for our lives. We can now wait for the data with the attention to prevent the amount of carbon dioxide emission.



Values are cited from Figure 3.1a and b in “CLIMATE CHANGE 2001: THE SCIENTIFIC BASIS”

References

[1] 吉川久幸，「温室効果ガスー炭素循環研究に着目してー」，日本気象学会機関誌「天気」(TENKI) 2007 年 9 月号

[2] Huang, J.-G., Y. Bergeron, B. Denneler, F. Berninger, and J. Tardif (2007), Crit. Rev. Plant Sci., 26, 265

[3] Francey, R. J. et al. (1995), Nature, 373, 326

[4] Friedlingstein, P. et al. (2006) J. Climate, 19, 3337

[5] 伊藤昭彦,「気候－炭素循環フィードバック」，日本気象学会機関誌「天気」(TENKI) 2010 年 5 月号

[6] Zichong Chen et al. (2021) Environ. Res. Lett., 16, 054041

[7] Annmarie Eldering et al. (2019) Atmospheric Measurement Techniques, 12, 2341