Hothouse in the Deep Past: Implications for Ongoing Climate Change

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The present climate change constitutes a serious threat to human society through the global warming and associated sea-level rise, changes in a hydrological cycle, and fundamental shifts in climatic zones and ecosystems. This climatic perturbation has been attributed to the massive and accelerating anthropogenic emission of greenhouse gases that causes energy imbalance in the Earth's surficial system. From a perspective of the nature of the global carbon cycle, looking back a greenhouse world in the geological past can provide new insights into the ongoing climate change.

The Paleocene-Eocene Thermal Maximum (PETM) at 56 million years ago is one of the most serious and well-studied global warming events in the Earth's history [1]. The PETM is characterized by a "geologically rapid" (within several thousand years) and extreme global warming by 5 to 8 °C, severe ocean acidification inferred from seafloor carbonate dissolution, and distinct decrease in the stable carbon isotope ratio ($^{13}C/^{12}C$) both in the marine and terrestrial environments. These features strongly suggest a massive injection of ^{13}C-depleted greenhouse gas(es) to the ocean-atmosphere system. The total of the released carbon is considered to be thousands of gigatons (Gt) of CO_2 and/or CH_4, which is comparable to a budget of fossil fuels on the modern Earth. Hence, the PETM has been regarded as a case study of the ultimate consequence of the human-made global warming.

It has been suggested that the rise of atmospheric CO_2 stimulated chemical reaction of continental rocks with CO_2 and biological productivity during the PETM. These processes consumed the atmospheric CO_2 and removed excess carbon from the ocean-atmosphere system, so functioned as negative feedbacks stabilizing the Earth system. Here, the question is whether these natural feedback mechanisms can mitigate the present climate change, as in the case of the recovery from the ancient global warming.

The point is the kinetics of the phenomena involved. A recent study indicated that the initial carbon release during the PETM onset occurred over ~4,000 years [2]. On the other hand, the recovery from the PETM required tens of thousands of years, implying that the negative feedback mechanisms in the nature likely function much slower than carbon emissions triggering climate changes. This is because only a small portion of carbon can be buried in geosphere and thus isolated from the ocean-atmosphere system immediately after the feedbacks start to work. Even after atmospheric CO_2 is chemically reacted or incorporated into organisms, the majority of the carbon will be recycled in the Earth's surface for more than 100,000 years, which is a matter of residence time of carbon in the ocean-atmosphere system. Moreover, the carbon emission rate was ~1 Gt/year even at the PETM, whereas the present anthropogenic carbon release is at ~10 Gt/year [2]. This suggests that the huge and "geologically instantaneous" (within a few hundred years or less) carbon emission by human activities absolutely overwhelms the capacity of natural recovery process, at least over the coming millennia.

Now, the cutting-edge knowledge on the global climate change tells us a serious concern: We might have already entered a new era that the past case is of no use. To mitigate the effects of the ongoing climate change, including a sea level rise, we have to consider some aggressive ways in geo-engineering and/or social infrastructure improvements.

[1] McInerney, F. A. & Wing, S. L. (2011) *Annu. Rev. Earth Planet. Sci*. **39**, 489-516.
[2] Zeebe, R. E. et al. (2016) *Nat. Geosci*. **9**, 325-329.