

## Effects of the formation of hydrocarbon aerosols on the climate stability of Earth-like planets and their habitability

\*Yasuto Watanabe<sup>1</sup>, Eiichi Tajika<sup>1</sup>, Kazumi Ozaki<sup>2</sup>, Peng Hong<sup>3</sup>

1. The University of Tokyo, 2. Toho University, 3. Chiba Institute of Technology

It is known that the haze particles composed of hydrocarbons can form in an anoxic atmosphere in which the  $\text{CH}_4/\text{CO}_2$  ratio exceeds the critical level ( $\sim 0.2$ ), as observed in Titan's atmosphere. The haze particles have characteristic optical properties that could affect the planetary climate as discussed in the context of the anoxic early Earth before the rise of atmospheric oxygen owing to the activity of oxygen-producing photosynthetic bacteria. Under low  $p\text{O}_2$  condition,  $\text{CO}_2$  and  $\text{CH}_4$  can be photochemically broken up to form CO, and the excess CO reacts with OH radical to form  $\text{CO}_2$ . If primitive anaerobic microbial ecosystem exists on the Earth-like planet as in the early Earth, it can also affect the balance between  $\text{CO}_2$ ,  $\text{CH}_4$ , and CO. Primitive marine microbial ecosystem may produce  $\text{CH}_4$  to the atmosphere-ocean system via methanogenesis. The primitive microbial ecosystem consumes  $\text{CO}_2$  from the atmosphere-ocean system via anoxygenic photosynthesis, but it also provides  $\text{CO}_2$  via decomposition of organic matters and methanogenesis, and/or other abiotic processes. This implies that the balance between  $\text{CO}_2$ ,  $\text{CH}_4$ , and CO in the early Earth must have been significantly different from that at present. Photochemical reactions and biological processes in the ocean may affect the stability of the planetary climate through the formation of the haze particles.

Here we developed a coupled atmospheric photochemistry-marine microbial ecosystem-global carbon cycle model to explore how the atmospheric photochemistry and the primitive marine microbial ecosystem can affect the carbon cycle and  $\text{CO}_2$  budget on the Earth-like planet. We found that when the primitive biosphere produces large  $\text{CH}_4$  flux ( $\sim 10^{11} \text{ cm}^{-2} \text{ s}^{-1}$ ), OH radicals should be consumed in the lower atmosphere through the reaction with  $\text{CH}_4$ . As a result, the reaction between CO and OH, which produces  $\text{CO}_2$ , cannot compensate the photolysis of  $\text{CO}_2$  in the upper atmosphere. This means that photochemical reactions may work as a net  $\text{CO}_2$  consumption process in the atmosphere-ocean system. The excess CO in the atmosphere is considered to have been converted to  $\text{CO}_2$  and  $\text{CH}_4$  through the CO-using chemosynthesis and methanogenesis in the oceans on the early Earth. Therefore, marine microbial reactions can work as a net  $\text{CO}_2$  production process in the atmosphere-ocean system. We also found that, when the  $\text{CO}_2$  level is so low that the hydrocarbon haze can form, the photochemical net consumption of  $\text{CO}_2$  exceeds the biospheric net production. In this case,  $\text{CO}_2$  is removed from the atmosphere-ocean system as the haze particle. As a result, the climate with the hydrocarbon haze should be unstable, and the climate is expected to change to the snowball state with low  $p\text{CO}_2$  or to the hot climate state ( $> \sim 310 \text{ K}$  on the  $\text{CO}_2$  degassing rate of the present Earth) with high  $p\text{CO}_2$  and  $p\text{CH}_4$  on the planets with anoxic environment and primitive microbial ecosystem in the ocean.

Our result would put a theoretical constraint on the existence of life on extrasolar Earth-like planets and their habitability.

Keywords: Habitability, Climate stability