地球類似惑星の気候安定性とハビタビリティにおける炭化水素エアロゾルの影響
Effects of the formation of hydrocarbon aerosols on the climate stability of Earth-like planets and their habitability

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It is known that the haze particles composed of hydrocarbons can form in an anoxic atmosphere in which the CH_4/CO_2 ratio exceeds the critical level (~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 pO_2 condition, CO_2 and CH_4 can be photochemically broken up to form CO, and the excess CO reacts with OH radical to form 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 CO_2, CH_4, and CO. Primitive marine microbial ecosystem may produce CH_4 to the atmosphere-ocean system via methanogenesis. The primitive microbial ecosystem consumes CO_2 from the atmosphere-ocean system via anoxygenic photosynthesis, but it also provides CO_2 via decomposition of organic matters and methanogenesis, and/or other abiotic processes. This implies that the balance between CO_2, 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 CO_2 budget on the Earth-like planet. We found that when the primitive biosphere produces large CH_4 flux (~10^{11} cm^{-2} s^{-1}), OH radicals should be consumed in the lower atmosphere through the reaction with CH_4. As a result, the reaction between CO and OH, which produces CO_2, cannot compensate the photolysis of CO_2 in the upper atmosphere. This means that photochemical reactions may work as a net CO_2 consumption process in the atmosphere-ocean system. The excess CO in the atmosphere is considered to have been converted to CO_2 and 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 CO_2 production process in the atmosphere-ocean system. We also found that, when the CO_2 level is so low that the hydrocarbon haze can form, the photochemical net consumption of CO_2 exceeds the biospheric net production. In this case, 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 pCO_2 or to the hot climate state (> ~310 K on the CO_2 degassing rate of the present Earth) with high pCO_2 and pCH_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.

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