Influence of atmospheric carbon species on the climates of terrestrial planets: the implications for CO worlds

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The stability of carbon species including CO in planetary atmospheres is largely influenced by their climates. Planetary climate, more specifically the temperature and resultant water vapor profiles determine the rate of H_2O photolysis. Photodissociation of H_2O forms OH radical, which acts as an oxidant of reducing carbon species including CO and CH_4. However, the climate is also influenced by atmospheric composition, especially carbon speciation, because CO_2 and CH_4 are strong greenhouse gases while CO is not. Thus, the climate and photochemistry are coupled by these feedback processes. Although these feedback processes have been implicitly considered in several previous studies (e.g., Hu et al. 2020) which treated climate and photochemistry in a self-consistent manner, their influence has not been systematically studied. Moreover, the effects of CO on climate have not been clarified; previous studies use another non-greenhouse gas N_2 as the substitute, and the climate effect of non-greenhouse gas itself has not been analysed in detail. This presentation aims to discuss the climate effect on the stability of CO on different types of planets based on the results of our series of studies.

We utilized the climate module CLIMA of an open-source code ATMOS (e.g., Kasting et al. 1984; Arney et al. 2016). The model implemented to CLIMA assumes a one-dimensional plane-parallel atmosphere, two-stream radiative transfer, and convection expressed with dry/moist adiabat. The water vapor profile in the troposphere is given with a relative-humidity model. In addition to CO_2 and CH_4 treatment in the original CLIMA, we implemented CO with its absorption coefficients, Rayleigh scattering parameters, and heat capacity model. We performed parameter study for variable carbon content, host stellar types, and relative humidity models (Manabe and Wetherald 1967; Kasting and Ackerman 1986).

We first review the findings of our studies. i) CO (and other non-greenhouse gases) affects the planetary surface through the combination of scattering of stellar irradiation, pressure broadening of greenhouse-gas absorption lines, and hydrological feedback; this allows variable heating and cooling with respect to stellar types and relative humidity models. ii) Visible and infrared absorption by CO does not influence the surface temperature significantly but the stratospheric temperature; this impacts the stratospheric water-vapor profile and consequently, the retention of water on the planetary surface.

We then discuss implications for the emergence and stability of CO-rich atmospheres on different planets. CO acts as a coolant and thus stabilizes itself for arid planets orbiting stars bright in shorter wavelengths. Early Mars is one of possible candidates which possess such environments (e.g., Kite et al. 2021). CO formed with photolysis of CO_2 may be stabilized by its cooling effect and the loss of CO_2 greenhouse effect. At the same time, the stratosphere may become warmer, which potentially leads to water loss and long-term oxidation of the atmosphere. On planets orbiting later-type stars such as M-types, CO can heat the surface. When we consider photolysis of CO_2 to form CO, this can partially compensate for cooling due to the loss of CO_2 greenhouse effect and stabilize CO_2, though the CO runaway itself can still happen (Hu et al. 2020).

Keywords: Terrestrial Planets, Atmospheres, Climate, CO Worlds

