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Line-by-line calculations of radiation properties for exoplanets with steam atmosphere

ONISHI, Masanori[1*] ; HASHIMOTO, George[2] ; KURAMOTO, Kiyoshi[3] ; TAKAHASHI, Yoshiyuki O.[1] ; TAKAHASHI, Yasuto[3] ; ISHIWATARI, Masaki[3] ; HAYASHI, Yoshi-yuki[1]

[1]Department of Earth and Planetary Sciences, Kobe University, [2]Department of Earth Sciecnes, Okayama University, [3]Department of Cosmosciences, Graduate School of Science, Hokkaido University

For a hot water rich atmosphere, there is an upper limit on the thermal emission that is unrelated to surface temperature (Simpson, 1927, Nakajima et al., 1992). The radiation limit is deeply related to evolution of planetary atmosphere. Hamano et al., 2013 showed that terrestrial planets can be divided into two distinct types on the basis of their evolutionary history during solidification from the initially hot molten state depending on whether incoming flux from a host star is larger or less than the radiation limit. On the other hand, the first direct image of an exoplanet has finally occurred in 2004 (Chauvin et al., 2004), it is expected to observe radiation spectrum from terrestrial planets near future. If we can observe the spectrum, we have potential to clarify the atmospheric and surface environment and history of the planets. In order to estimate the planetary environment from the observation, numerical simulation of radiative transfer is needed. The most reliable calculation method of the radiation is line-by-line treatment. Goldblatt et al., 2013 calculates the radiative transfer of a pure water atmosphere by line-by-line treatment. Goldblatt et al., 2013 investigates only one case of surface water amount, one current ocean mass case. In this study, we calculate the radiative transfer in steam atmosphere by line-by-line treatment in several surface water amount cases.

Absorption cross section of water vapor was calculated from HITEMP2010 (Rothman et al., 2010) and MT_CKD continuum model (Mlawer et al., 2012). We used a 1D convective model in pure water atmosphere. The surface temperature was varied from 250 to 2000 K. The total water amount of water was varied from 0.01 to 5 current Earth ocean mass (270 bar). For rapid calculation, we prepared absorption cross section table and calculated required absorption cross section by cubic spline interpolation. A two-stream approximation (Toon et al., 1989) was used to calculate radiative transfer by line-by-line treatment with resolution of 0.01 cm^{-1} wavelength.

A radiation limit of our study is 282 W m^{-2}. The value is good agreement with that of Goldblatt et al., 2013. When the total water amount is lesser, increasing of outgoing thermal flux over radiation limit occurs in lower surface temperature conditions. In 0.01 current ocean mass condition, increasing of flux occurs in lower than 1000 K. In this case, most of flux radiate from 10 micron and 4 micron window region. Results of optical depth calculation indicate that we can't detect NIR and IR radiation from the surface of planets with surface temperature higher than 1500 K, even if the planet has 0.01 water amount.

Keywords: steam atmosphere, radiative property, radiation limit