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The Complete Evaporation Limit for Land Planets: A Study with 1D EBM

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Liquid water is thought to be essential for the origin and evolution of life on the Earth. Planets globally covered with liquid water just like the Earth are called 'aqua planets'. Using 1D radiative-convecticve model, Nakajima et al. (1992) discussed the presence of the critical flux of planetary radiation that an aqua planet can emit. If the atmosphere is saturated with water vapor, there appears an upper limit (critical flux) on infrared radiation the planet can emit. If net insolation exceeds the value, an aqua planet cannot emit energy that balances with incoming solar radiation. Then the surface temperature increases until the troposphere comes unsaturated, thus there no longer exits liquid water on its surface. According to their analytic model, the critical flux is about 123 % of net insolation of present Earth.

On the other hand, there could be planets that have liquid water not globally but locally. Abe et al. (2005) investigated the climate of a theoretical planet with very small amount of water using 3D general circulation model (GCM). They showed that the local balance between precipitation and evaporation of water makes liquid water localize in high latitudes, and low latitudes become dry desert. Such a planet is called a 'land planet'. According to their numerical experiments, liquid water on a land planet is completely evaporated when net insolation exceeds 170 % of present Earth (for an Earth-sized planet with 1 bar atmosphere). We call such limit the 'complete evaporation limit'.

The complete evaporation limit was investigated for a certain limited condition of a planet (1 bar air atmosphere, 0 obliquity and no transport of ground water). Our goal is to understand the mechanisms that determine the complete evaporation limit. For the first step, we investigate the dependence of the complete evaporation limit on the transport of ground water, which affects the localization of the ground water. We modified the 1D gray model used by Nakajima et al. (1992) in order to consider the partly unsaturated atmosphere of land planets. We use a meridional 1D energy balance model (EBM) used by North et al. (1981). The transport of ground water and water vapor depending on mass gradient are also taken into account. We carried out numerical experiments with various efficiencies of the transport of ground water.

We found that if ground water exists from the pole to low latitudes, the complete evaporation limit is the same value as the critical flux for aqua planets; therefore the climate is similar to that of aqua planets. As ground water becomes localized, the complete evaporation limit gradually gets larger. Thus, the complete evaporation limit is controlled by the degree of ground water localization. The extent of ground water is controlled by the balance between the transport of ground water and water vapor in the atmosphere. These results imply that even if the atmospheric composition or pressure changes, we can estimate the extent of ground water as long as we know the transport of water vapor and ground water; consequently we can estimate the complete evaporation limit, if we know the relationship between complete evaporation limit and the extent of ground water.

In addition, in order to understand the mechanism of complete evaporation, we carried out an analysis on the stability of the surface temperature using a vary simple model, in which the planet is divided into two regions, the dry region and wet one, and energy is transported beyond the boundary. As a result, at insolation slightly smaller than the complete evaporation limit, the wet high latitudes emit planetary radiation at a little smaller rate than the critical flux of aqua planets. It implies that complete evaporation occurs even if the wet region is not required to emit radiation exceeding the critical flux.