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A suggestion for complete evaporation limit on land planet using 1-dimensional energy-balance model

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Presence of liquid water on the planetary surface is thought to be essential for the origin and evolution of life. Using a simple one-dimensional radiative-convective equilibrium model, Nakajima et al. (1992) have calculated the atmospheric structures, and obtained the relationship between the surface temperature and the outgoing infrared radiation. They have shown that there is an upper limit of the outgoing infrared radiation (called 'radiation limits') if there is liquid water on the surface. From their results with 0.3 of albedo, the radiation limits on an Earth-like planet which has a globally covered ocean (called 'aqua planet') corresponds to be 122% of the incident solar flux that the present Earth receives. On the other hand, Abe et al. (2011 submitted) have investigated the climate on planets which have little water on their surface (called 'land planets'). The notable features of land planets are the local balance between precipitation and evaporation. They, using GCM (global circulation model), have shown that liquid water is localized on the high latitudes, while the low latitudes are dried up. As a result, the value for incoming radiation by which the liquid water on the planet is completely evaporated ('complete evaporation limit') corresponds to 170% of the incident solar flux the Erath receives, which is substantially larger than that on an aqua planet. The key for a land planet to have a large value for the complete evaporation limit seems to be localization of liquid water on the surface. The GCM used by them, however, includes the climate to be controlled only by transportation of water vapor. In other words, it does not include the transportation of water on the surface of the planet. We investigate how much influence water transport on the surface may have upon the climate of the planet which possesses little water. We expand the atmospheric model used by Nakajima et al. so that we can consider limited water content. We investigate the relationship among the surface temperature, the water content and the outgoing infrared flux. Then, in order to take water transport into account, we expanded the meridionally 1-dimensional EBM (energy-balance model) used by North (1975) by giving efficiency of water transport as a parameter and adding a term for latent heat.

It is revealed that when water on the surface is transported very efficiently (in our model, one tenth as efficient as the water vapor transport in the atmosphere), liquid water can exist from the high latitudes to the low on the planet. The complete evaporation limit corresponds to 122% of the incident solar flux the Earth receives, which is the same value for that on an aqua planet, despite the planet possesses little water. On the other hand, when liquid water on the surface is not transported so easily (one five hundredth the efficiency of the water vapor transport), liquid water on the surface is localized on the high latitudes. In our model, the complete evaporation limit of the planet corresponds to 130% of the incident solar flux the Earth receives, which exceeds the radiation limits of the aqua planet. If a planet possesses little water, water transportation on the surface is thought to be quite different from that on an aqua planet. Given that a land planet possesses very little water, the liquid water on the surface should be absorbed into the soil. Consequently, it would act like groundwater. The efficiency of water flow through a medium that consists of sand or mud can be estimated by applying Darcy's law. In fact, we can see that the water flow through fine sand is roughly 10^{-10} times as smaller as the transportation of water vapor in our model. In such cases, the liquid water cannot exist on the low latitudes because the mechanism that transports water from the high latitudes to the low does not work. Thus, the climate of such planets would act like a land planet.