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The influence of clouds on the onset of a Runaway Greenhouse in a one-dimensional radiative-convective equilibrium model

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Several studies have shown that for certain simple atmospheric models consisting of at least one greenhouse gas, the outgoing longwave radiation (OLR) has an upper limit. If the incoming shortwave radiation exceeds this upper limit, a Runaway Greenhouse occurs, since there is a steady gain in energy by the atmosphere. Therefore the maximum distance between a planet and a star at which a Runaway Greenhouse occurs, may define the inner limit to the habitable zone of solar systems. Furthermore a Runaway Greenhouse may have occurred in the early history of Venus.
Most previous studies on the Runaway Greenhouse were conducted with conceptual equilibrium models with either a very simple representation of clouds or with no cloud representation at all. Therefore the influence of clouds and especially of the cloud-albedo feedback on the onset of a Runaway Greenhouse is still poorly understood.
In the present study on the Runaway Greenhouse we use a model with an interactive cloud representation, namely a modified single-column version of the general circulation model ECHAM6. Our atmospheric configuration corresponds to Earth-like conditions, but with increased total solar irradiance (TSI). We consider only the early phase of a Runaway Greenhouse, that is, before the surface temperature attains 120 C.
Comparisons between experiments with clear-sky conditions (clouds are transparent to radiation) and full-sky conditions (clouds affect radiation) indicate that clouds provide a strong negative feedback augmenting the critical solar irradiance to trigger a Runaway Greenhouse substantially. Clouds become substantially thicker with increasing TSI and the associated increase in albedo outdoes the warming longwave effect, allowing for equilibrium to settle for markedly higher TSI. Our results thus indicate that the critical incoming shortwave radiation is crucially influenced by cloud feedbacks.