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The Runaway Greenhouse in a Cloudy Column

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The climate system is expected to react to an increase of total solar irradiance (TSI) by warming and hence by emitting more longwave radiation thereby restoring the global energy balance. Previous studies with simple radiative-convective models suggest, however, that there is an upper bound for the outgoing longwave radiation (OLR). If the TSI exceeds this upper bound of OLR, a Runaway Greenhouse occurs, since there is a steady gain in energy by the atmosphere.

However, the models employed in previous studies on the Runaway Greenhouse did either only include a very simple representation of clouds or did not include a cloud representation at all. Therefore the influence of clouds on the onset of a Runaway Greenhouse is still poorly understood.

In our 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 TSI. We consider only the early phase of a Runaway Greenhouse, that is, before the surface temperature attains 400 K.

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.