On the effects of clouds and hazes in the atmospheres of hot Jupiters: semi-analytical temperature-pressure profiles

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Motivated by the work of Guillot (2010), we present a semi-analytical formalism for calculating the temperature-pressure profiles in hot Jovian atmospheres which includes the effects of clouds/hazes and collision-induced absorption. Using the dual-band approximation, we assume that stellar irradiation and thermal emission from the hot Jupiter occur at distinct wavelengths ("shortwave" versus "longwave"). For a purely absorbing cloud/haze, we demonstrate its dual effect of cooling and warming the upper and lower atmosphere, respectively, which modifies, in a non-trivial manner, the condition for whether a temperature inversion is present in the upper atmosphere. The warming effect becomes more pronounced as the cloud/haze deck resides at greater depths. If it sits below the shortwave photosphere, the warming effect becomes either more subdued or ceases altogether. If shortwave scattering is present, its dual effect is to warm and cool the upper and lower atmosphere, respectively, thus counteracting the effects of enhanced longwave absorption by the cloud/haze. We make a tentative comparison of a 4-parameter model to the temperature-pressure data points inferred from the observations of HD 189733b and estimate that its Bond albedo is approximately 10%. Besides their utility in developing physical intuition, our semi-analytical models are a guide for the parameter space exploration of hot Jovian atmospheres via three-dimensional simulations of atmospheric circulation.

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