What controls the tropopause level of the Jovian atmosphere ?

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Introduction: The primary definition of the tropopause of a planetary atmosphere may be the level which divides the convective region and upper stably stratified region. For the Earth atmosphere, on the other hand, the tropopause is often defined as the level of first temperature minimum which occurs in the temporal-mean vertical temperature profile above the surface. This may be an approximation of the true boundary between the two regions, because the stably stratified region possibly includes a layer with negative vertical temperature gradient. This approximation is not worse for the Earth atmosphere because the change in lapse rate around the tropopause level is sharp and therefore the difference from the primary definition is minimal.

Major equilibrium cloud condensation models (ECCMs) [1] and some cloud convection models [2] assume that the Jovian atmosphere is enough convective in the region below a level about 0.1 bar, where the temperature minimum exists in the representative temperature profile retrieved by observations. However, we need to revisit it more carefully. In a radiative-convective model of Jovian atmosphere Appleby and Hogan, 1984 [3], the temperature minimum occurs at a level around 0.1 bar, while the radiative-convective boundary may occur at much a deeper level around 0.5-0.75 bar. It means that the generation of NH_3 cloud by convection, a widely accepted picture for the Jovian uppermost cloud formation, may be indeed marginally possible because the ECCM predicts that little condensation of NH_3 would occur at such deeper level depending on the mixing ratio of condensable gases.

Objective and model: In order to understand how the tropopause level is controlled in the Jovian atmosphere, we have been developing a new numerical model of radiative-convective equilibrium in H_2-rich atmosphere taking into account the up-to-dated gas absorption models and knowledge on the atmospheric composition. Our model is a 1D radiative-convective equilibrium model for a plane parallel atmosphere. In this model, the temperature of lower boundary (taken 10 bar) is given constant in accordance with the Galileo probe data. We only solve the transfer of long wave radiation with wave number range from 10 to 10,000 cm^{-1}. Here, we use HITRAN database [4] for line absorption for condensable gas species, and Borysow (1989, 2002) [5] for continuum absorption due to H_2-H_2 and H_2-He collision. The temperature of each atmospheric layer is changed step by step according to the calculated amount of radiative heating or cooling until it converges into the steady state, or radiative-convective equilibrium state with applying convective adjustment for the unstable layer. Atmospheric compositions are given within the range consistent with the Galileo probe experiment.

Results and Discussion: Out preliminary results are shown in Figure 1. It is confirmed that the tropopause by primary definition is formed around 0.5 bar level almost independent on the mixing ratio of condensable species. Note that the temperature tends monotonically decreases with altitude for most cases because the solar heating is neglected in these calculations. If the solar heating was included, the tropopause level likely shifts deeper. Our obtained temperature profiles are compared with the NH_3 condensation curves, showing that little NH_3 condensation occurs within the convective region when given nominal NH_3 concentration or below. On the other hand, a NH_3 condensable layer spans above the tropopause. This implies that the uppermost cloud layer of Jovian atmosphere would be mostly composed of stratospheric cloud rather than convective cloud. Because the uppermost cloud play an important role in determining the planetary albedo, development of stratospheric cloud model would be essential to understand the radiative energy budget in the Jovian atmosphere.

References:

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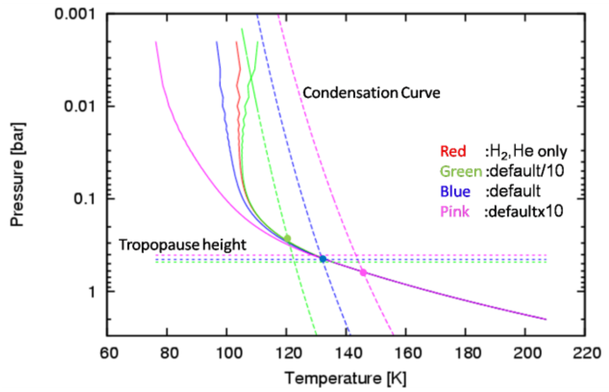

Figure 1: Temperature profiles (solid curves) in radiative convective equilibrium calculated by our model with simplified line absorption data. Here each color means ratio of condensable gases. In "Default" calculation (blue), the mixing ratios of H_2O and NH_3 relative to H_2 are $1x10^{-8}$ and $3x10^{-5}$, respectively, at 1.0 bar in accordance with the composition model[6] consistent with the Galileo probe experiment. For "Default/10 (Green)" and "Default x 10 (Pink)" calculations, 1/10 and 10 times larger mixing ratios are given. The pure H_2-He atmosphere case is also shown. The atmospheric composition is constant at all altitude. The dotted lines represent tropopause levels dividing the convective region and stably stratified region, and the dashed curves are the NH_3 condensation curves. NH_3 condensation little occurs within the convective region when the mixing ratio of NH_3 is nominal or below whereas the formation of stratospheric NH_3 cloud in the upper atmosphere is possible for a wide range of the mixing ratio.