What controls the tropopause level of the Jovian atmosphere?

Yasuto TAKAHASHI¹, George L HASHIMOTO²,³, Masanori ONISHI⁴, Kiyoshi KURAMOTO¹,³
¹Hokkaido Univ, ²Okayama Univ, ³CPS(Center for Planetary Science), ⁴Kobe Univ

1. Introduction

1-1. Why we study Jupiter?
- Characterization of planetary atmosphere, including those of exoplanets is necessary to know planetary formation and/or evolution.
- Jupiter is the most familiar H₂-rich planet for us, and many of observed exoplanets likely have such atmosphere. We are developing a numerical model to reproduce the thermal structure of H₂-rich atmosphere and have carried out calculation for the Jovian atmosphere as the first step.

1-2. Jovian cloud structure
- Cloud formation is important for Jupiter because cloud covers Jupiter globally and affects planetary spectrum and albedo.
- Equilibrium Cloud Condensation Model (ECCM) [1,2] predicts 3 layered cloud (H₂O, NH₃, SH, NH₄) from thermochemical calculations, but it assume a simple adiabatic air uplift (fig. 1).
- Cloud convection model [3] with micro cloud physics and dynamical processes indicates that cumulonimbus cloud activity could have intermittency under some radiative cooling settings, but assuming a simple cooling profile (fig. 2).
- Radiative-convective equilibrium model [4] predicts that the boundary of radiative equilibrium and convective (tropopause) one occurs around 0.5bar, almost the same level for the initiation of NH₃ condensation in an adiabatically uplifted air parcel.

2. Purpose

2-1. Revisit the level of tropopause
- Cloud top of the Jovian atmosphere is thought as NH₃ cloud from estimated temperature profile, but it remains unclear whether it is stratospheric or convective cloud. This issue is revisited with our model.

2-2. Estimate the cooling rate in troposphere
- Radiative cooling drives convection in troposphere. We calculate its rate and discuss about cloud convection intermittency.

3. Model

3-1. Assumptions & settings
- 1D radiative-convective equilibrium model
- Transfer of thermal radiation is solved with given the potential temperature of troposphere.
- Neglects solar irradiation and the opacity due to condensates.
- Calculated wavenumber range is 0 – 10,000 cm⁻¹ (10,000 cm⁻¹ = 1 μm), with 10 cm⁻¹ band.
- Gravity is 24.82m/s² (Jovian equator)
- Volume Mixing Ratio (VMR) is changed along saturation vapor pressure.

3-2. Line & CIA absorption
- H₂O, CH₄, NH₃ line absorption from HITRAN2008 [6].
- Line by line calculation is reduced to wavenumber resolution to 10cm⁻¹.
- H₂O, H₂, H₂-He Collision induced absorption from Borysow 1989, 2002 [7,8].

3-3. Radiative transfer & convective adjustment
- F_R = \int \epsilon \sigma T^4 d \lambda
- F_C = \int \epsilon \sigma T^4 d \lambda
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- T = \left( \frac{P}{P_S} \right)_{T_C}

4. Results

4-1. Temperature profile & Volume mixing ratio
- No thermal inversion occurs because of no solar irradiation.

5. Discussions & Conclusions

5-1. Tropopause is formed on 0.33bar level
- This suggests that convective NH₃ cloud would be ubiquitously formed.
- But note that this calculation neglects some potentially important factors including the solar heating which would stabilize the upper atmospheric layer.

5-2. Heat flux and Cooling rate profile
- Good agreement between calculated and observed heat flux (4-3) means the total amount of radiative cooling is well reproduced by our model. Total energy loss 11.4 W/m² assumed for convective layer in [3] is also near that of our model while the calculated peak cooling rate is twice larger than the observed value at the Galileo probe entry site.
- The cloud convection intermittency by [3] is supported from our results.
- Further modelling study is needed to clarify how the realistic cooling profile affects cloud formation.

References