EPSC Abstracts
Vol. 9, EPSC2014-322, 2014
European Planetary Science Congress 2014

Radiative cooling profiles of the Jovian-planet atmospheres in radiative-convective equilibrium

Yasuto Takahashi (1), G. L. Hashimoto (2), M. Ishiwatari (1), Yoshiyuki Takahashi (3), M.Onishi (3) and K. Kuramoto (1)
(1) Hokkaido University, Japan, (2) Okayama University, Japan, (3) Kobe University, Japan (takayasu@ep.sci.hokudai.ac.jp)

Abstract

In order to understand cloud convection in the Jovian-planet atmospheres, we have estimated the radiative cooling profiles with a newly developed numerical model. This model computes a radiative-convective equilibrium state of atmosphere with given potential temperature and composition of deep atmosphere. The modeled outgoing thermal radiation and tropopause level are found to be little dependent on deep H_2O abundance. From the modeled radiative cooling profile as well as the extent of wet convection zone, one can derive the temporal interval of tall cumulonimbus activity by equating the amount of radiative cooling and latent heat release associated with vapor condensation. The estimated interval increases with deep H_2O abundance. Prolonged intervals of large scale cloud features appeared on Jupiter and Saturn imply enrichment of H_2O in their deep atmosphere relative to the solar proportion, consistent with the estimation range from studies of internal structure modeling.

1. Introduction

The Jovian-planets have hydrogen-rich, thick atmospheres with cloud activities that are thought to be closely related to radiative cooling processes in troposphere [1]. Recent numerical fluid simulations indicate that the intermittency of cumulonimbus cloud activities is likely controlled by the net cooling rate of the wet convective layer above the H_2O cloud base [5,6]. In spite of its significance, the radiative cooling profile has never been systematically estimated so far, except the estimation based on the Galileo Net Flux Radiometer data characterizing the probe entry site hotter than the mean Jovian atmosphere.

Recently we have developed a numerical model describing radiative-convective equilibrium state of atmospheres of gas-giant planets with a variety of boundary conditions and bulk compositions. By using this model, here we derive radiative cooling profiles of Jupiter and Saturn in order to understand cloud convection on both planets. In particular, we focus on the dependence on deep abundance of H_2O which is the most important species generating tall cumulonimbus activity and controlling the static stability of wet-convective layer due to the large amount of latent heat for condensation [e.g. 5,6] . We will estimate the relationship between the cumulonimbus activity interval and deep H_2O abundance and propose an interpretation for intermittency of large-scale cloud features having observed on Jupiter and Saturn with a link to internal modeling.

2. Model description

In our plane-parallel, 1D radiative-convective equilibrium model, the lower atmosphere is adjusted to the adiabatic temperature profile kept by convection while the upper one is in radiative equilibrium. The tropopause level, dividing the convective equilibrium layer and the radiative equilibrium one, is found where the divergence of net upward thermal flux becomes positive (that means radiative cooling) when searching from the atmospheric top. The potential temperature of convective layer of each planet is given from the thermal profile obtained from the radio occultation data. The mixing ratios of H_2O, CH_4, NH_3, H_2S, PH_3 and NH_4SH follow their saturation vapor pressures in the altitudes where their condensation occurs and have fixed values in deep atmosphere consistent with observational constraints except H_2O. The deep H_2O abundance is poorly constrained and therefore varied from 1 to 20 times the equivalent of the solar oxygen relative to hydrogen. Collision induced absorptions of H_2-H_2 and H_2-He, and line absorptions of H_2O, CH_4, NH_3, H_2S, and PH_3 are included while the extinction by condensates is neglected. The radiative transfer is solved over the wavenumber range 0-5,000 cm^{-1} with 0.01 cm^{-1} resolution. With these settings, a radiative-convective equilibrium structure is obtained by iterations of radiative transfer calculation and convective adjustment.

3. Results and discussion

In the radiative-convective models of Jupiter, the troposphere is formed at levels around 0.44 bar, which are within the main part of NH_3 condensation layer. On the other hand, the Saturn models have the tropopause at levels around 0.28 bar which are well above the main part of the NH_3 cloud layer. The radiative cooling rate profiles have the peak value with 2.5×10^{-7} K/s at levels around 0.75 bar in the Jupiter models, and 0.5×10^{-7} K/s around 0.5 bar in the Saturn models. These results are little affected by H_2O abundance, because H_2O condenses in much lower atmosphere.

According to the fluid simulations [5,6], the intermittency of tall cumulonimbus activity is described by the cyclic sequence of the rapid release of latent heat by cloud formation and the gradual radiative cooling. Since the latent heat release produces negative thermal buoyancy in the wet convection zone, the next cloud formation should wait until the layer becomes cooled enough. From the modeled radiative cooling profile across the wet convection zone, one can derive the temporal interval of tall cumulonimbus activity by equating with the latent heat release associated with vapor condensation. The estimated interval increases with deep H_2O abundance as shown in Figure 1.

On Jupiter, the fading/revival cycle in the south equatorial belt have been known as a significant large-scale intermittency of cloud activity. If this cycle is driven by the sequence of latent heat release by cloud convection and radiative cooling, the observed inteval suggests deep H_2O abundance from 7 to 17 times the solar abundance. The intermittent appearance of great white spots (GWS) on Saturn may also be a phenomena driven by the similar mechanism. If this is the case, the observed interval of GWS appearances suggests deep H_2O abundance about 5 times the solar. These results are consistent with estimations of H_2O abundance based on planetary interior modeling [2,3].

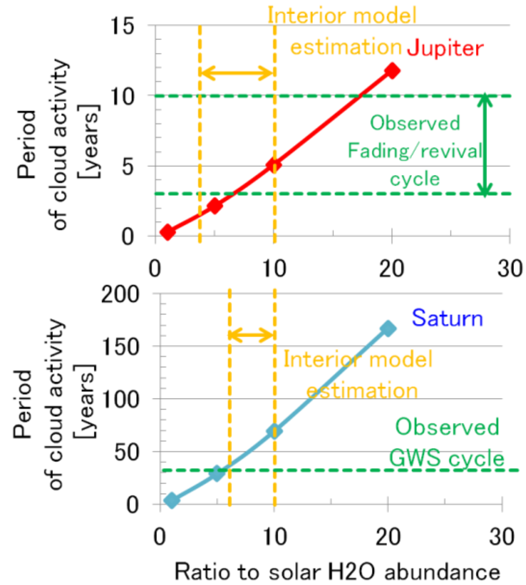

Figure 1: Relationships between deep H_2O abundance and the period of cloud activity estimated for Jupiter (red) and Saturn (blue). Green dashed lines show observed interval time of cloud features. Constraints from planetary interior modeling are also shown.

References

[1] Fletcher, L. N. et al.: Jovian temperature and cloud variability during the 2009-2010 fade of the South Equatorial Belt , Icarus, Vol. 213, pp. 564-580, 2011.

[2] Fortney, J. J. and Nettelmann, N.: The interior structure, composition, and evolution of giant planets, Space Science Reviews, Vol. 152, pp. 423-447, 2009

[3] Nettelmann, N.: Predictions on the core mass of Jupiter and of giant planets in general, Astrophysics and Space Science, Vol. 336, pp. 47-51, 2011.

[4] Sromovsky, L. A. et al.: Galileo probe measurements of thermal and solar radiation fluxes in the Jovian atmosphere, Journal of Geophysical Research, Vol. 103, pp. 22,929-22,977, 1998.

[5] Sugiyama, K. et al.: Numerical simulations of Jupiter's moist convection layer: Structure and dynamics in statistically steady states, Icarus, Vol. 229, pp. 71-91, 2014.

[6] Sugiyama, K. et al.: Intermittent cumulonimbus activity breaking the three-layer cloud structure of Jupiter, Geophysical Research Letters, Vol. 38, L13201, 2011.