

A thermodynamic calculation for jovian planetary atmospheres --- vertical profiles of temperature and static stability

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1. Introduction

In the study of convective structure of an atmosphere with condensible component, possible vertical profiles of temperature and static stability can be considered by calculating the adiabatic change of an air parcel. This is a necessary procedure in the study of the Jovian planets, where the latent heat released from many condensible species and reaction heat from many chemical processes possibly produce complicated structure of static stability.

In our previous study (Sugiyama et al., 2001a), the dependence of temperature and static stability on elemental composition of a model Jovian atmosphere is examined. However, the thermodynamic equilibrium state of the actual Jovian atmospheres can not be considered except for Jupiter, since the values of specific heat in low temperature are insufficient. Furthermore, the calculation scheme in our previous study cannot obtain the equilibrium state when the species contained in two different phases are completely the same.

In this study, we investigate the dependence of temperature and static stability profiles on elemental composition of all the Jovian planetary atmospheres by reinforcing the thermodynamic values and improving the calculation method.

2. Calculation method

The method is basically the same as Sugiyama et al. (2001b). The atmospheric thermal equilibrium state is obtained by minimizing Gibbs free energy. The minimum value of Gibbs free energy for given temperature and pressure is calculated iteratively by expanding the expression of Gibbs free energy as a quadratic function of atmospheric composition.

A deficit of this method emerges when the species contained in two different phases are completely the same. For example, in the case of an air parcel composed of one specie with two phases, Gibbs free energy for given temperature and pressure becomes a linear function of the composition; it is impossible to obtain the value of minimum Gibbs free energy. In order to avoid this problem, we assume that the phase whose chemical potential is smaller than those of the other phases actually exists.

The values of physical quantities required in this method are Gibbs free energy and entropy at the reference state and specific heat as a function of temperature for each chemical species. The values of specific heat from 100 K to 0 K are extrapolated by using Spline function for all species except for H₂. All species are assumed to behave as ideal gas and ideal solution.

3. Calculation Results

Figure 1 shows the vertical profiles of static stability for a model Saturn's atmosphere with 1 x solar abundance as incondensable volatile elements. Solid line and broken line denote the results with 1 x and 3 x solar abundance for condensable volatile elements, respectively. Static stability of the atmosphere is determined from the deviation of moist adiabatic lapse rate from dry adiabatic lapse rate, where the moist air contains all condensible volatiles, while the dry air contains only incondensable volatiles. The standard pressure of the calculation and temperature there are chosen as 1.2 bar and 143 K respectively, according to the observation obtained by Voyager.

Four peaks of static stability profiles corresponds to condensation of NH₃(s), NH₄SH(s), H₂O(s) and H₂O-NH₃(aq), respectively, as observed from the top of the atmosphere. As the result of improvement of calculation method, a sharp phase transition between, for example, H₂O-NH₃(aq) and H₂O(s), is represented. The peak of static stability associated with condensation of H₂O-NH₃(aq) is the most remarkable, but its value is $1.4 \times 10^{-5} \text{ sec}^{-2}$ at most (see broken line). It is about 0.1 times smaller than that ($1.0 \times 10^{-4} \text{ sec}^{-2}$) of the terrestrial atmosphere.

4. Reference

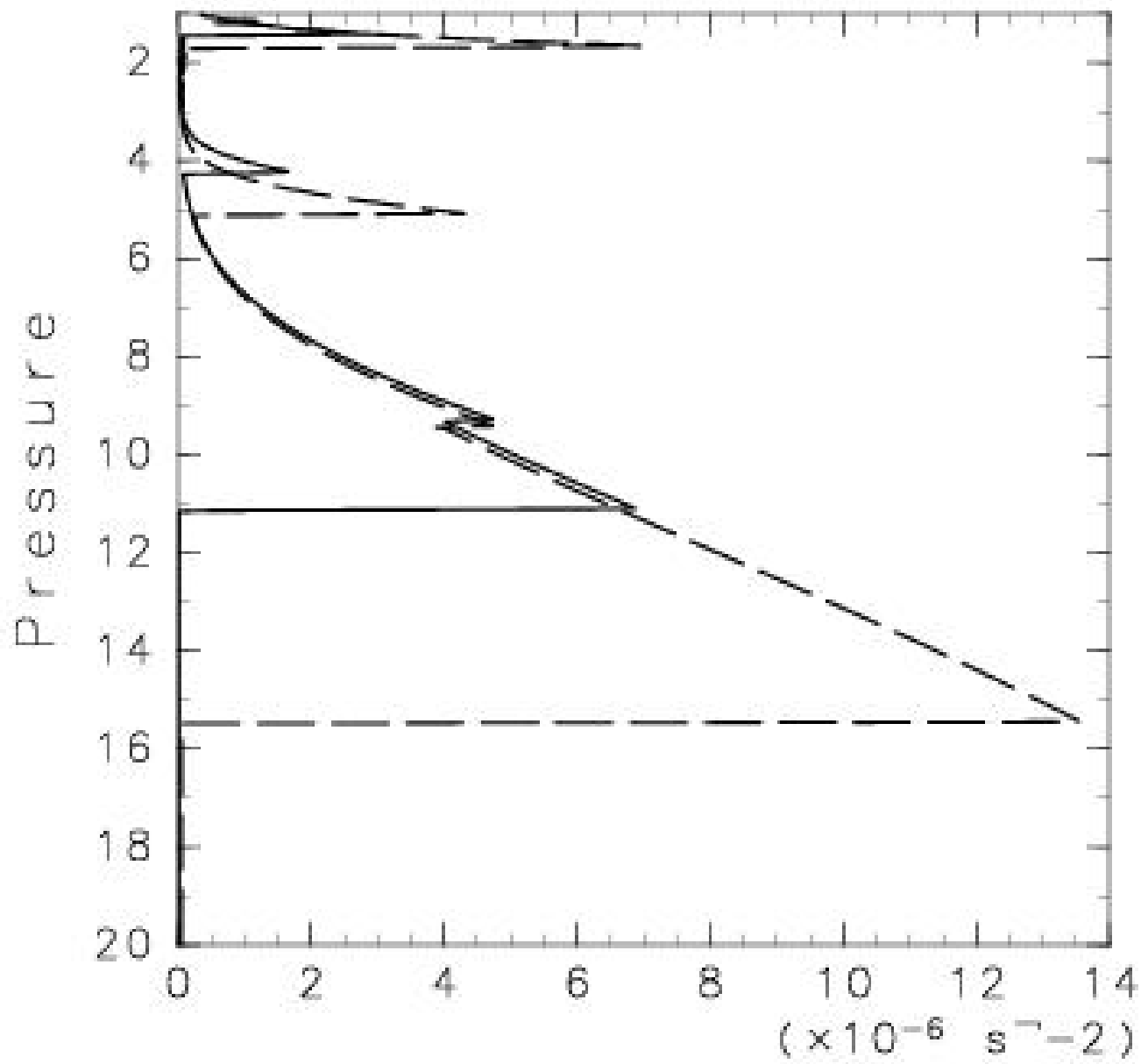
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<http://www.gfd-dennou.org/arch/oboro/>
GFD Dennou Club.

($\times 10^5$ Pa)

saturn



Stability