Development of a sulfuric acid cloud transfer/condensation/evaporation scheme in a Venusian GCM

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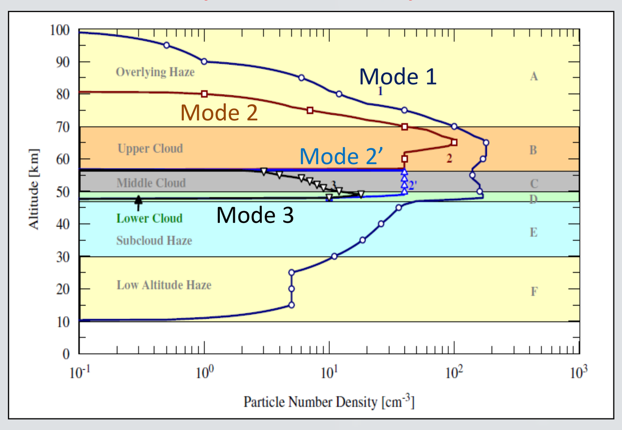
1.INTRODUCTION

-Sulfuric Acid Cloud-

- Distributing between 50km and 70km altitude(Fig.1).
- Classified in 4 modes by their each radius.
- Each mode has its own characteristics of vertical distribution and thermal absorption efficiency.

-It is important to detect the distribution of each mode theoretically for the study of the thermal structure.



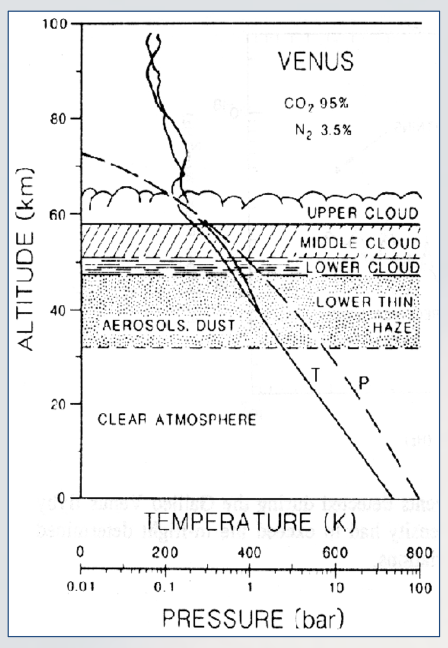


Fig.1(right). Venusian atmosphere [Russell, 1995]
Fig.2(left). Vertical Distribution of each mode aerosols [Haus et al., 2010]

Table1. Effective radius of each mode [μm]

Mode1	Mode2	Mode2'	Mode3
0.3	1.0	1.4	3.65

-Our VGCM-

Characteristics:

- Based on the CCSR/NIES/FRCGC AGCM [Ikeda, 2011]
- 32(lat) x 64(lon) grid points and 52 vertical levels up to 95km.
- Calculate dynamical and physical processes at each point every 20 minutes.
- Output:
  -Temperature, Surface pressure, Wind velocity (zonal and meridional), the quantity of a sulfuric acid aerosols and vapor.

Big Problem of the Previous Model

-Aerosols forced by only convection and sedimentation in our model.
-Large particles continue to descend and the peak height of mode3 aerosols become ~30km after 1 Venusian day.

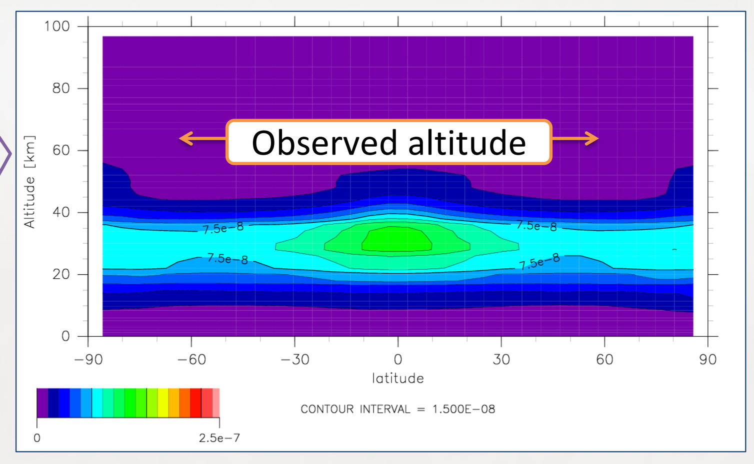


Fig.3. Mode3 lat-alt profile calculated after a Venusian day. Color contour is mass mixing ratio [kg/kg].

-Purpose of Our Study-

- **Introduction of a sulfuric acid condensation/evaporation scheme.**
- **Discussions about the influence of this scheme on cloud distribution and temperature profile.**
  -Especially we also considered the effect of latent heat.

2.DEVELOPED SCHEME

-Condensation/Evaporation -

- For the development of a sulfuric acid cloud condensation/evaporation scheme (C/E Scheme), we introduced the saturation mass mixing ratio of a sulfuric acid calculated from Ayers et al. [1980]:

$$q_{sat} = \frac{2.2562\times10^3}{P}\times\exp\left(\frac{-1.0213\times10^4}{T}+16.259\right)$$

- The excess vapor is transformed to 75% sulfuric acid aerosols if supersaturated, and that the aerosols are transformed to the vapor phases if undersaturated.
- The generated sulfuric acid aerosols are distributed into 4 modes at each altitude according to the abundance ratio based on Haus et al. [2010](Fig.2).

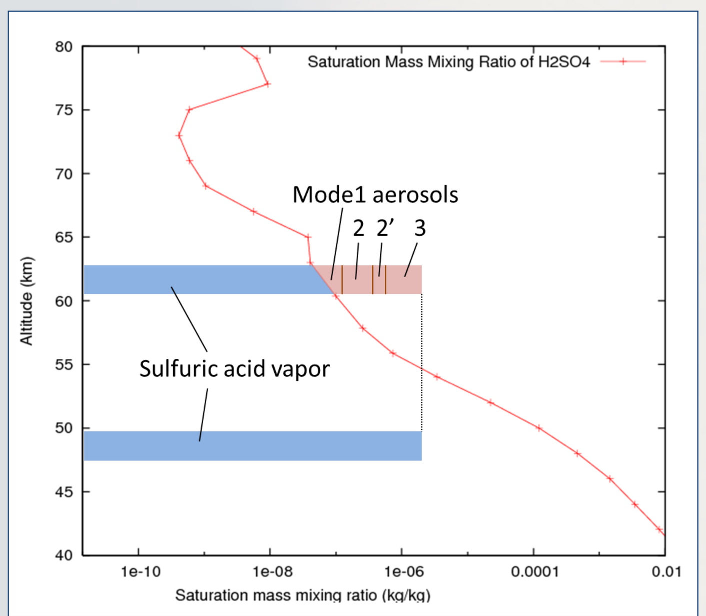


Fig.4. Global mean saturation mass mixing ratio of sulfuric acid with the temperature and pressure used as first conditions. Color bars are the examples of condensation and evaporation.

-Latent Heat-

- We also calculated the effect of latent heat transfer with Clausius-Clapeyron Equation written as :

$$\frac{dP_{sat}}{dT} = \frac{L}{T\Delta V}$$

where P_{sat} is the saturation vapor pressure of sulfuric acid, L is the latent heat.

3.RESULTS & DISCUSSION

-Cloud Altitude-

- Every mode of the cloud now evaporates below 50km altitude. Especially mode3 aerosols peak at the both poles, mid-altitude (Fig.5). It is consistent with past observations.

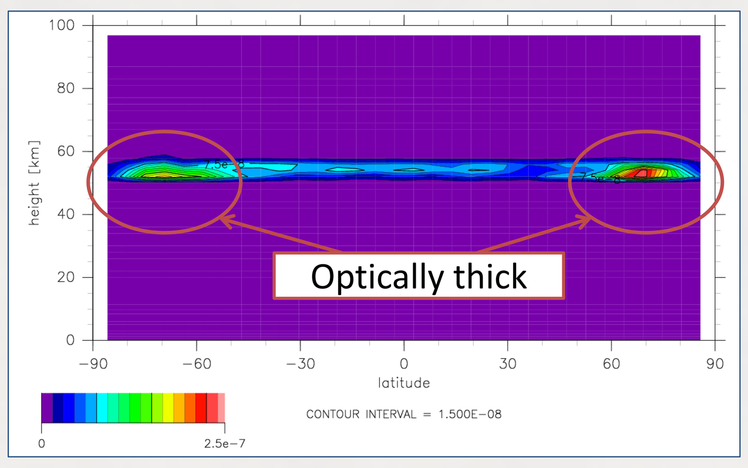
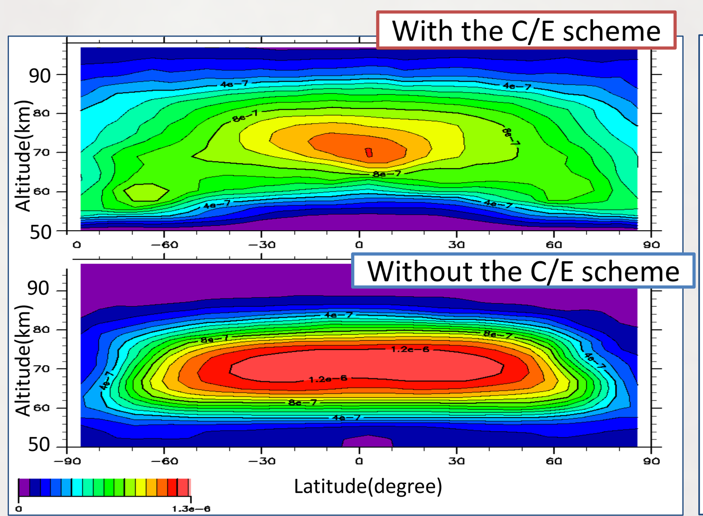


Fig.5. Mode3 lat-alt profile calculated after a Venusian day with a condensation/evaporation process.

- Mode2 aerosol distribution extended to high latitudes and altitudes. We consider that it is because the aerosols were evaporated when the undersaturation, and they transported by the Hadley circulation (Fig.6 and Fig.7).



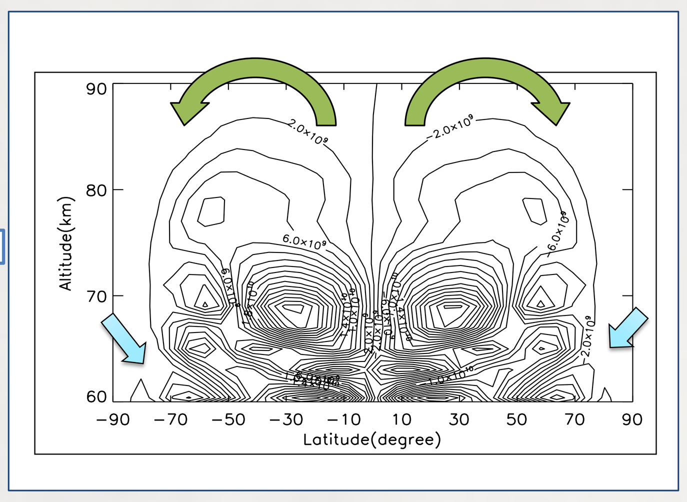


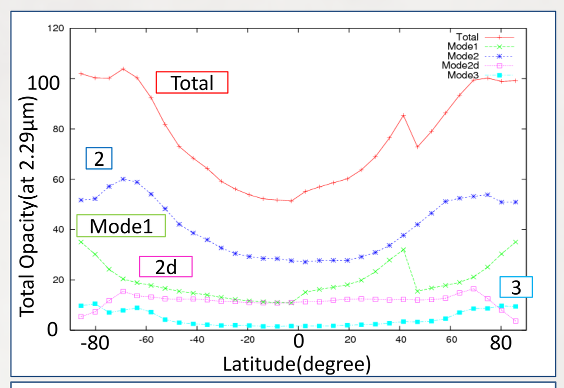
Fig.6(left). Mode2 lat-alt profile calculated after a Venusian day. The top one is the result with a condensation/evaporation scheme, and the bottom one is without the scheme.
Fig.7(right). Mass stream function calculated after a Venusian day.

-Cloud Opacity-

- The total opacity at each latitude is calculated with the equation [Nakajima et al., 2000]:

$$\Delta\tau = \frac{3}{4}\frac{Q_e \rho q_{H_2SO_4}}{r_{eff}\rho_{H_2SO_4}}\Delta z$$

- The extinction efficiency at 2.29μm is shown in Table.2 from Crisp [1986].
- As a result, there are optically thick at high latitudes, and we got asymmetric profile between both hemispheres because of the asymmetry of the mode1 aerosols.
- It is consistent with the observations [Kuroda, 2013], but our result is about 2 times larger than them.



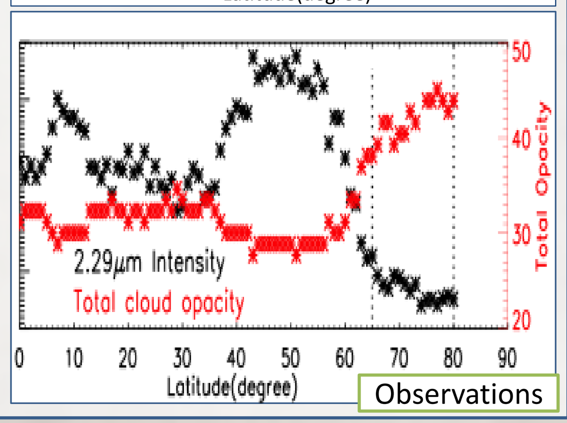


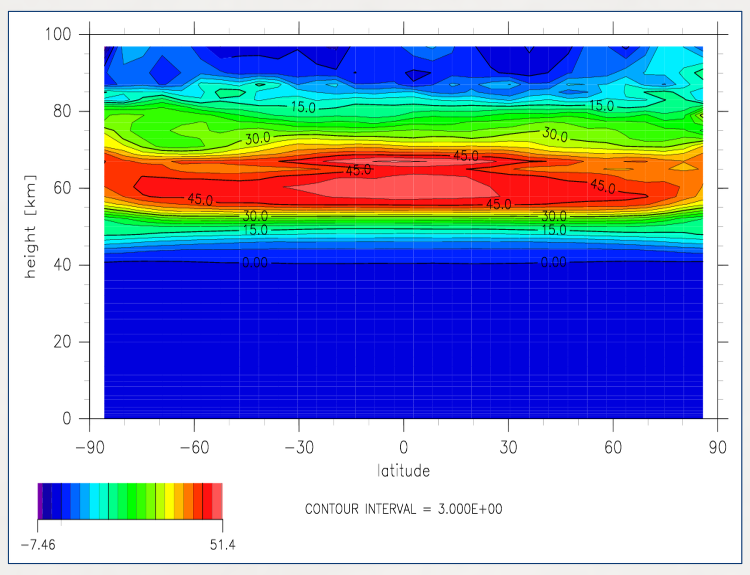
Fig.8(top). Total cloud optical depth at each latitude.. Model1(green), mode2(blue), mode2d(pink), mode3(sky-blue) , and sum of them(red).
Fig.9(bottom). Observed total opacity at each latitude [Kuroda, 2013].

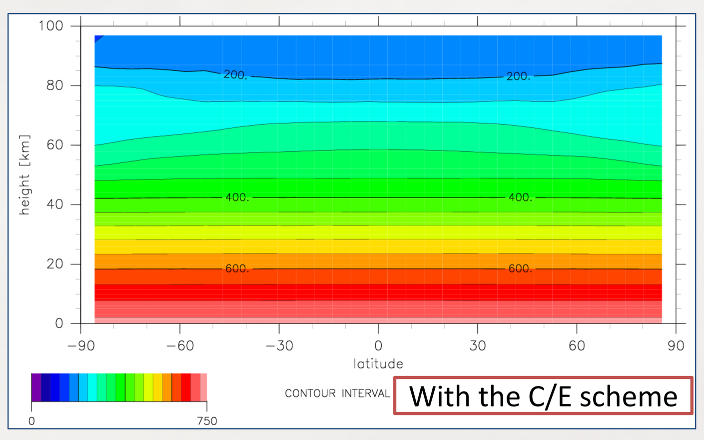
Table2. Extinction efficiencies at 2.29μm of each mode aerosols [Crisp, 1986].

Mode1	Mode2	Mode2'	Mode3
0.440	2.381	3.138	2.331

-Temperature-

- The effect of the C/E scheme is shown in Fig.10.
- Temperature increases up to 50K at the equator, 60km altitude where the aerosols are most concentrated.
- Temperature distribution (Fig.11) shows that although the temperature increases with the latitude below about 70km, polar regions are warmer that equatorial regions above 70km.
- This distribution is qualitatively similar to the observations (Fig.12), but our result is much warmer than them up to about 50K.





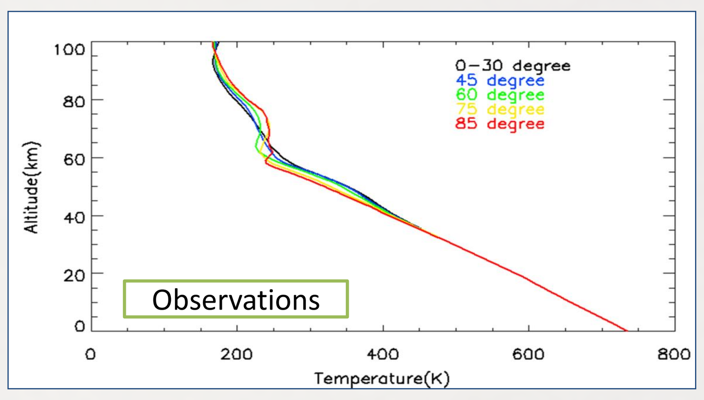


Fig.10(top-left). The difference of the temperature lat-alt distribution between with and without the C/E scheme.
Fig.11(top-right). Temperature lat-alt distribution with the process calculated after a Venusian day.
Fig.12(bottom-right). Observed vertical profiles of the temperature at each latitude [Seiff et al., 1985].

4.CONCLUSION

-Summary-

- We introduced a condensation/evaporation scheme of the sulfuric acid aerosols into the VGCM developed by Ikeda [2011].
- We reproduced the distribution of the cloud which is consistent with previous observations. Especially, total opacity is similar to observations [Kuroda, 2013].
- There are possibility of overestimation of the effect of the latent heat.
- We should think more about initial conditions.

-Future Suggestions-

-Growth Rate-

- In current our scheme, sulfuric acid evaporates immediately with the undersaturation.
- If we can evaporate the particles gradually with the growth rate, we may get more realistic results.
- Growth rate is written as:

$$\frac{dr}{dt} = \frac{D}{r}\frac{\rho_{CO_2}}{\rho_{H_2SO_4}}\frac{e-e_s}{e_s}$$

-Chemical Reactions-

- To derive more realistic sulfuric acid profile, we should consider about chemical reactions(Fig.13).

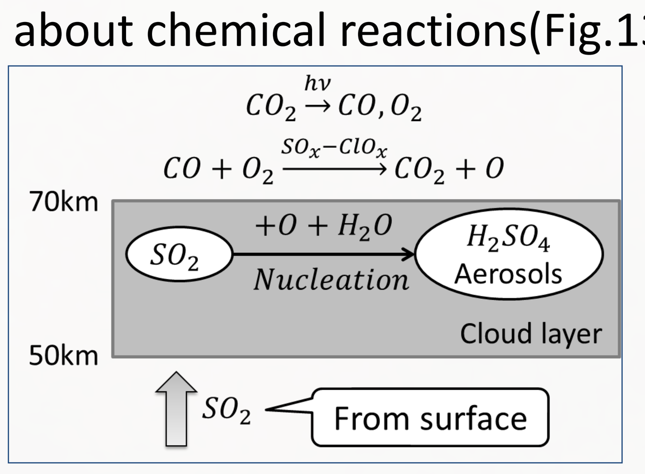


Fig.13. Cloud formation process

-Cloud Radiation-

- Our C/E scheme is not linked to the scheme of radiation yet.
- By connecting to the radiation scheme, we can get more realistic change of the temperature.

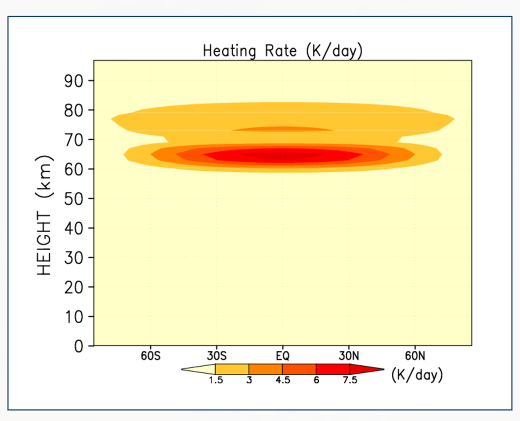


Fig.14. Heating rate by short wave [Ikeda, 2009]