Warming of early Mars induced by CO_2 ice clouds :

Estimations of cloud condensation flux, column density and radius by a one-dimensional radiation model

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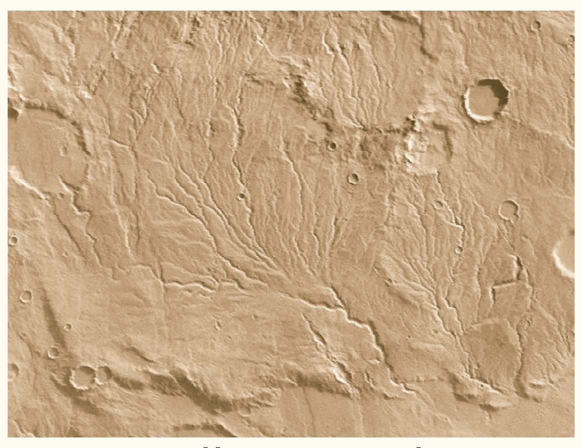
1. Introduction: The faint young sun paradox on Mars

Present : cool and dry climate

Major component : CO_2
Atmospheric pressure : 0.006 atm
Surface temperature : 216 K
liquid water not to exist stability



Valley networks

38 Gyr ago : warm and wet climate

Major component : CO_2 (photochemical stability)
Valley networks exist : Denser atmosphere and higher surface temperature enough for liquid water to exist stably

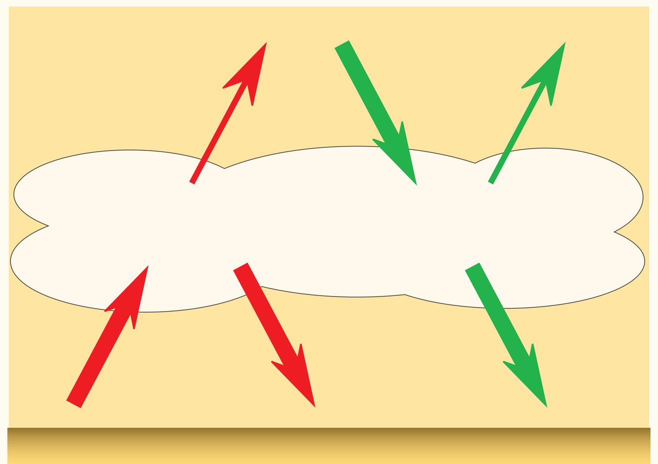
Young Sun was dark. "The faint young sun paradox"

Earth: Explainable if CO_2 pressure had been higher (Kuhn and Kasting, 1983)
Mars: Unexplainable because upper limit exists in atompspheric pressure. (Kasting,1991)

- 1-D radiative - convective model (CO_2 - H_2O atmosphere)
- Consider vertical temperature construction changed by atmospheric condensation. (But he neglected the radition processes of clouds)
- The surface freazing and collapse condensation couse if atmospheric pressure more than the upper limit.

2. The scattering greenhouse effect of CO_2 ice clouds

Pierrehumbert and Erlick (1998)



If the backward scattering of the planetary radiation is larger than that of solar radiation by the clouds, we can expect climate warming.

Scattering greenhouse effect of cloud

Cloud particle radius : 10 ～ 20 μm
(they can effectively reflect IR radiation)
Climate warming strongly

Previous studies (Mischna et al. 2002; Yokohata et al. 2002; Colaperete and Toon, 2003)

- The level of the greenhouse effect strongly depends on cloud parameters (particle radius and column density)
- Climate become warm for appropriate values of cloud parameters

However

- The particle radius dependency of surface temperature has not been examined
- Feasibility of the such values has not been examined

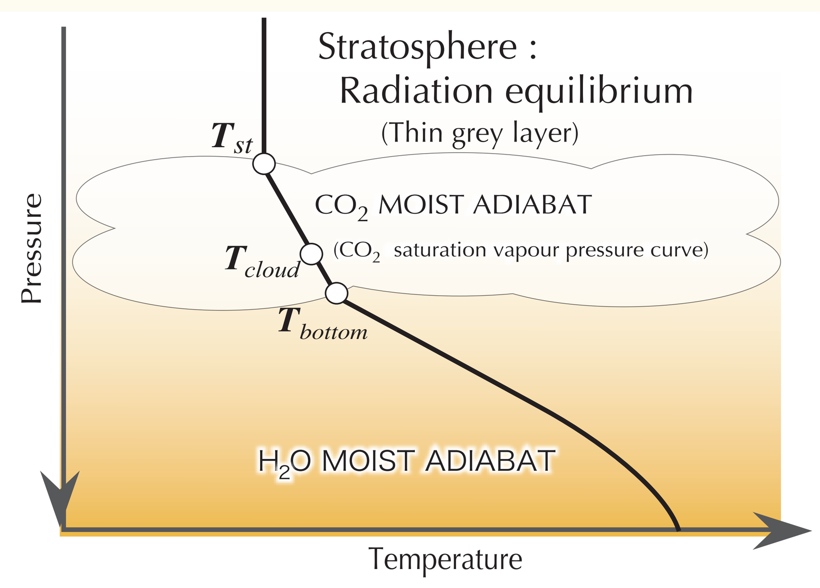
Goal of this study :

Investigation of radius dependency on surface temperature

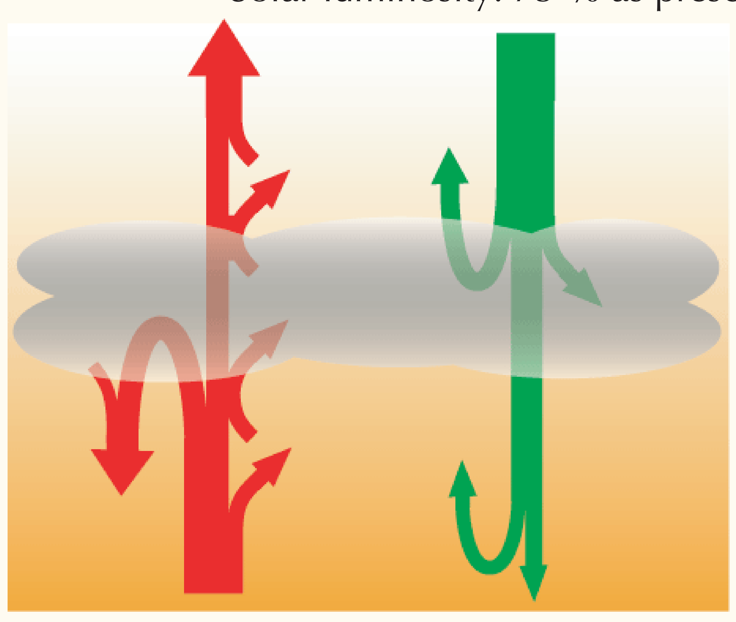
Estimations of the column density and particle radius

3. The vertical construction and 1-D radiative transfer model

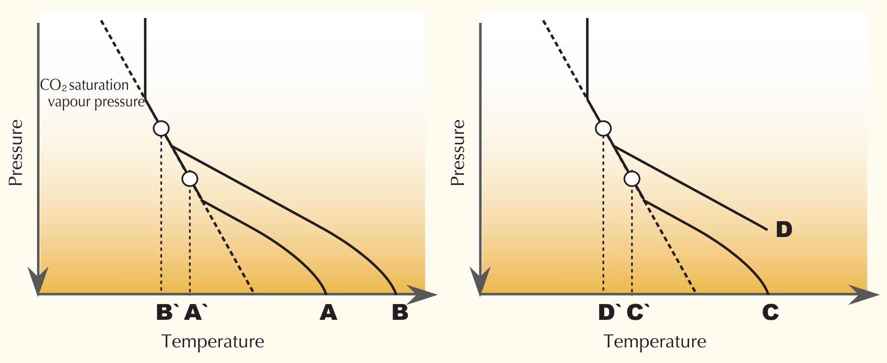
Atmospheric components : CO_2, H_2O



Solar luminosity: 75 % as present



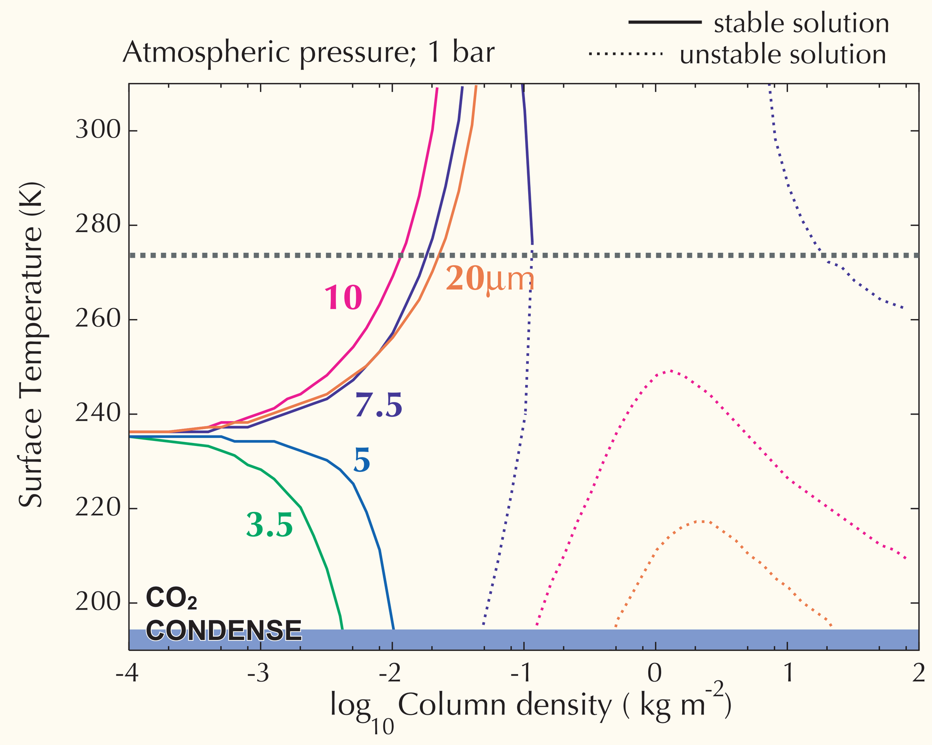
Surface albedo: 0.216



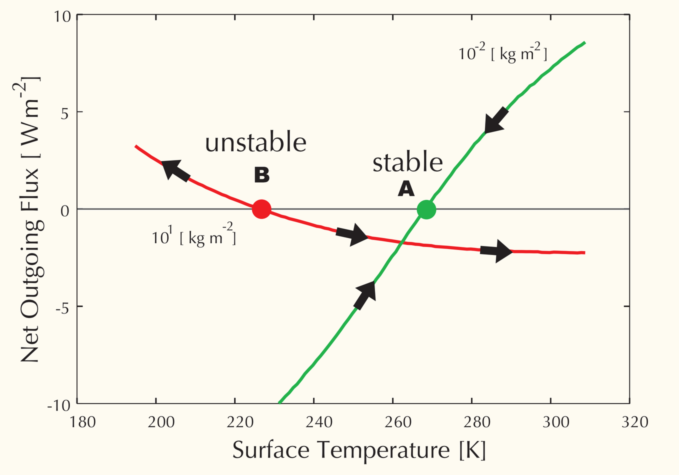
Cloud layer : Delta-edington approximation
Cloud particle : Mie theory (assuming spherical particles)
Complex indices of CO_2 ice (Warren, 1986)
Gas : the random model
band parameters (Houghton, 2002)
Gas-only layer : Two-stream approximation
Line-by-line method (CO_2, H_2O)
absorption line parameters (HITRAN2000)

4. Results and Discussion

4.1 Surface temperature under radiative balance - the particle radius dependency -



- 5 μm: anti-greenhouse effect
7.5 μm - 20 μm: greenhouse effect, the column density > 10^{-1} kg m^{-2} ; unstable solution



4.2 Condensation flux; energy flux of atmospheric condensation

Net radiative cooling energy in cloud layer

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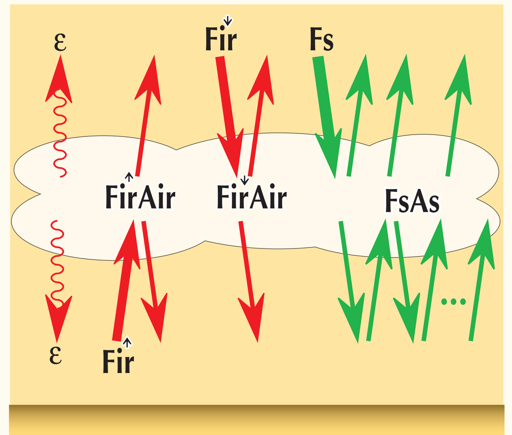
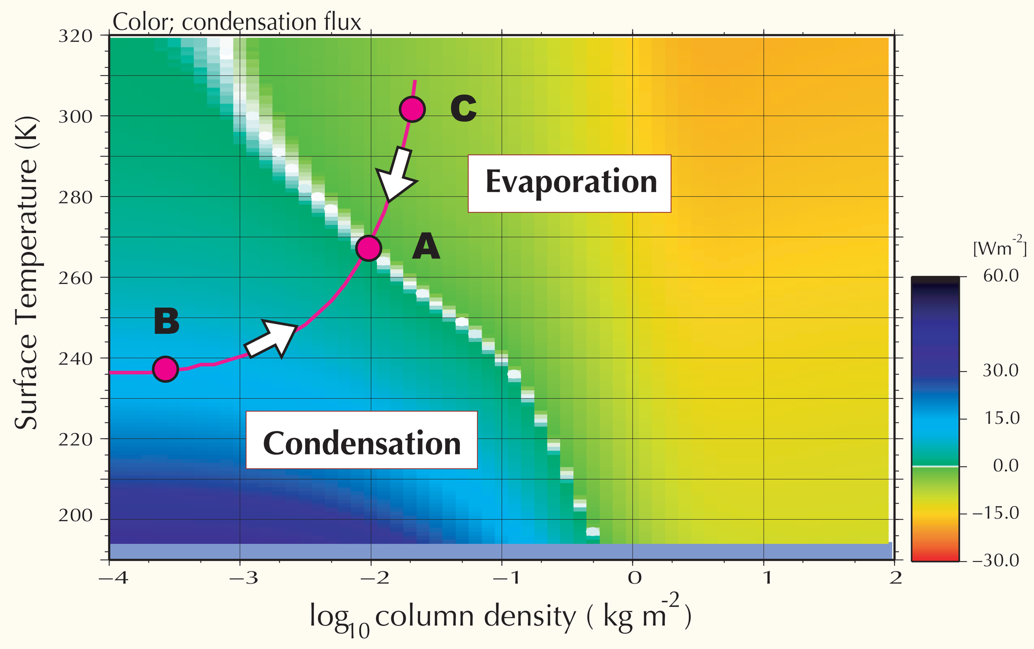
Condensation flux

$F_L = 2\varepsilon$ - (Fir↓ + Fir↑) Air - FsAs

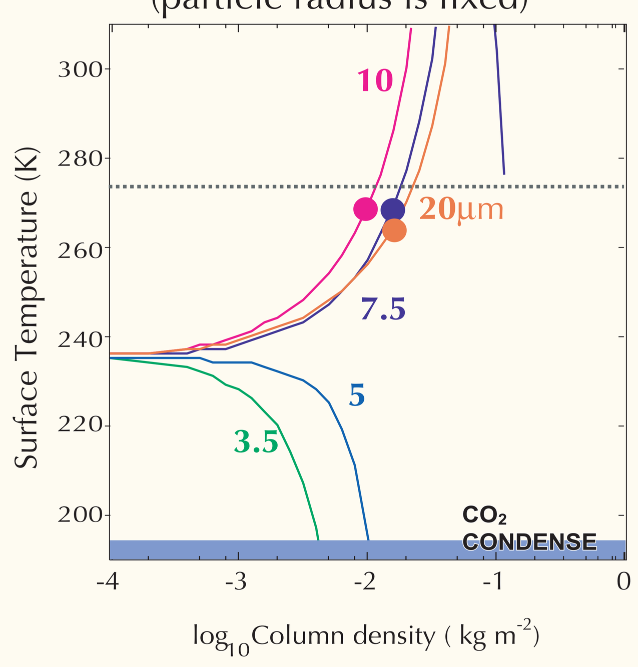




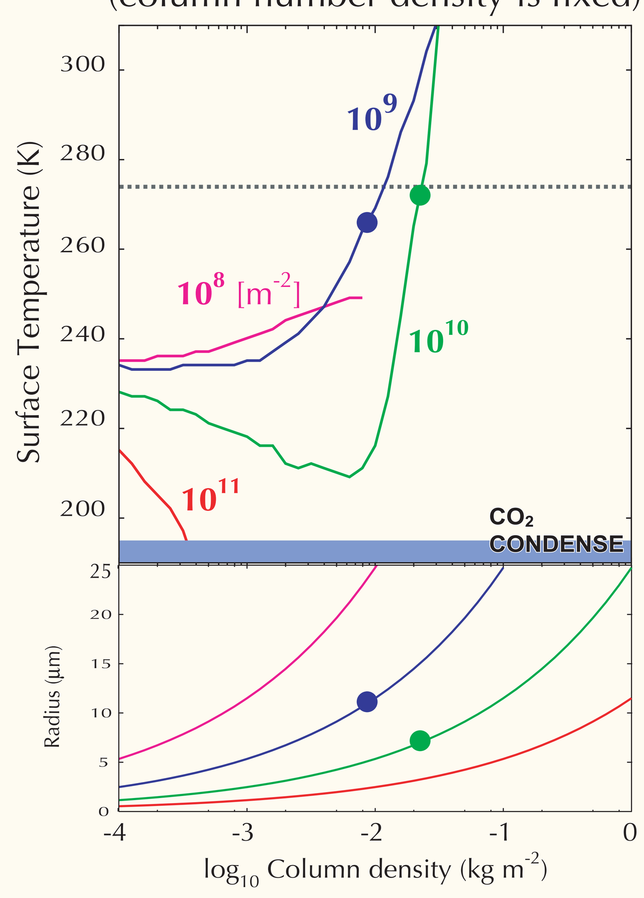
- Condensation flux decreases when surface temperature and column density increase
- Negative feedback mechanism of codensation flux for cloud column density change makes climate stable
- condensasion-evaporation equilibrium is archived (But, neglect particle radius changed by condensation)
- Under this equilibrium the cloud column density and particle radius have a relationship (they were treated independent parameters !)

4.3 Estimations of the column density and particle radius by condensation flux

1) Neglect particle radius changed (particle radius is fixed)



2) Consider particle radius changed (column number density is fixed)



Particle radius 7.5 ～ 20 μm or
Column number density 10^9 ～ 10^{10} m^{-2} ;

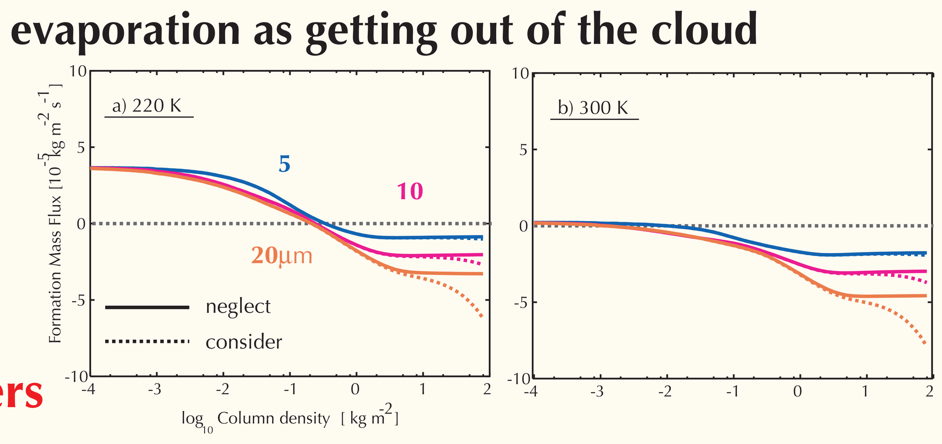
Surface temperature ～ 270 K

4.4 The column density decreases by evaporation as getting out of the cloud

Estimation by Yokohata et al. (2002)

- Neglect vertical distribution of density
- Particles go down by Stokes settling velocity

This effect poor influences on estimations of cloud parameters



5. Conclusion

We estimate the level of the greenhouse effect and the cloud parameters by the 1-D radiation model under CO_2-H_2O atmosphere which is assumed as early Martian atmosphere.

Negative feedback mechanism of codensation flux for changing in cloud column density makes climate stable.

- We can estimate the column density as the function of the particle radius or the column number density
- When atmospheric pressure is fixed as 1 bar,
  - \+ Column density 1.0 x 10^{-2} kg m^{-2} : (@ radius 10 μm) surface temperature 268 K
  - \+ Column density 2.0 x 10^{-2} kg m^{-2} : (@ column number density 10^{10} m^{-2}) surface temperature 270 K
- These estimations do not changed when we consider the column density decreases by evaporation as getting out of the cloud.

The minimum requisites to induce the warm and wet climate :
Atmospheric pressure is more than about 1 bar, the column number density nearby equals to 10^9 ～ 10^{10} m^{-2}