Japanese-French model studies of planetary atmospheres
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Radiation model development and its use for exoplanets

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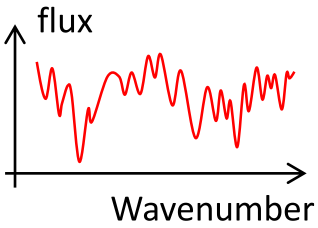
1. Introduction

Radiative transfer model is a fundamental tool to clarify planetary environment

<u>Spectral analyses of radiation from a planet</u>
which give us information about temperature and composition of its atmosphere

→ a high resolution spectral calculation is required

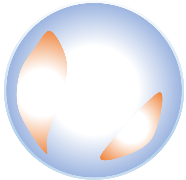


Estimate composition: e.g. Kreidberg et al., 2014

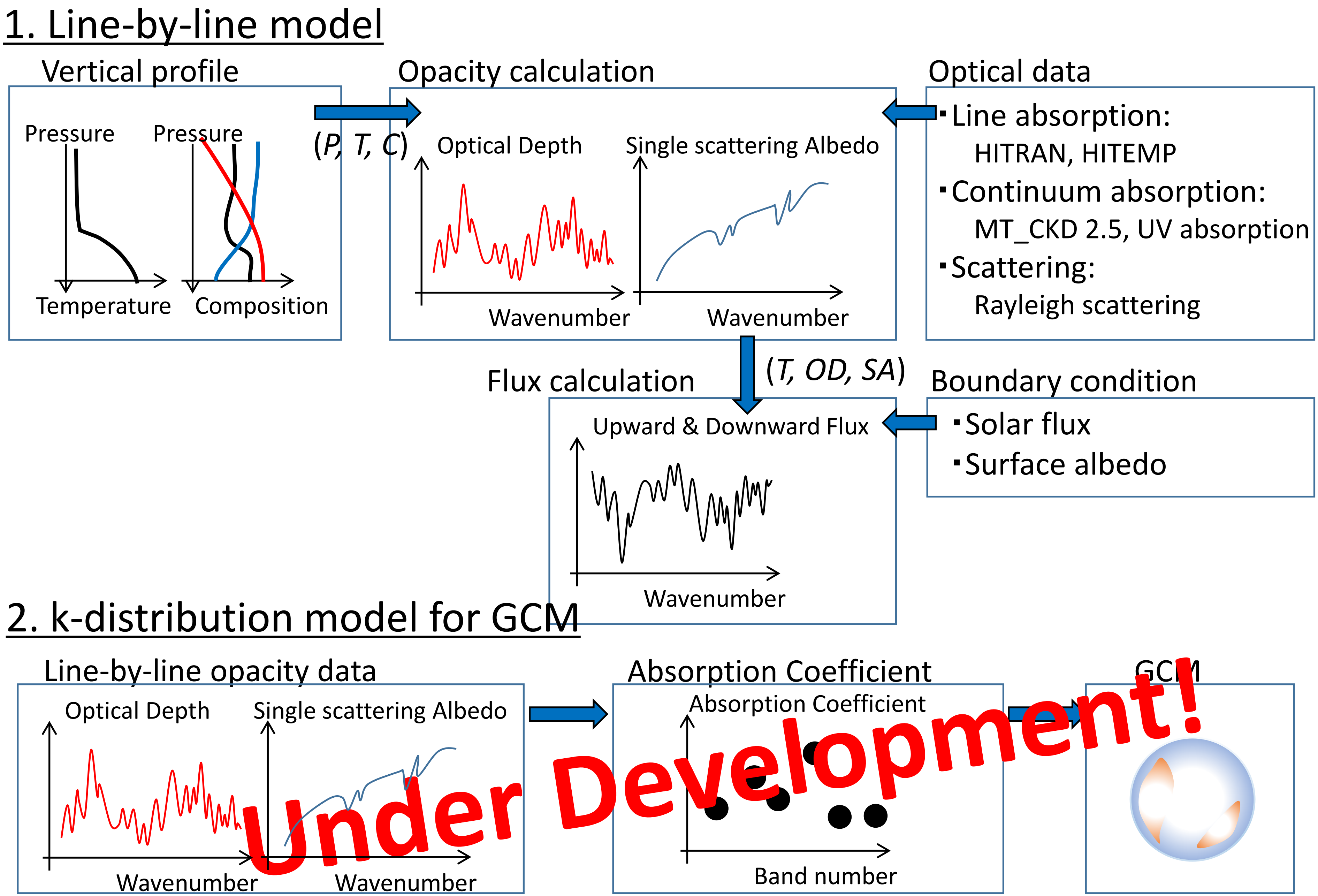
<u>Energy budget calculations</u>
with which we can proceed to discuss such as circulation of an atmosphere and evolution of a planet

→ a high speed calculation covering a wide spectral range is required

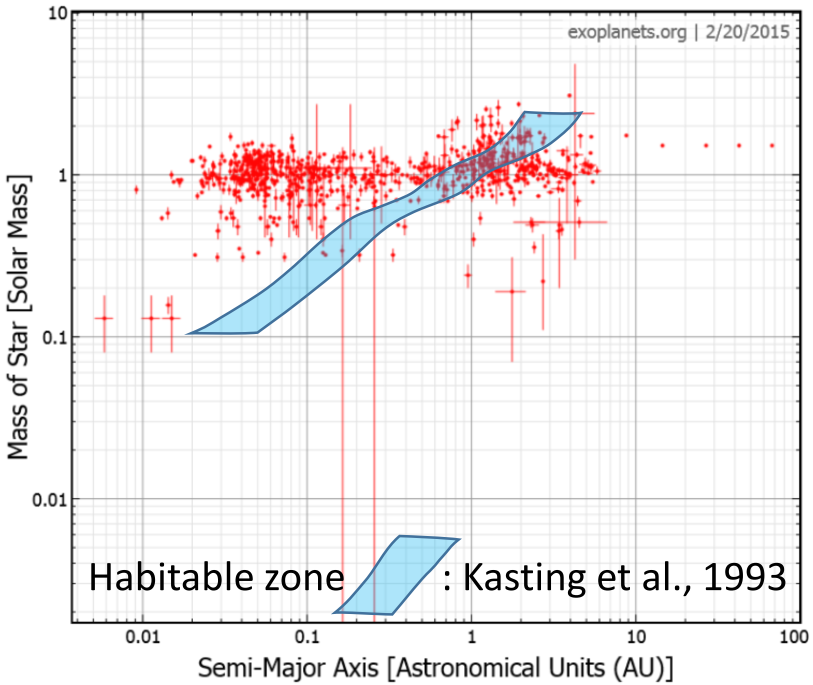
Habitable zone: e.g. Kopparapu et al., 2013
Planetary evolution: e.g. Hamano et al., 2013



2. Model Overview



Tropopause of steam atmosphere and inner edge of habitable zone



Inner edge of habitable zone:

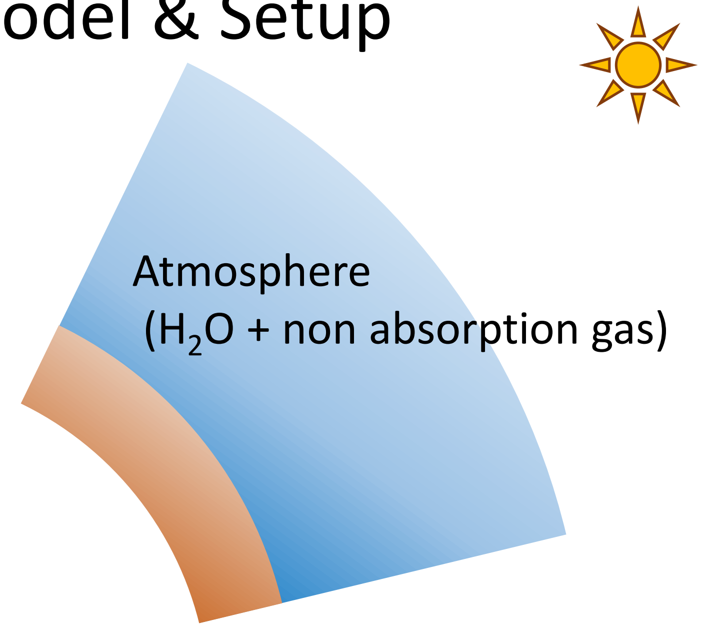
1. Runaway greenhouse limit:
   net solar irradiance = radiation limit
2. Water loss limit:
   a planet has ocean as long as 4.6 billion yr.

- Kasting+1993: 0.95AU
- Kopparapu+2013: 0.99AU

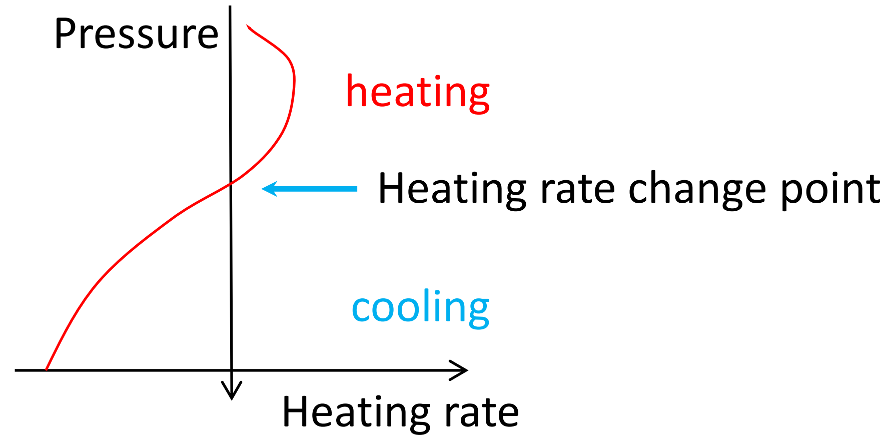
The model stratosphere was taken to be isothermal at 200K; this assumption has negligible effect on the runaway greenhouse limit but may have a significant effect on the "water loss" limit. (Kasting+1993)

We are trying to estimate tropopause temperature by 1-D lime-by-line model.

Model & Setup



Estimate of tropopause



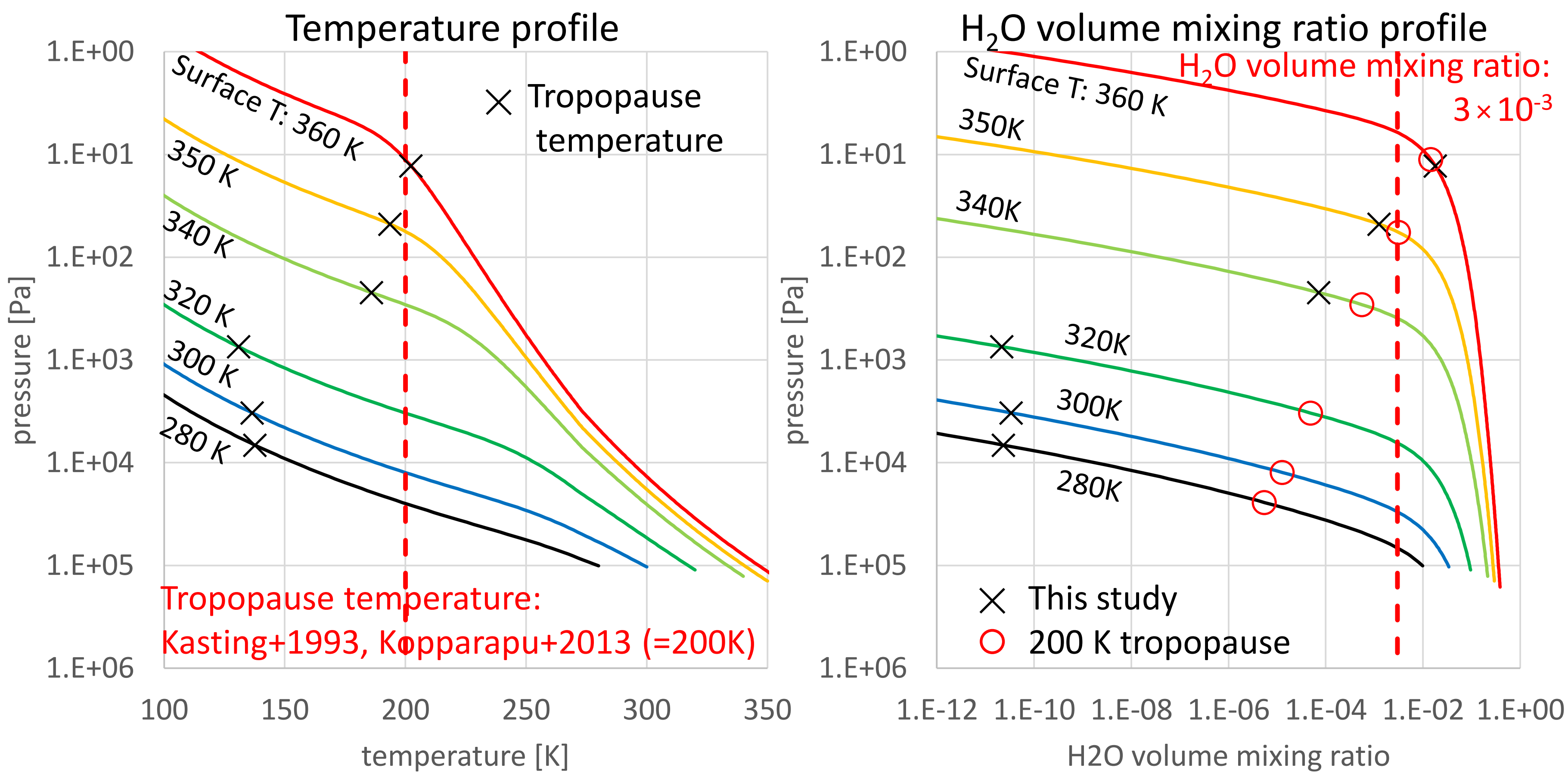
Temperature profile
H_2O mixing ratio profile
→
Optical depth
Single scattering albedo
→
Radiation budget
Heating rate

- H_2O + non-absorption gas (10^5 [Pa])
- Convective atmosphere up to TOA
- Moist pseudoadiabatic lapse rate
- Surface temperature:
  280, 300, 320, 340, 350, 360 [K]

- Line absorption:
  HITRAN 2008
- Continuum absorption:
  MT_CKD 2.5, Chan et al., 1993
- Rayleigh scattering cross section:
  Goldblatt et al., 2013

- Solar irradiance:
  5800[K] black body
- Surface albedo:
  0 – 3000cm-1: 0.0
  > 3000cm-1: 0.2
- Wavenumber range:
  0 – 100000cm-1

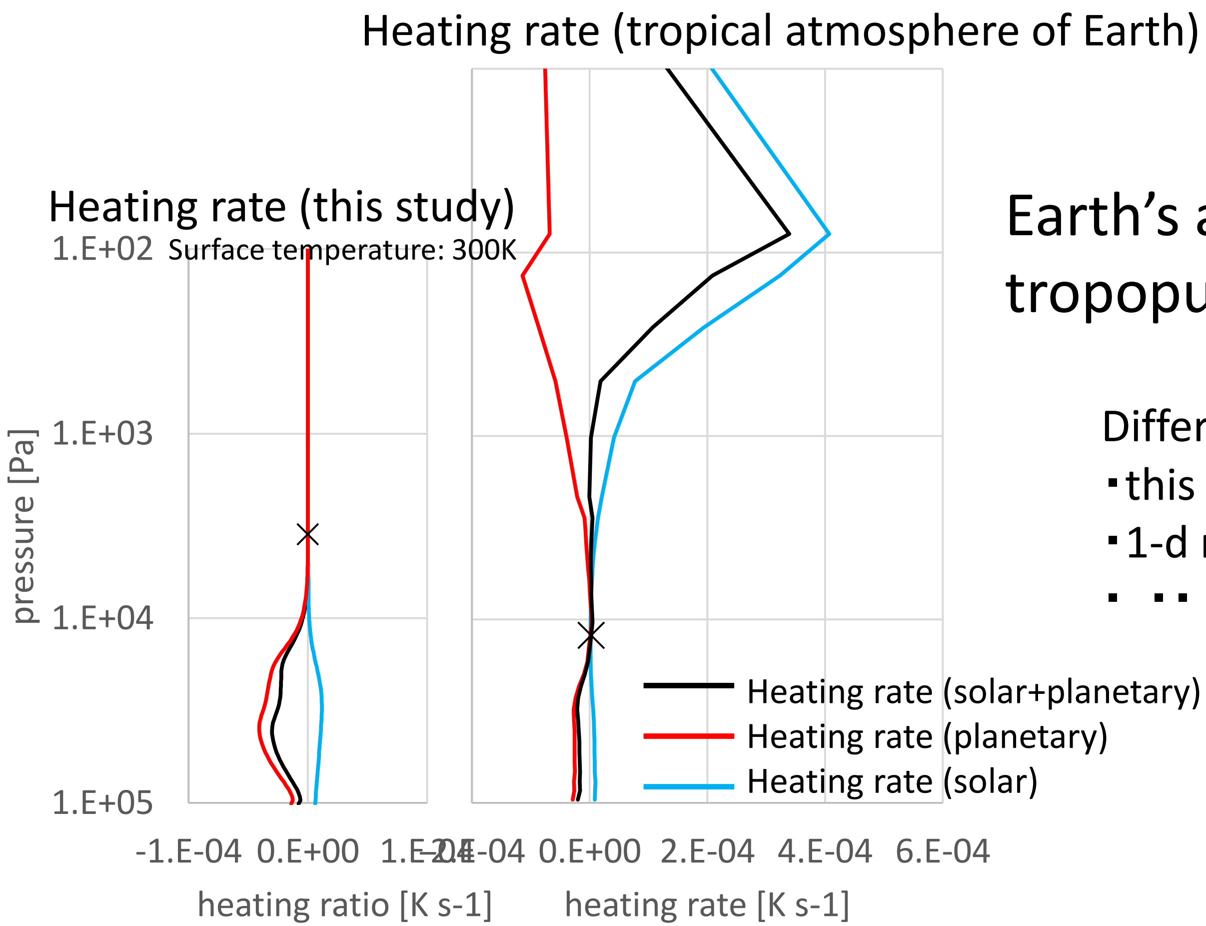
Results: Estimate of tropopause temperature & mixing ratio



Water loss limit is estimated near the previous studies.

We have been developing k-distribution model and trying to calculate 1-D radiative convective profiles.

Comparison of Earth atmosphere

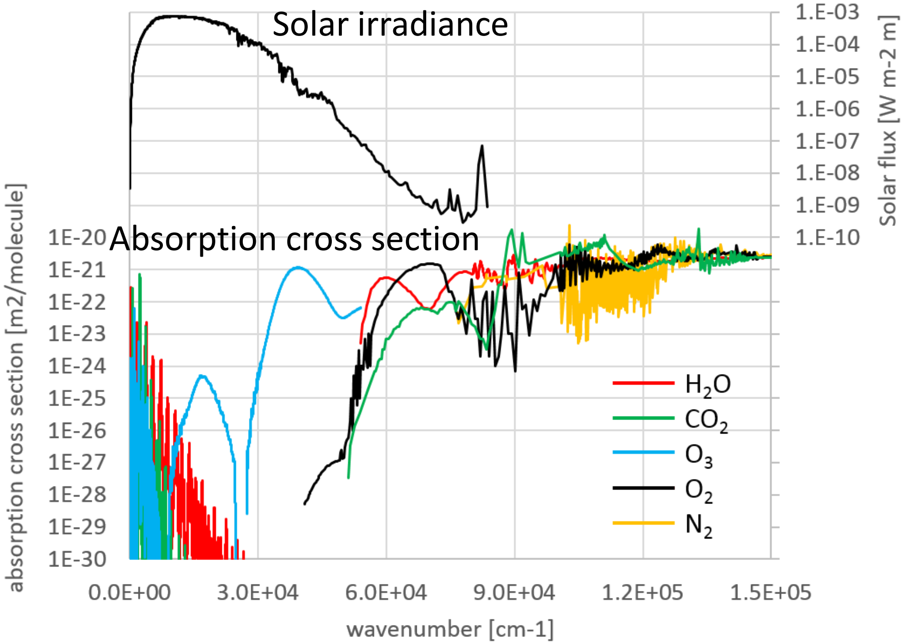


Earth's atmosphere has lower tropopuase than this study.

Different points between both:

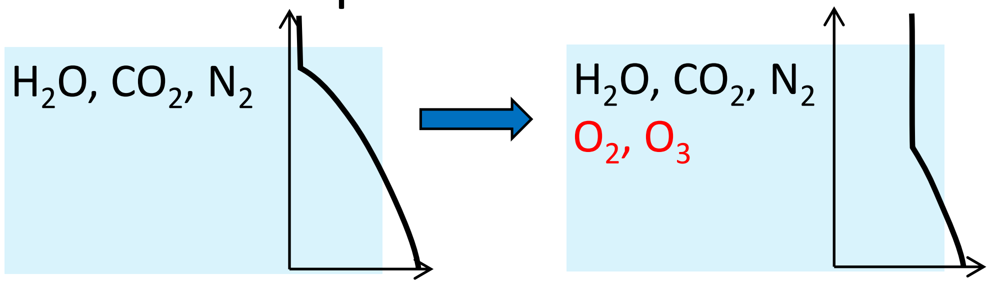
- this study is lack of O_3
- 1-d model and 3-d Earth
- ・・・

Atmospheric evolution and tropopause level

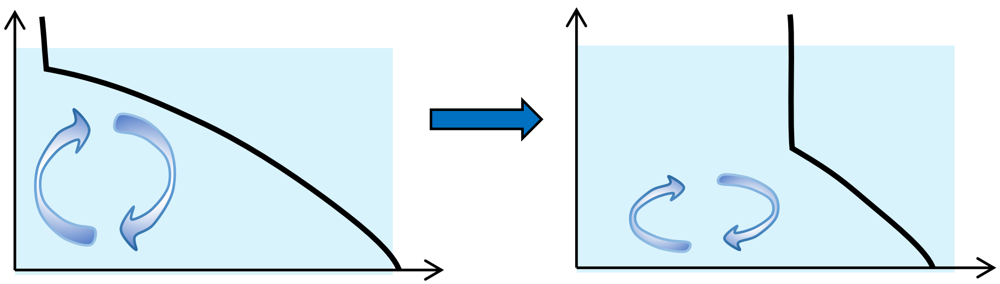


Solar radiation: NREL, 2000 ASTM Standard Extraterrestrial Spectrum Reference E-490-00
H_2O: HITRAN2008, MT_CKD2.5, Chan+1993
CO_2: HITRAN2008, MT_CKD2.5, Cairns&Samson 1966, Cook&Metzger 1964, Edward et al., 1953, Thompson et al., 1963
O_3: HITRAN2008, MT_CKD2.5
O_2: Hudson 1971, Cook&Metzger 1964, Watanabe&Marmo 1956, Nagata&Todomatsu 1973
N_2: Hudson 1971, Cook&Metzger 1964, Watanabe&Marmo 1956

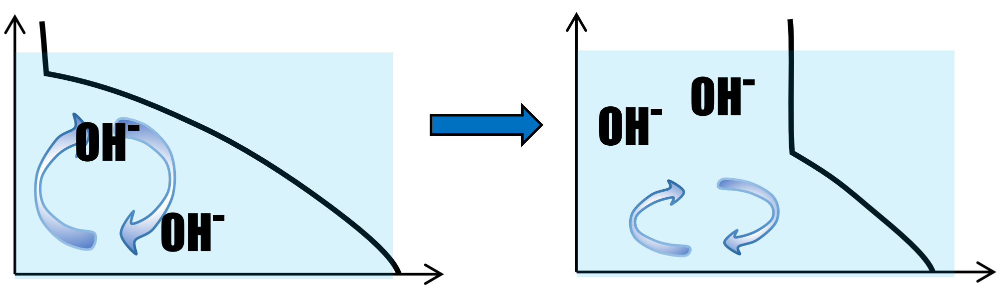
Atmospheric evolution



1. General circulation is modified?



2. Chemical radical is well mixed?



4. Summary

- We have been developing a radiative transfer model for exoplanets.
  - Line-by-line model and k-distribution model for GCM (under development)

- The model is applied to exoplanet atmosphere.
  - We estimate tropopause temperature of convective atmosphere by 1-D line-by-line model.
  - Tropopause temperatures are lower than 200K as in surface temperature is lower than 340 K.
  - Water loss limit is estimated near the previous studies.