A Simple Spectral Model for Earth's Albedo

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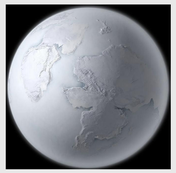
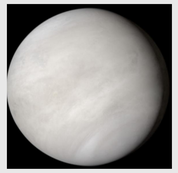
Introduction



Snowball Earth

Current Earth



Runaway Greenhouse

How does planetary albedos change between these limits?

Here we use **spectrally-resolved** reasoning to propose a simple model for the albedo of an Earth-like atmosphere, and validate it using line-by-line calculations.

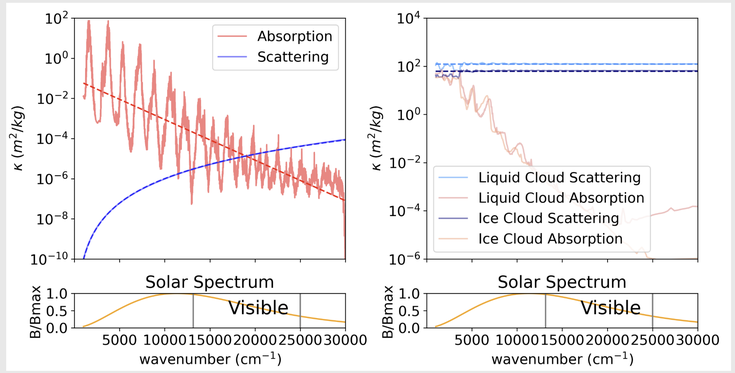
Core Approach

Assume the atmosphere is a 1-D column in RCE, which consists of 1 bar N_2 and saturated H_2O

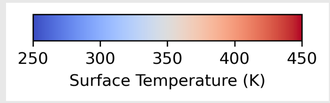
For every single wavenumber, we suggest that:

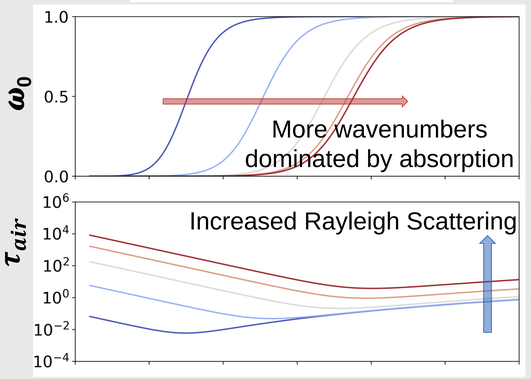
- cloud-free atmosphere is approximately either perfectly absorbing (due to water vapor absorption) or perfectly scattering (due to Rayleigh scattering) in the shortwave spectrum
- clouds are approximately perfect scatterers throughout the shortwave

H_2O Cross-section **Cloud Cross-section**



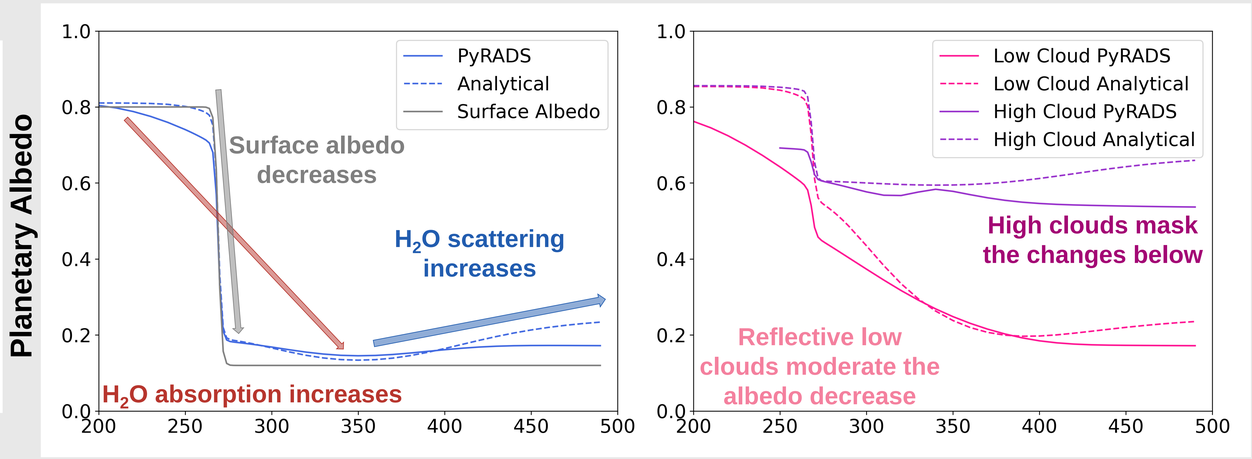
Absorption dominated **Scattering dominated** **Scattering dominated**





ω_0: Single Scattering Albedo

Results



Our Simple Spectral Model

Planetary albedo is the **spectral average** of the monochromatic albedo

$$\alpha_p = \frac{\int \alpha_\nu(\nu)\, B_*(\nu)}{\int B_*(\nu)}$$

Single layer atmosphere (Clear-sky)

Purely Absorbing $(\omega_0 \approx 0)$

$$\alpha_\nu = \alpha_{abs} = \alpha_s e^{-\frac{\tau_{air}}{\mu}\frac{\tau_{air}}{1/2}}$$

Purely Scattering $(\omega_0 \approx 1)$

$$\alpha_\nu = \alpha_{sca} = 1 - (1-\alpha_s)\frac{\left(\frac{1}{2}+\gamma\mu\right)+\left(\frac{1}{2}-\gamma\mu\right)e^{-\frac{\tau_{air}}{\mu}}}{1+\gamma(1-\alpha_s)\tau_{air}}$$

- Boundary Condition at TOA :
  Direct solar radiation is μS, no downward diffuse flux
- RTE in the Purely Absorbing / Scattering Atmosphere
- Boundary Condition at Surface :
  The surface albedo is α_s

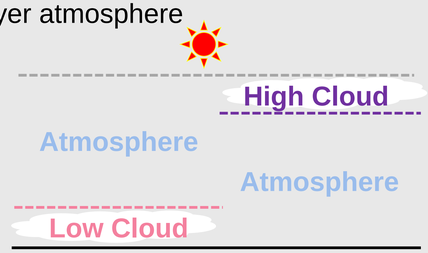
$$\alpha_s = 0.46 - 0.34 \tanh \frac{T_s - 269.15K}{2K}$$

- Optical Thickness:

$$\tau_{air} = WVP \times (\kappa_{H_2O,abs} + \kappa_{H_2O,sca}) + AP \times \kappa_{N_2,sca}$$

Double layer atmosphere (Cloud)

Add a purely scattering cloud layer **either on top of or at the bottom of** the single layer atmosphere



New Boundary Conditions:
The continuity of radiation fluxes at the interface

LBL Calculation

LBL Model: PyRADS-shortwave
Cloud

- Low Clouds: The cloud base fixed at 0.9 surface pressure level, liquid
- High Clouds: The cloud top fixed at a constant temperature of roughly 225 K (fixed anvil temperature hypothesis), solid

Take Home Message

- Although based on simple assumptions, this analytical model can successfully capture the behaviors of planetary albedo from the snowball to the steam limit.
- For present-day Earth, barring the change of cloud cover and content, this model predicts the planetary albedo should decrease as surface warms, which is testable through satellite observation.