1. Radiation and optical depths

A satellite is viewing a cloud (optical depth τ_c) above a surface at temperature T_{surf} at a wavelength where the atmosphere is transparent and non scattering.

(a) What is the radiance observed by the satellite for a cloud at a constant temperature T_{cloud}? How optically thick does the cloud have to be before only 5% of the radiance is a contribution from the surface? (Hint: Consider the Schwarzschild equation with a constant cloud source function B_{cloud})

(b) The temperature variation is small, so the Planck function can be linearised ($B = B_0 + B_1 \Delta T$). If the temperature in the cloud varies linearly ($\Delta T = \alpha \tau$), what is the observed radiance?

(c) If the cloud is optically thick ($\tau_c >> 1$), what is the effective emitting temperature of the cloud? What optical depth does this correspond to?

(d) (Extra points) How does this change for a cloud with an arbitrary emission profile $B_{cloud}(\tau) = f(\tau)$?

2. The Venusian atmosphere

The solar constant on Venus is about twice that for Earth, at 2,626 $\mathrm{Wm^{-2}}$ but it's bond albedo is larger (0.76). It has a similar surface gravity (8.88 $\mathrm{ms^{-1}}$), but the atmosphere is composed primarily of CO_2 ($c_p = 830\mathrm{J\ kg^{-1}K{-}1}$).

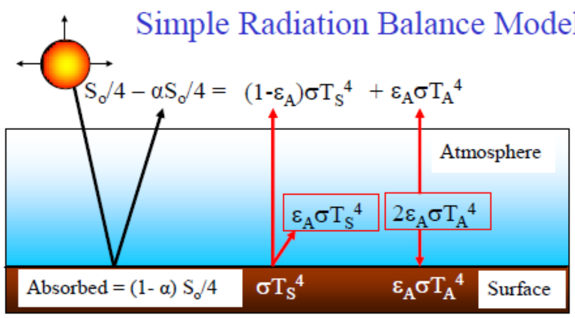
(a) What is the equilibrium emitting temperature (T_E) of Venus?

(b) Calculate the temperature of the stratosphere (assuming it is optically thin)

(c) What is the lapse rate?

(d) The surface temperature is 730K, how high is the tropopause? How does this compare to Earth?

3. A simple radiative balance model



(a) Using sensible values (for Earth) of ϵ_A (0.8), S_0 (1361 $\mathrm{Wm^{-2}}$) and α (0.3), estimate T_A and T_S for this simple model of the atmosphere

(b) Calculate the surface emission

(c) Estimate the "effective radiating emissivity" ϵ', the emissivity required for the outgoing longwave radiation (OLR) to be equal to $\epsilon' \sigma T_S^4$.

Increasing CO_2 leads to a radiative forcing of $\Delta F_{CO_2} = 5.35 \ln(CO_2/CO_2^{initial})$

(d) Calculate the new OLR immediately after doubling CO_2

(e) What is the new ϵ' and what change in T_S is required to restore net balance at the TOA?

(f) What sort of feedbacks might be operating in this system? How could you express them mathematically?