The global energy balance

ATM2106

Today's topics

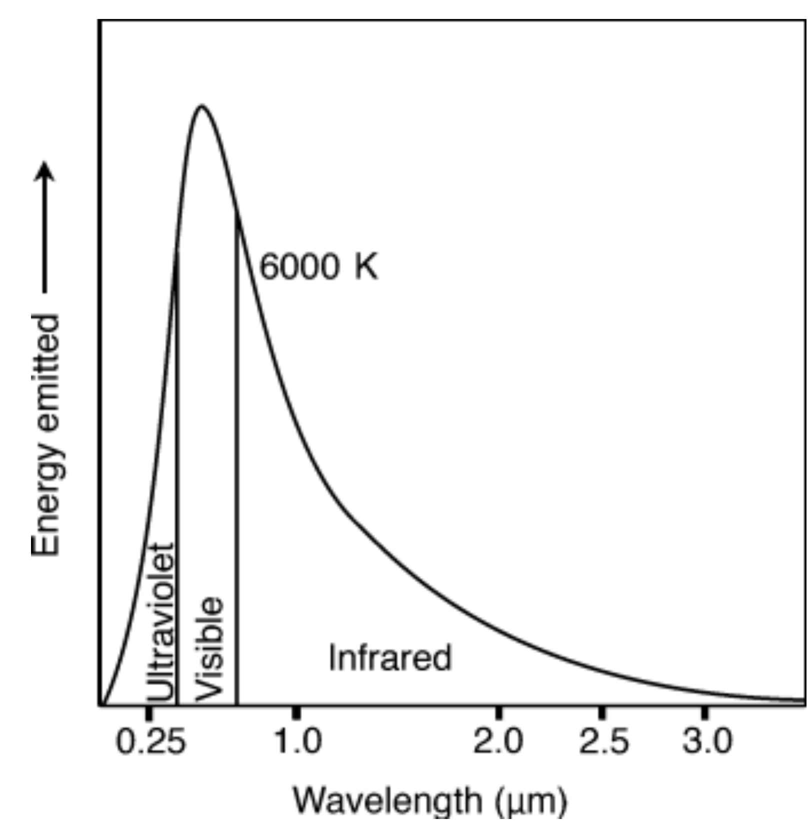
- Planetary emission temperature
- The atmospheric absorption spectrum
- The greenhouse effect
- Climate feedbacks

1. Planetary emission temperature

- The energy that the sun emits : Q = 3.87 x 10^{26} W
- The solar constant : The flux of solar energy that the Earth receives

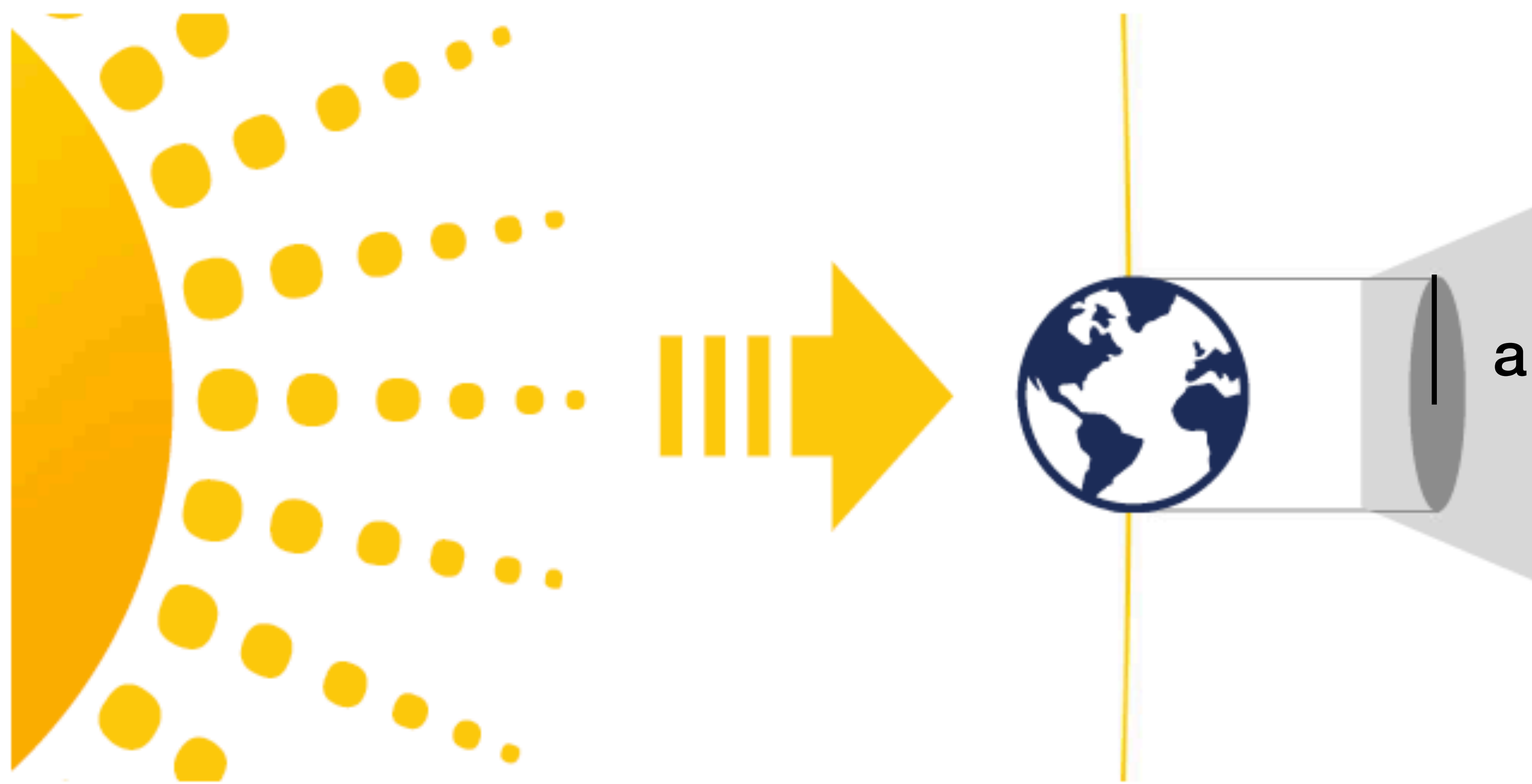
$$S_0 = Q/4\pi r^2$$

- On average, $S_0 = 1367 \text{ W m}^{-2}$
- The solar energy flux and wavelength



1. Planetary emission temperature

- Solar power incident on the Earth = $S_0 \pi a^2$ = 1.74 x 10^{17} W
- So, is this the amount of solar energy that the Earth absorbs?
- NO! A significant fraction is reflected.



1. Planetary emission temperature

- Albedo (α_p) : The ratio of reflected to incident solar energy
- On average,

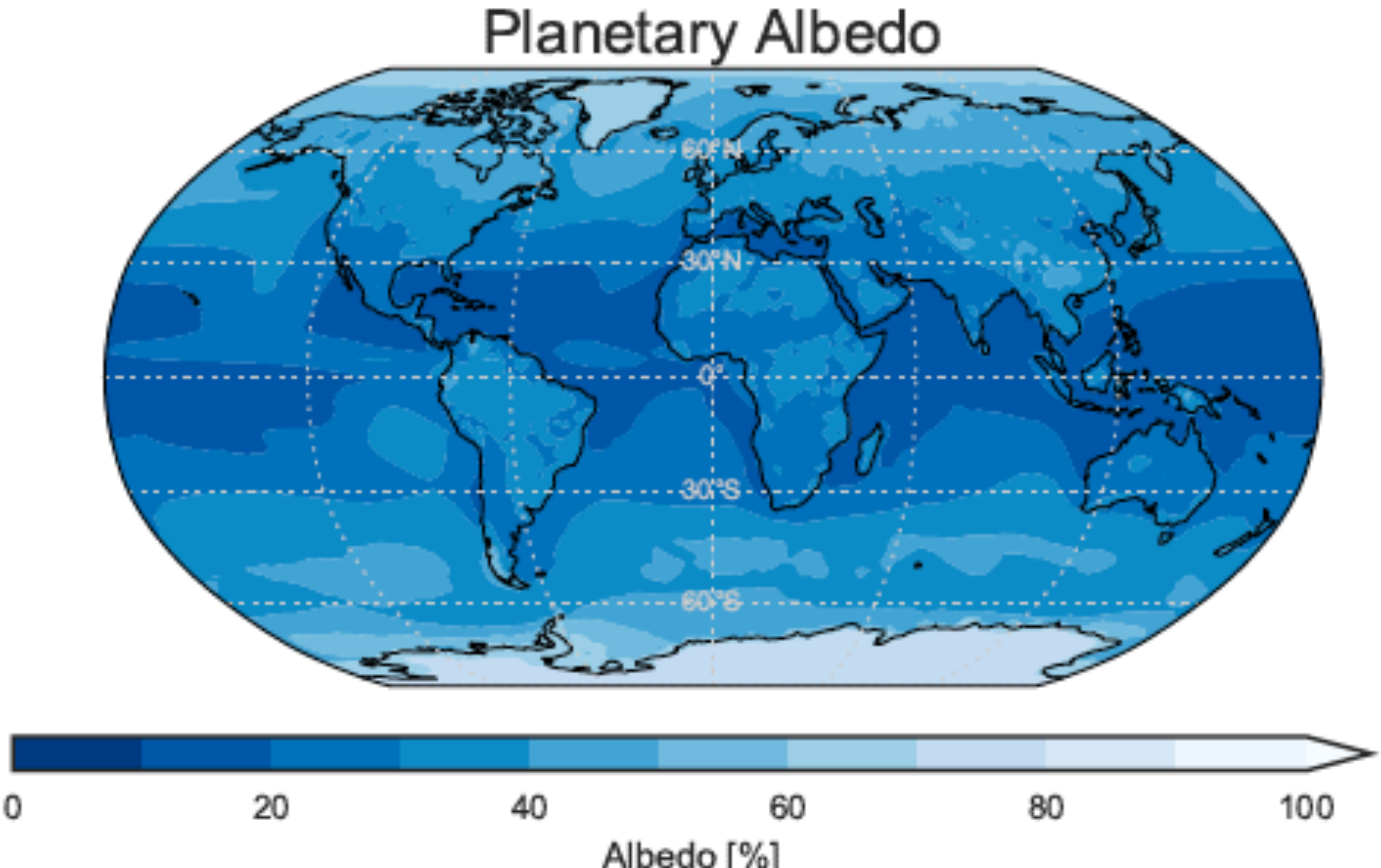
$$\alpha_p \approx 0.30$$

- It is called as the planetary albedo.
- Solar radiation absorbed by the Earth:

$$(1-\alpha_p)\, S_0 \pi a^2 = 1.22 \times 10^{17} W$$

TABLE 2.2. Albedos for different surfaces. Note that the albedo of clouds is highly variable and depends on the type and form. See also the horizontal map of albedo shown in Fig. 2.5.

Type of surface	Albedo (%)
Ocean	2–10
Forest	6–18
Cities	14–18
Grass	7–25
Soil	10–20
Grassland	16–20
Desert (sand)	35–45
Ice	20–70
Cloud (thin, thick stratus)	30, 60–70
Snow (old)	40–60
Snow (fresh)	75–95



Planetary Albedo
60°N
30°N
0°
30°S
60°S
0
20
40
60
80
100
Albedo [%]

1. Planetary emission temperature

- The first law of thermodynamics : Energy is conserved.

$$\frac{dT}{dt} = E_{in} - E_{out} = 0$$

- We know E_{in}
- What is E_{out}?
- Following Stefan-Boltzmann law, the radiative energy that the Earth emits per unit area is

$$\sigma T_e^4$$

$$\sigma = 5.67 \times 10^{-8}\ \mathrm{W\ m^{-2}\ K^{-4}}$$

1. Planetary emission temperature

- Total energy that the Earth emits:

$$E_{out} = 4\pi a^2 \sigma T_e^4$$

- Then by setting $E_{in} = E_{out}$, we can obtain the expression for the planetary emission temperature, T_e

$$T_e = \left[\frac{S_0 \left(1 - \alpha_p\right)}{4\sigma} \right]^{1/4}$$

- If we use numbers we know,

$$T_e \approx 255 \text{ K}$$

1. Planetary emission temperature

TABLE 2.1. Properties of some of the planets. S_0 is the solar constant at a distance r from the Sun, α_p is the planetary albedo, T_e is the emission temperature computed from Eq. 2-4, T_m is the measured emission temperature, and T_s is the global mean surface temperature. The rotation period, τ, is given in Earth days.

	r 10^9 m	S_0 W m^{-2}	α_p	T_e K	T_m K	T_s K	τ Earth days
Venus	108	2632	0.77	227	230	760	243
Earth	150	1367	0.30	255	250	288	1.00
Mars	228	589	0.24	211	220	230	1.03
Jupiter	780	51	0.51	103	130	134	0.41

$$T_e \approx 255 \text{ K}$$

Too cold!

2. The atmospheric absorption

- Wien's displacement law

$$\lambda_m T = constant$$

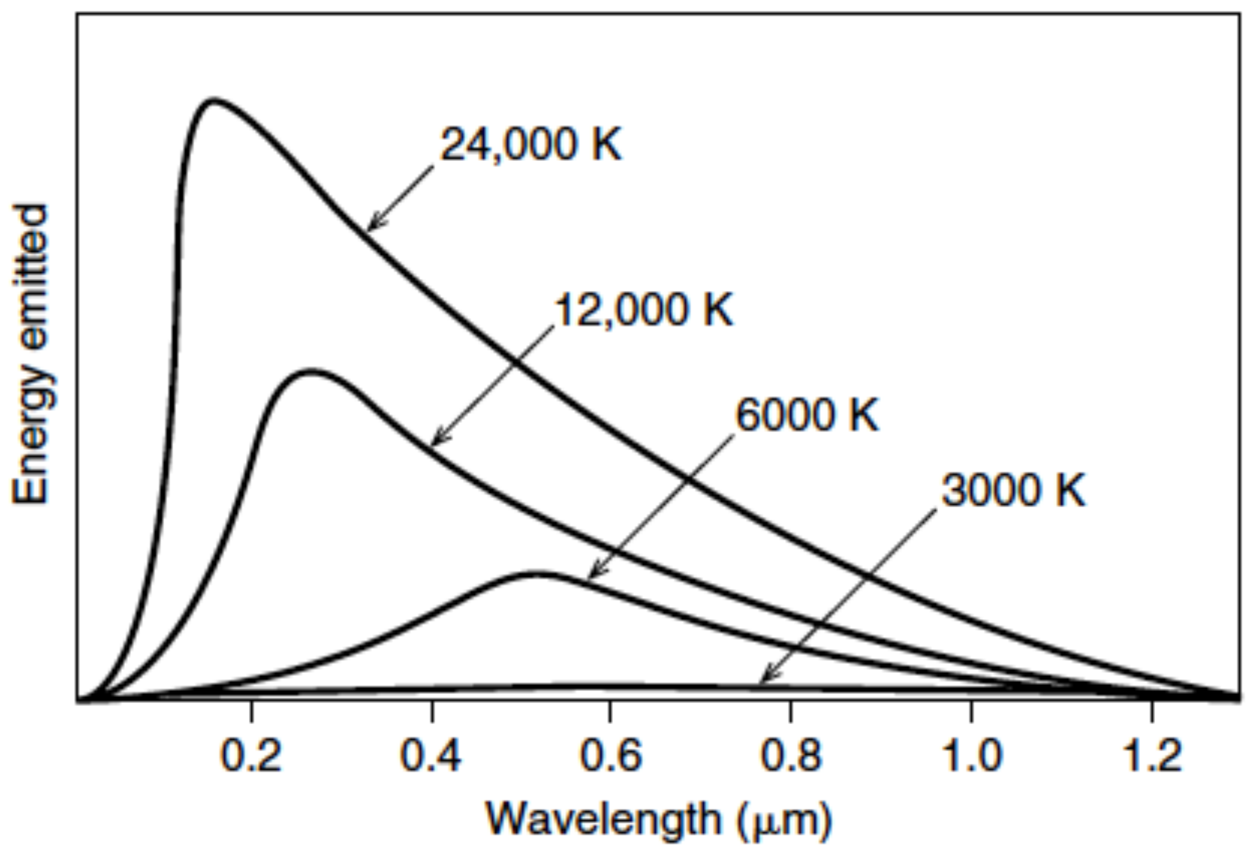
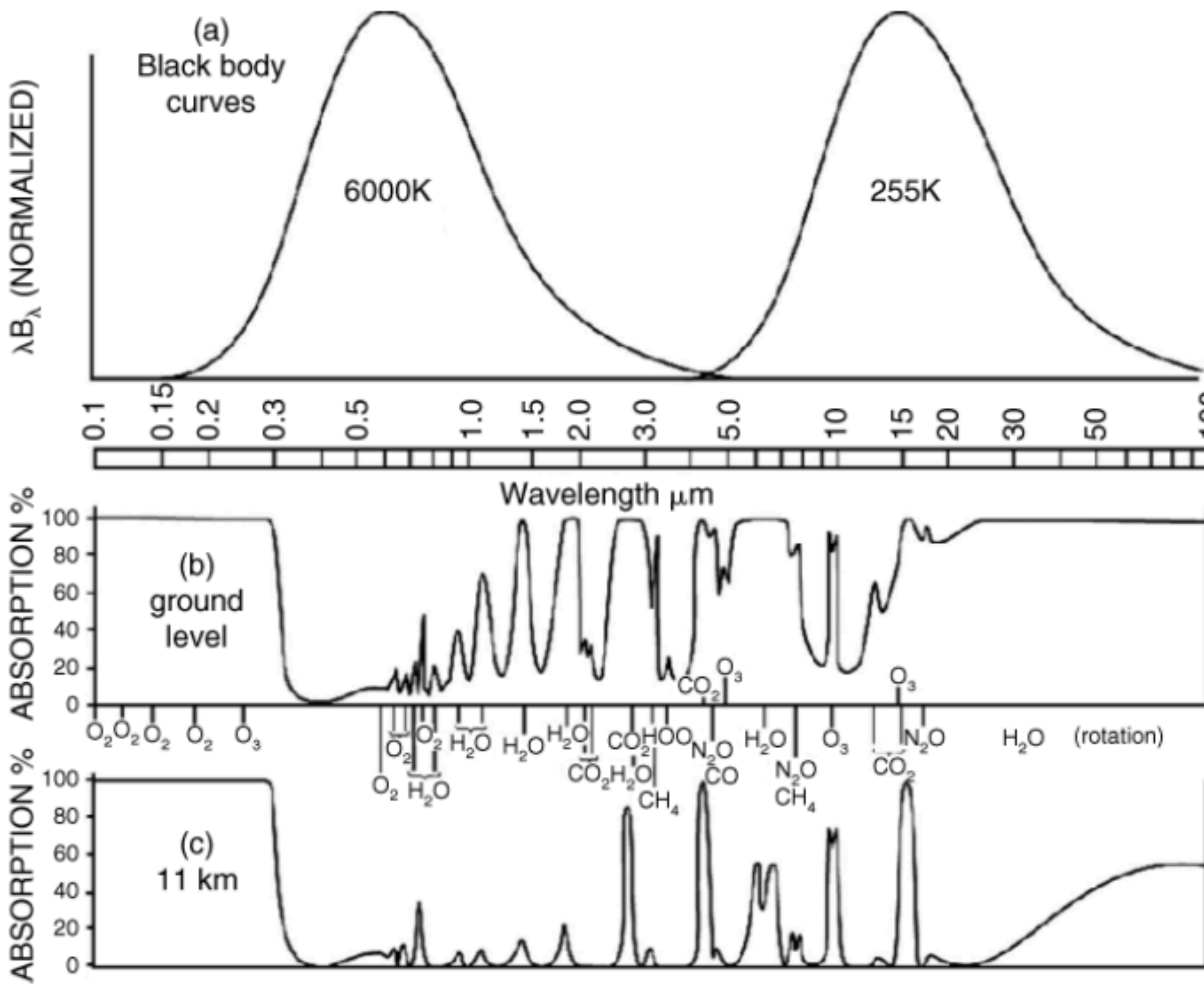


FIGURE 2.3. The energy emitted at different wavelengths for blackbodies at several temperatures. The function $B_\lambda(T)$, Eq. A-1, is plotted.

2. The atmospheric absorption



2. The atmospheric absorption

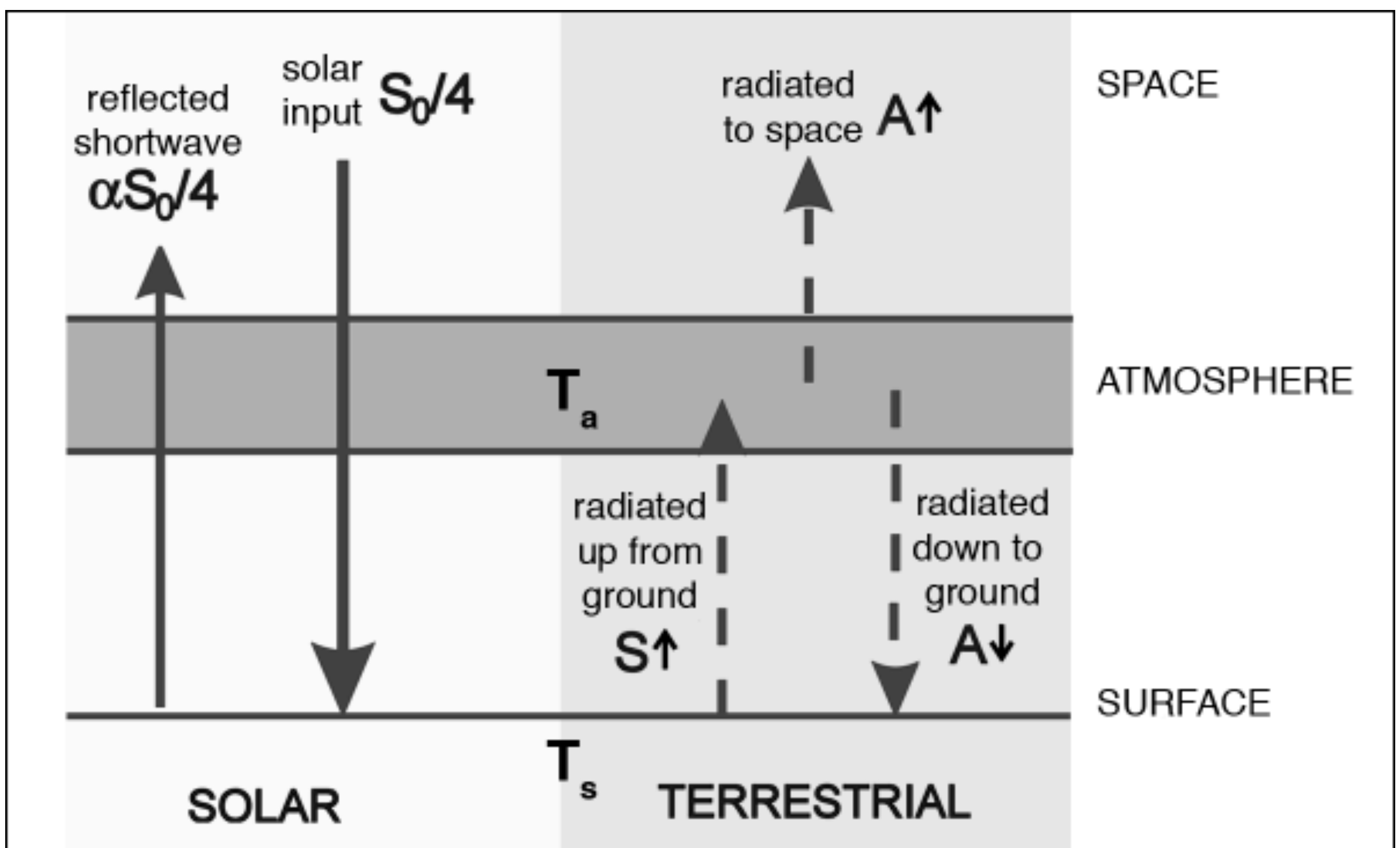
- The atmosphere is almost completely transparent in the visible spectrum.
- It is very opaque in the UV spectrum.
- The absorption of the IR spectrum by the atmosphere varies.
- Almost no contribution from N_2.
- O_2 absorbs in the UV (little solar energy) and near the IR spectrum.
- The absorption of the radiation occurs by triatomic molecules: O_3, H_2O and CO_2

3. The greenhouse effect

- The emission temperature is too cold! $T_e \approx 255\ \mathrm{K}$
- The atmosphere is not transparent to the IR.
- Much of the radiation from the surface will be absorbed by, mainly H_2O and comes back to the surface.
- Hence, the surface gets both solar radiation and longwave radiation from the atmosphere and is warmer than T_e.
- This is known as *the greenhouse effect*.

3. The greenhouse effect: a. An opaque model

- Assumption
  - Completely transparent to shortwave solar radiation
  - Completely opaque to outgoing longwave radiation

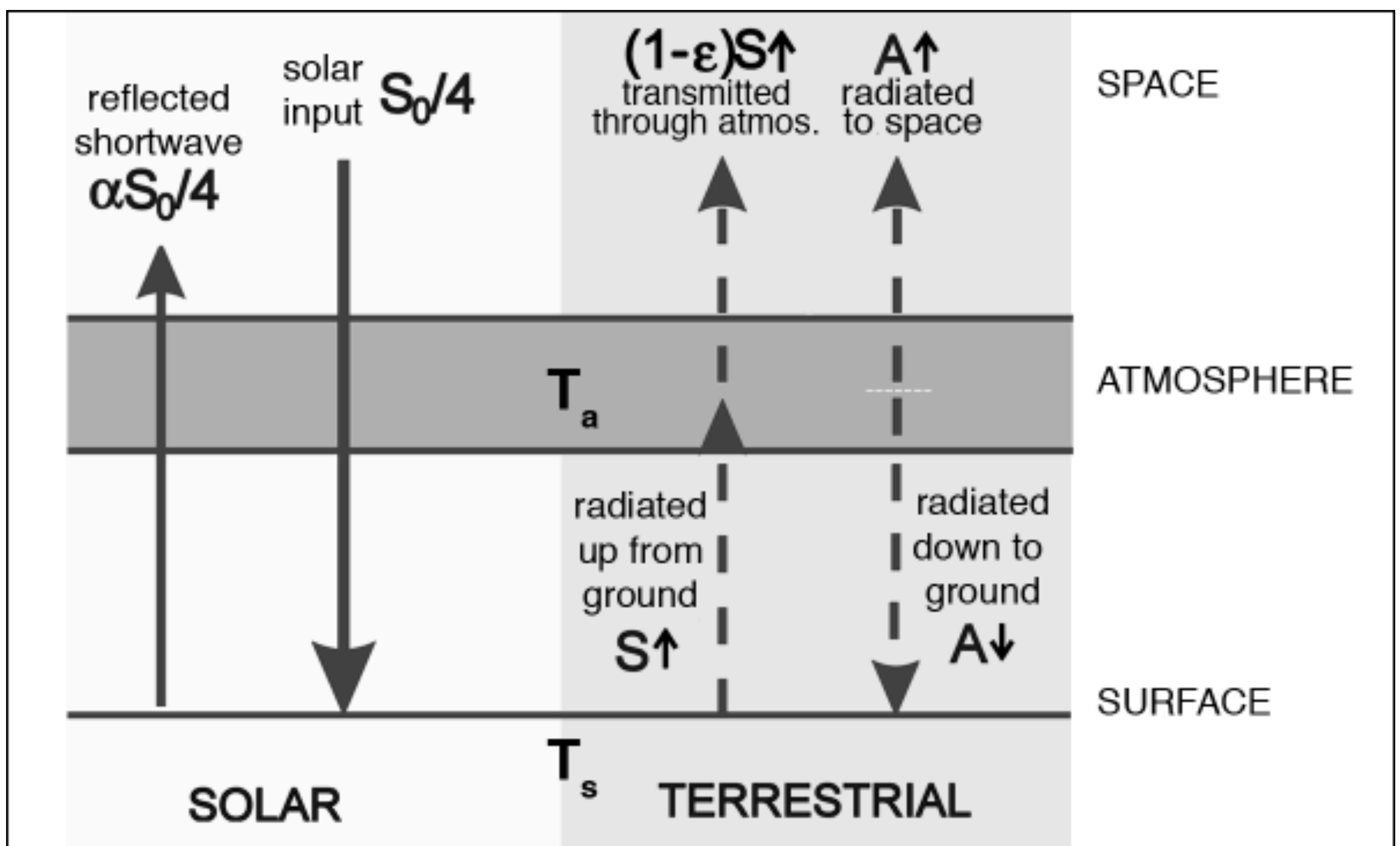


3. The greenhouse effect: a. An opaque model

- What is wrong with this model?
  - The atmosphere is not completely transparent to the solar radiation: typically 20~25% is absorbed by the atmosphere.
  - The atmosphere is not completely opaque to the outgoing longwave radiation.

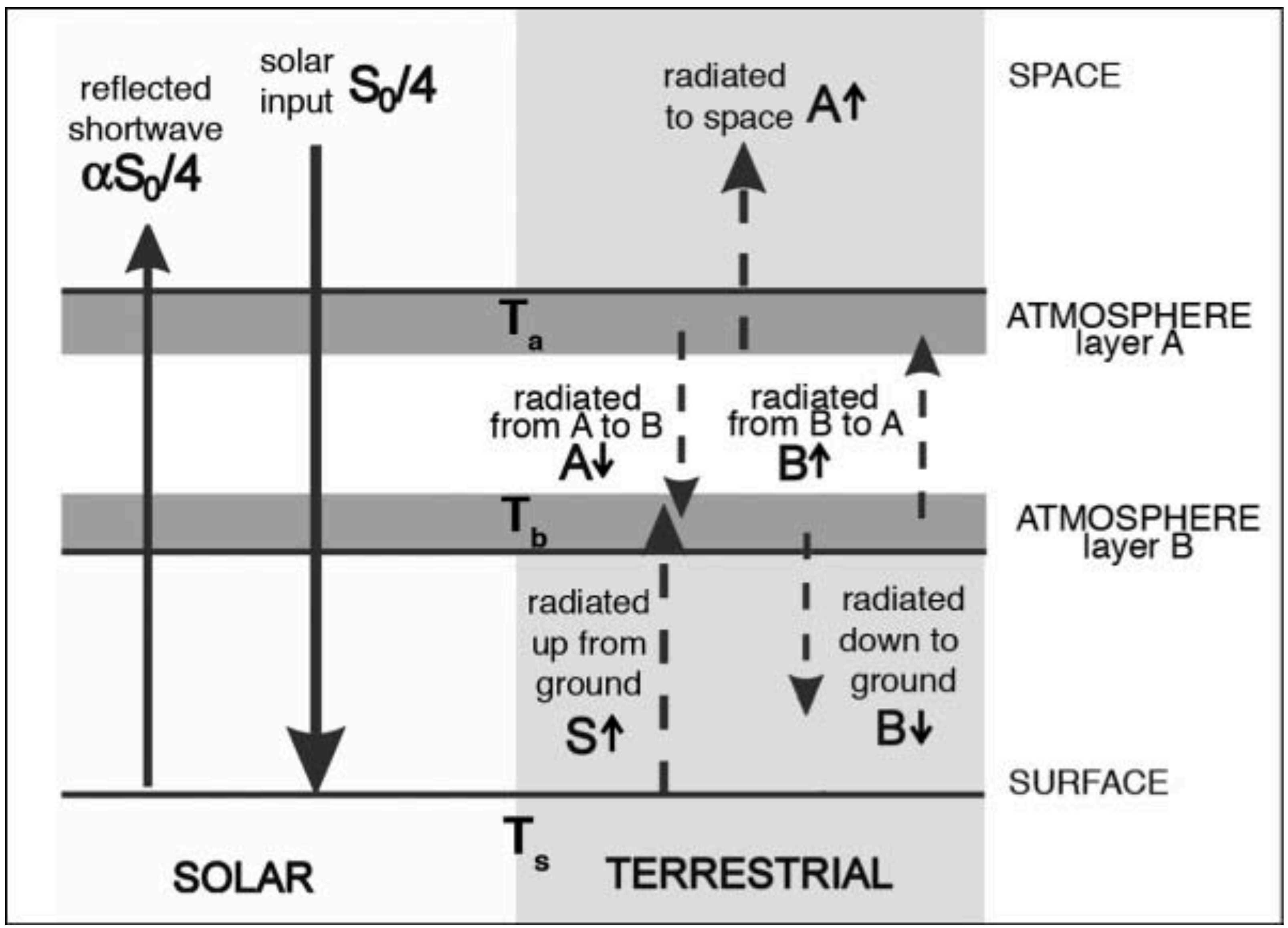
3. The greenhouse effect: b. A leaky greenhouse

- The absorptivity, ϵ
  - A fraction of IR that is absorbed by the atmosphere

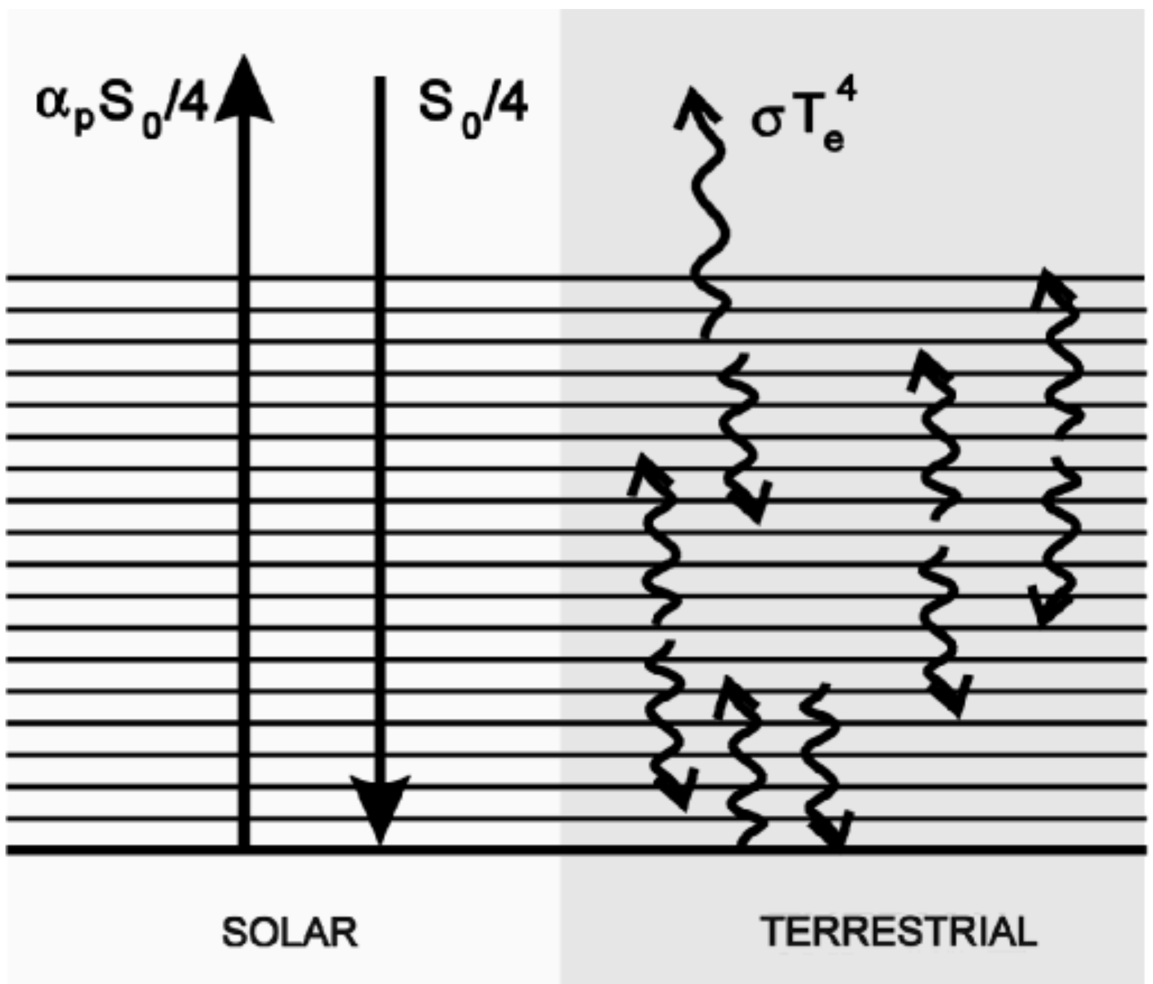


3. The greenhouse effect: d. A more opaque greenhouse

- A series of opaque atmospheric layers
  - An example with two opaque layers

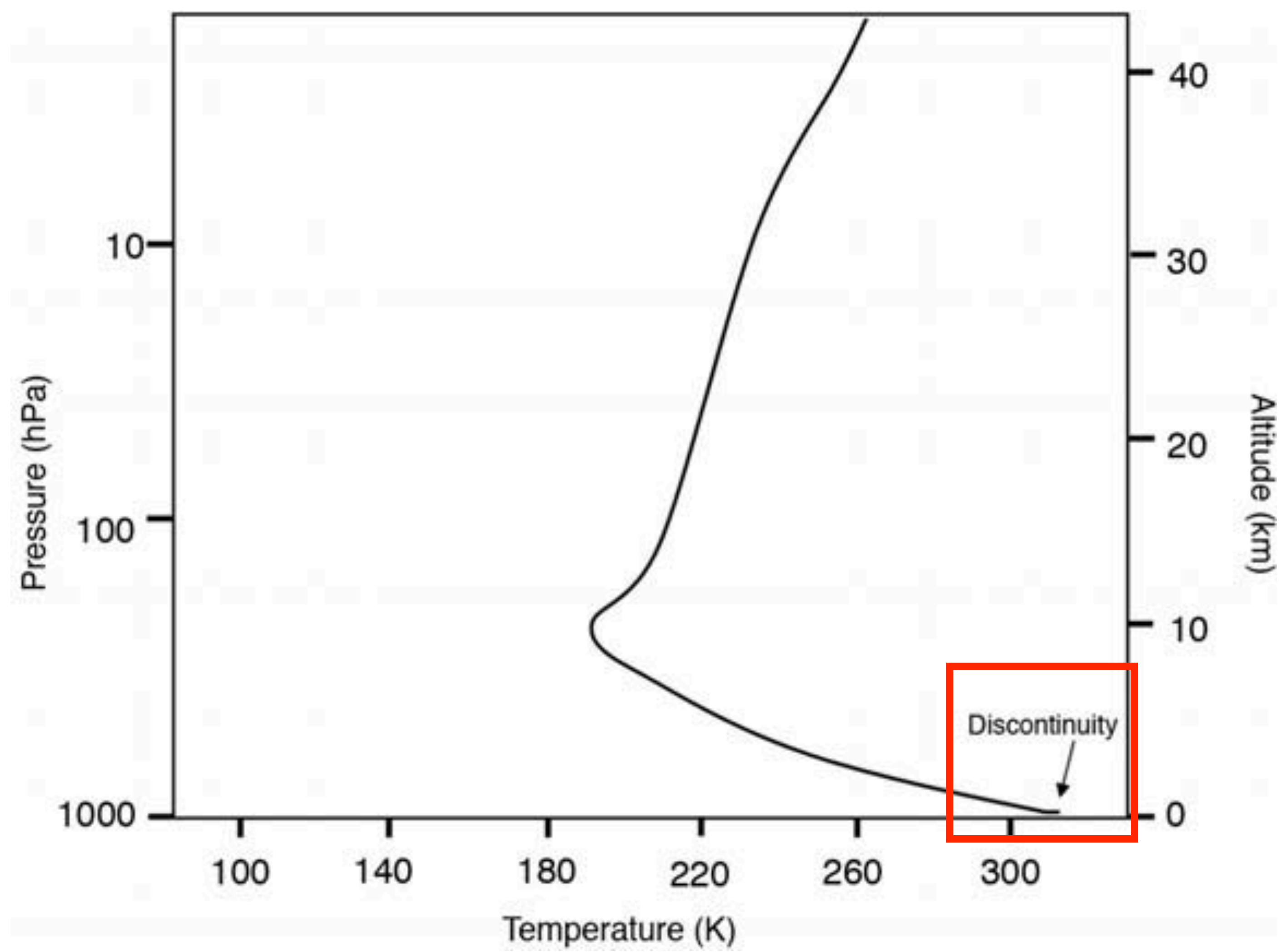


3. The greenhouse effect: d. A more opaque greenhouse



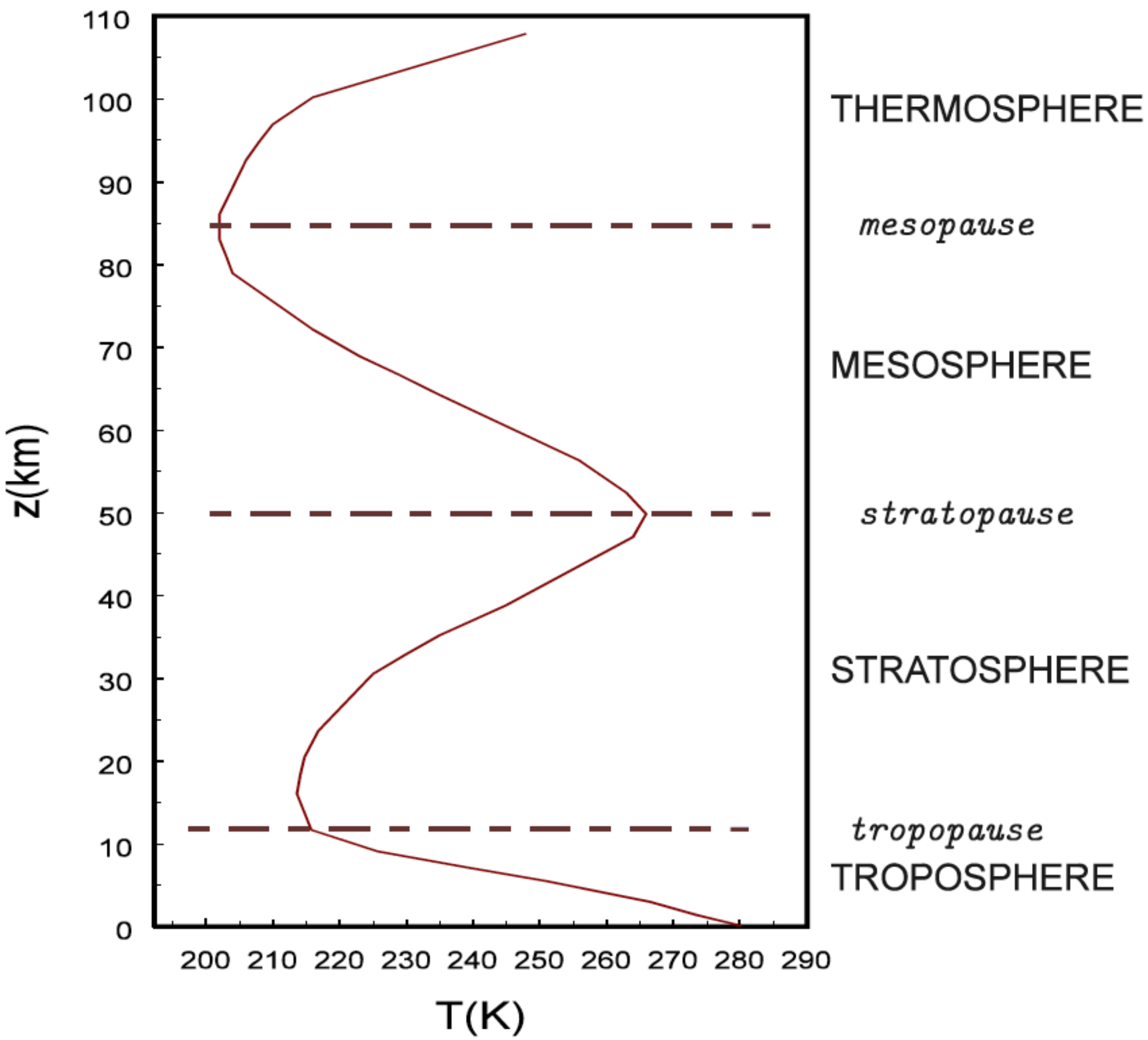
Schematic of a radiative transfer model with many layers

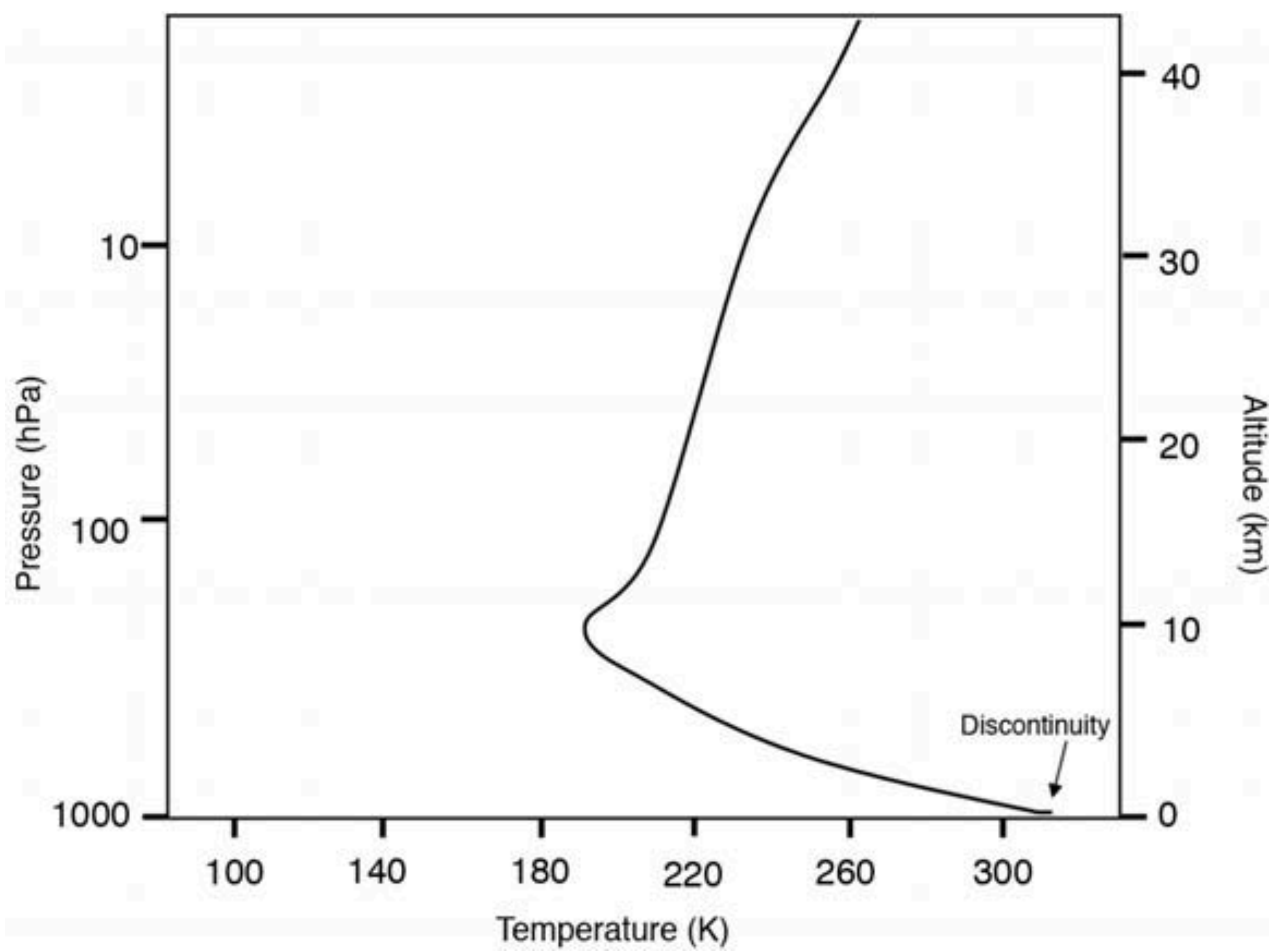
The radiative equilibrium T profile
if heat transport occurs only by radiation



Convection : dynamical heat transport

3. The greenhouse effect: d. A more opaque greenhouse





4. Climate feedbacks

- How sensitive of T_s is to the energy input, Q?

$$\frac{\partial T_s}{\partial Q}$$

Climate sensitivity

- Climate sensitivity associated with the blackbody radiation is

$$\frac{\partial T_s}{\partial Q_{BB}} = (4\sigma T_e^3)^{-1}$$

= 0.26 K (W m^{-2})$^{-1}$

- A negative feedback regulating outgoing longwave radiation

4. Climate feedbacks

- A positive climate feedback by saturated water vapor pressure, e_s.

$$\frac{de_s}{e_s} = \beta dT$$

$$\beta \rightarrow 0.067 \ ^\circ\mathrm{C}^{-1}$$

- It means that e_s increases by nearly 7% per 1°C increase.
- A combined climate feedback by blackbody and water vapor processes.

$$\frac{\partial T_s}{\partial Q_{BB,H_2O}} = 0.5 \ \mathrm{K} \ (\mathrm{W \ m^{-2}})^{-1}$$

- The climate feedback by albedos is also important.