Andrews atmospheric physics: Chapter 3

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atmospheric radiation:

define 3 region: near infra-red (0.7 → 4 μm)
thermal infra-red (4 → 50 μm)
far infra-red (50 μm → 1 mm)

2 classes of photons: solar photons: short wave, emitted by the sun, between 0.1 & 4 μm.
thermal photons: long wave, emitted by atmosphere or earth, 4 → 100 μm

Spectral region for black body emission of 6000 K (sun)
spectral region black body (earth) emission at 288 K.

spectral radiance: power per unit area per unit solid angle per unit frequency interval

$$B_\nu(T) = \frac{2h\nu^3}{c^2(\exp(h\nu/k_BT)-1)}$$

Planck function.

spectral radiance is also power per unit area, per unit solid angle per unit λ interval

$$B_\lambda(T) = \frac{2hc^2}{\lambda^5(\exp(hc/\lambda k_BT)-1)}$$

⇒ integrating B_λ over all λ ⇒ black body radiance

$$\int_0^\infty B_\lambda(T)\, d\lambda = \frac{\sigma}{\pi}T^4$$

concept of black body is an idealisation ⇒ real body emits less radiation.
⇒ spectral emittance ε_ν is the ratio of spectral radiance of a body to spectral radiance from a black body

can also define spectral absorbance a_ν fraction of energy per unit frequency interval falling on a body that is absorbed

Radiometric quantities:

spectral radiance: $L_\nu(\underline{r},\underline{s})$ ⇒ $L_\nu = B_\nu(T)$ power per unit area per unit solid angle per unit freq interval

radiance is power per unit area per unit solid angle

$$L(\underline{r},\underline{s}) = \int_0^\infty L_\nu(\underline{r},\underline{s})\, d\nu$$

spectral irradiance = power per unit area per unit freq ⇒ $\int_{2\pi} L_\nu(\underline{r},\underline{s})\,\underline{n}\cdot\underline{s}\; d\Omega(\underline{s})$

$W\,m^{-2}\,Hz^{-1}$ ⇔ $F_\nu(\underline{r},\underline{n})$ normal surface

the irradiance (or flux density) is the power per unit area at a point through a surface

$F(\underline{r},\underline{n})$:

irradiance has a direction ie up or downwards ⇒ net upwards power per unit area

$$F_z = F^{\uparrow} - F^{\downarrow}$$

$$F(\underline{r},\underline{n}) = \sigma T^4$$

Greenhouse effect using a 2 layer atmosphere:

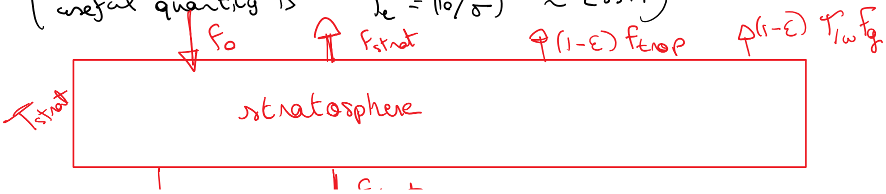
2 layers: lower T_{trop} ⇒ troposphere T_{lw} in the infrared
T_{sw} short wave

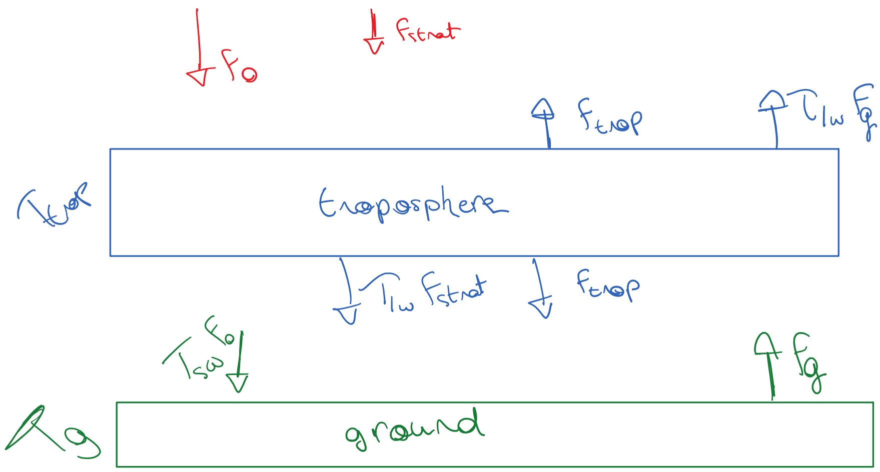
upper layer T_{strat} ⇒ stratosphere. emittance $1-T_{lw}$ in the infrared.

⇒ assume transparent to short waves & optically thin in the infrared

absorbance $\varepsilon \ll 1$
emittance is also ε & thus transmittance $1-\varepsilon$

ground at T T_g. assume emits as black body.
unreflected incoming solar irradiance F_0 is $240\ W\,m^{-2}$
(useful quantity is $T_e = (F_0/\sigma)^{1/4} \approx 255\,K$)





balancing upwards & downwards irradiance at strat, we have

$$F_0 = F_{strat} + (1-\varepsilon)(F_{trop} + T_{lw} F_g) \quad ①$$

where $F_{strat} = \sigma \varepsilon T_{strat}^4$ as doesn't emit as black body $F_{trop} = \sigma(1-T_{lw}) T_{trop}^4$ $F_g = \sigma T_g^4$

balance of irradiance between strat & trop implies

$$F_0 + F_{strat} = F_{trop} + T_{lw} F_g \quad ②$$

combining ① & ② $\Rightarrow$ $\underbrace{2F_{strat}}_{\text{net radiative power leaving strat. (up \& down ie } F^{\uparrow} + F^{\downarrow})} = \varepsilon(F_{trop} + T_{lw} F_g)$ ③

↳ net power absorbed by strat from trop & ground.

solar irradiance does not appear as assumed to pass through strat without absorption

eliminating $F_{trop} + T_{lw} F_g$ from ① & ② we obtain $\sigma \varepsilon T_{strat}^4 = F_{strat} = \frac{\varepsilon F_0}{2-\varepsilon}$ ④

$\varepsilon \ll 1$ so $\sigma T_{strat}^4 \approx F_0/2$

$T_{strat} \approx 214K$

balance of irradiance between troposphere & ground implies

$$T_{sw} F_0 + T_{lw} F_{strat} + F_{trop} = F_g = \sigma T_g^4 \quad ⑥$$

from ③ & ④ we obtain ⑤ $F_{trop} = \frac{2F_0}{2-\varepsilon} - T_{lw} F_g$

& by combining ④, ⑤, ⑥ we can obtain F_g in terms of F_0

$$\sigma T_g^4 = F_g = T_{sw} F_0 + T_{lw}\left(\frac{\varepsilon F_0}{2-\varepsilon}\right) + \frac{2F_0}{2-\varepsilon} - T_{lw} F_g$$

$$\Rightarrow \boxed{F_g = \frac{F_0}{1+T_{lw}}\left(T_{sw} + \frac{\varepsilon T_{lw}}{2-\varepsilon} + \frac{2}{2-\varepsilon}\right)}$$

as in chapter 1, $T_{sw} = 0.9$

76°F (−60°C), and at the upper bound around −26°F (−3°C).

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asing resolts from chapter 8 $\alpha_0 = \varepsilon^{1/4} \alpha_{BB}$

where $\alpha_{BB} = 3.8 \, W m^{-2} K^{-1}$

& we assume $\alpha_0 = 1 \, W m^{-2} K^{-1}$

, ε could be equol to $\varepsilon = \left(\frac{1}{3.8}\right)^4$