

Radiation balance for Earth

Radbal 1

Total radiation of sun (luminosity of sun): $L = 3.826 \times 10^{26} \text{ W}$.

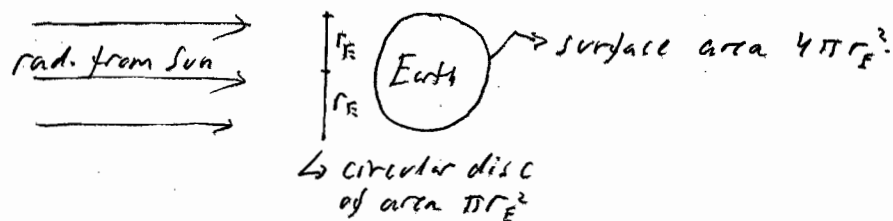
Radiation intensity at Earth at distance $r_{SE} = 1.496 \times 10^{11} \text{ m}$:

Solar constant $S = \frac{L}{4\pi r_{SE}^2} = 1360 \text{ W m}^{-2}$.

Total power hitting Earth, radius r_E : $S \times \pi r_E^2$

Average intensity over whole area of Earth:

$$\frac{S \pi r_E^2}{4\pi r_E^2} = \frac{1}{4} S = \underline{340 \text{ W m}^{-2}}.$$



Power balance of Earth:

$$\begin{aligned} \text{Netto power in} &= \text{power in} - \text{power out} \\ &= S(1-\alpha)\pi r_E^2 - \epsilon \sigma 4\pi r_E^2 T^4 \end{aligned}$$

$\alpha = \text{albedo} = 0.30$. $\epsilon = \text{emissivity} \approx 1$.

Average intensity balance for Earth surface:

divide power balance with $4\pi r_E^2$:

$$\begin{aligned} *1 \text{ Netto intensity in} &= I_{in} - I_{out} \\ &= \frac{1}{4} S(1-\alpha) - \epsilon \sigma T^4. \end{aligned}$$

Surface heat capacity $C_s \approx 4 \times 10^8 \text{ J K}^{-1} \text{ m}^{-2}$

Netto heat energy in = $Q = C_s A \Delta T$ (A area).

$$Q = (I_{in} - I_{out}) \cdot A \cdot \Delta t$$

$$*2 \text{ so: } \underline{\Delta T = \frac{Q}{C_s \cdot A} = \frac{(I_{in} - I_{out}) \Delta t}{C_s}}$$

Dynamics of T

$$*1 \quad I_{in} - I_{out} = \frac{1}{4} S(1-\alpha) - \epsilon \sigma T^4$$

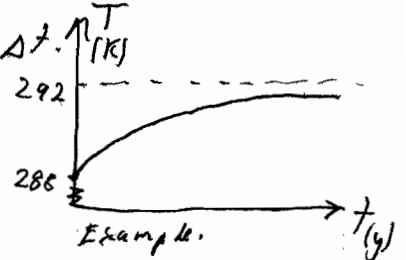
$$*2 \quad \Delta T = \frac{1}{C_s} (I_{in} - I_{out}) \cdot \Delta t$$

Given I_{in} and a temperature T , e.g. so $I_{in} > I_{out}$.

*1 gives $I_{in} - I_{out}$. *2 gives ΔT in timestep Δt .

$$\text{New } T = \text{Old } T + \Delta T.$$

*1 gives new $I_{in} - I_{out}$. *2 gives new ΔT , etc.

Examples of models of energy balance of Earth

See JordEncl. pdf

Model 1 No atmosphere.

$$\text{Earth: } \frac{1}{4} (1-\alpha) S = \sigma T_E^4 \quad \left[\frac{1}{4} S = 339 \text{ W m}^{-2} \right], \quad T_E = 254 \text{ K.}$$

Model 2 Atmosphere passes radiation from Universe to Earth, but absorbs radiation from Earth and re-radiates to Earth & Universe, each of σT_A^4 .

$$\left. \begin{array}{l} \text{Atmosphere: } \sigma T_E^4 = 2\sigma T_A^4 \\ \text{Earth: } \frac{1}{4} (1-\alpha) S + \sigma T_A^4 = \sigma T_E^4 \end{array} \right\} \begin{array}{l} T_A = 254 \text{ K} \\ T_E = 302 \text{ K} \end{array}$$

Model 3 Atmosphere absorbs 19% of radiation from Universe.

$$\left. \begin{array}{l} \text{Atmosphere: } \frac{1}{4} \times 0.19 S + \sigma T_E^4 = 2\sigma T_A^4 \\ \text{Earth: } \frac{1}{4} (1-\alpha-0.19) S + \sigma T_A^4 = \sigma T_E^4 \end{array} \right\} \begin{array}{l} T_A = 254 \text{ K} \\ T_E = 291 \text{ K} \end{array}$$

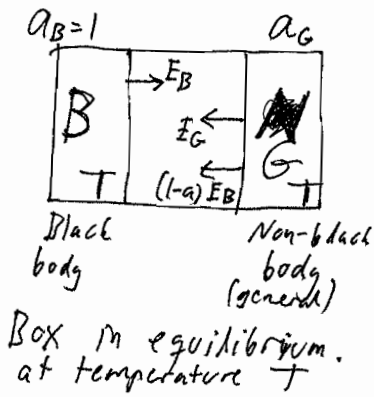
That atmosphere absorbs all radiation from Earth is the worst considered "pure" greenhouse effect.

See model 4 for more realistic value at present, where atmosphere only from Earth absorbs $\sigma T_E^4 - 20 \text{ W m}^{-2}$.

Compare also with diagram in Kitt p. 76 upper.

1. Kirchhoff's law of thermal radiation

Heat radiation from a body depends only on properties of the body, especially its temperature T , and does not depend on the surroundings. So the body emits radiation independently of the surroundings, but of course it also absorbs radiation from the surroundings.



A black body absorbs all heat rad.

Absorption coefficient: a .

Reflection coefficient: $1-a=r$

For a blackbody: $a_B=1$.

G has abs. coeff. $a_G < 1$.

B emits energy E_B . G emits energy E_G .

In thermodynamic equilibrium B emits the same energy (or power or intensity) as B receives.

B receives from G the energy emitted by G and the energy reflected from G: $E_G + (1-a_G)E_B$

so: $E_B = E_G + (1-a_G)E_B \Leftrightarrow E_G = a_G E_B$.

Emissivity is defined as $\epsilon_G = \frac{E_G}{E_B}$. For B: $\epsilon_B = 1$.

From $E_G = a_G E_B$ we get: $\epsilon_G = a_G$ (at a given temp. T).

\Rightarrow Kirchhoff's corollary $\epsilon_G < 1$ (because $a < 1$)

At a given temp. a body can never thermally radiate more energy than a blackbody at same temperature, when equilibrium

$\epsilon_G = a_G = 1 - r_G \Rightarrow$ "A poor reflector is a good emitter, a good reflector is a poor emitter."