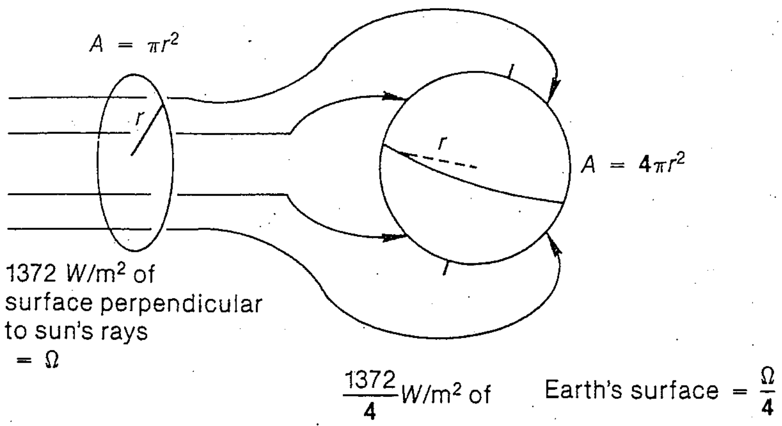
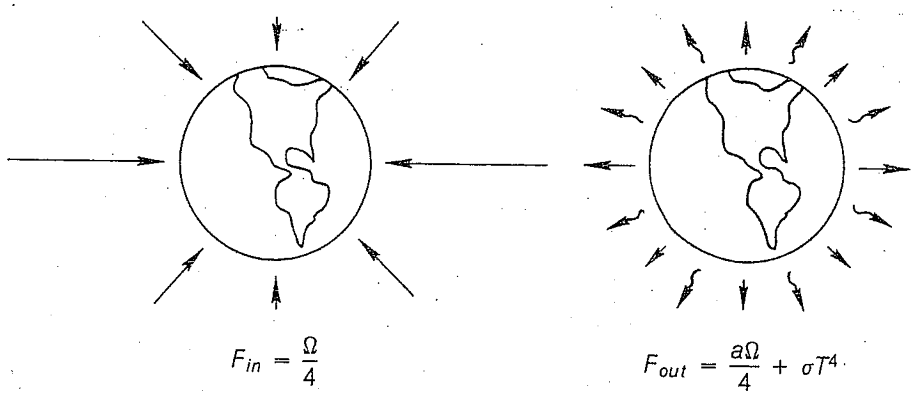
Climate Change: Surface Temperatures and Greenhouse Gases

Balancing the incoming captured solar energy, $((1-A)\Omega/4)$ with the energy emitted from the Earth (σT^4) allows us to calculate a steady state temperature of 255 K (~ 35 degrees Kelvin) below the Earth's actual average temperature of ~290 K. This discrepancy is accounted for by the presence of IR absorbing gases in the atmosphere (**H_2O, CO_2, O_3, CH_4, N_2O**). Although these gases are transparent to visible light, they absorb radiation in the IR region where the Earth emits 'blackbody' radiation. To correct for the presence of this co-called 'greenhouse effect' the equation for the overall energy balance is given by;





$$\sigma T^4 = \frac{(1-A)\Omega}{4} + \Delta E$$

where;

σ is the Stefan – Boltzmann constant (5.67×10^{-8} W m^{-2} K^{-4})

A is the Earth's albedo – the fraction of the solar radiation reflected from the Earth (0.3)

Ω is the solar flux (1372 W m^{-2})
and
ΔE is the magnitude of the 'greenhouse effect'

1. What would be the Earth's atmospheric temperature if the magnitude of the greenhouse effect (ΔE) is increased by 10%?

[*Answer; T = 290.7 K*]

Solution; first we must calculate the magnitude of ΔE term. to do this, we will need to use current conditions $T = 288\ K$ $A = 0.30$

$$\sigma T^4 = \frac{(1-A)\Omega}{4} + \Delta E$$

$$\therefore \Delta E = \sigma T^4 - \frac{(1-A)\Omega}{4}$$

$$= \left(5.67\times10^{-8} \frac{W}{m^2K^4}\right)(288\ K)^4 - \frac{(1-0.30)\ 1372\ W/m^2}{4}$$

$$= (390.0 - 240.0)\frac{W}{m^2} = 150.0\ \frac{W}{m^2}$$

If this were to increase by 10%

$$\Delta E = 150\ \frac{W}{m^2} \longrightarrow 165\ \frac{W}{m^2}$$

Calc. new temp.

$$T = \left[\frac{\frac{(1-A)\Omega}{4} + \Delta E}{\sigma}\right]^{1/4} = \left[\frac{405\ \frac{W}{m^2}}{5.67\times10^{-8}\ \frac{W}{m^2K^4}}\right]^{1/4}$$

$$= 290.7\ K$$

$\therefore$ ΔT from a 10% increase in 'greenhouse effect' is 2.7°C global annual average.

2. What was the change in the Earth's *albedo* resulted from the eruption of Mt. Tambora in 1816, if the average temperature in the Northern Hemisphere dropped by 0.60 °C?

[*Answer; ΔA = 0.005*]

This temperature decrease was observed in the N. hemisphere only, where the aerosols were dispersed. Therefore, the global average temperature decrease was 0.30 °C.

$$\sigma T^4 = \frac{(1-A)\Omega}{4} + \Delta E$$

where $T = 287.7$ K and $\Delta E = 149.98 \frac{W}{m^2}$

$$\therefore (1-A) = \frac{(\sigma T^4 - \Delta E)4}{\Omega}$$

$$= \frac{\left[\left(5.67\times10^{-8}\frac{W}{m^2K^4}\right)(287.7\text{ K})^4 - 149.98\frac{W}{m^2}\right]4}{1372\ \frac{W}{m^2}}$$

$$= 0.6953$$

$$\therefore A = 0.3047$$

so $\Delta A = 0.0047$

note that such a small change in albedo has observable effect on temperature.

3. An empirical relationship between atmospheric $\mathbf{CO_2}$ concentration and ΔE (the magnitude of the greenhouse effect in W m^{-2}) is given by;

$$\Delta E = 133.26 + 0.044\,[\mathbf{CO_2}]$$

where $[\mathbf{CO_2}]$ is the atmospheric concentration of $\mathbf{CO_2}$ in ppm. If the ambient atmospheric $\mathbf{CO_2}$ concentration and albedo were increasing at 0.2% per year, what would the Earth's average temperature be in 100 years?

[*Answer; T = 284.8 K*]

Starting with CO_2 conc. of 380 ppm$_v$ increasing at 0.2% yr^{-1} over 100 yrs gives CO_2 conc of 456 ppm$_v$

The albedo will increase from 0.30 $\rightarrow$ 0.36 over this 100 yrs period.

$$\Delta E = 133.26 + 0.044\,[456] = 153.32\ \frac{W}{m^2}$$

So $$T = \left[\frac{(1-A)\,S/4 + \Delta E}{\sigma}\right]^{1/4}$$

$$= \left[\frac{(1-0.36)\,\frac{1372}{4}\,\frac{W}{m^2} + 153.32\ W/m^2}{5.67\times10^{-8}\ \frac{W}{m^2K^4}}\right]^{1/4}$$

$$= 284.8\ K$$

overall cooling effect if both CO_2 and A are increasing by the same 0.2% yr^{-1}