Climate Change: Surface Temperatures and Greenhouse Gases

Balancing the incoming captured solar energy, ((1-*A*)Ω/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'

Gases that contribute the most to the greenhouse effect are: **H_2O**(g), **CO_2** and **O_3**

CO_2 is increasing at 0.4% per year. **CH_4** and **N_2O** are minor contributing greenhouse gases whose concentrations are increasing at about 0.6% and 0.2% per year.

As the concentration of greenhouse gases increases, the value of ΔE increases and the atmospheric temperatures increase. Gases that absorb in a region of the IR spectrum that is currently transparent (IR 'windows'), have a greater potential to influence atmospheric temperatures. Other factors that influence the global warming potential of a gas are the inherent absorptivity of that gas and their atmospheric lifetime.

IR windows in Earth's atmosphere;

$\lambda \approx 4 – 6$ μm ($2800 – 2400$ cm^{-1})
$\lambda \approx 8 – 12$ μm ($1400 – 800$ cm^{-1})
$\lambda \approx 16 - 20$ μm ($600 – 400$ cm^{-1})

The global warming potential (GWP) of a greenhouse gas is a measure of the potential for global warming per unit mass relative to carbon dioxide over some period of time.

Gas	Lifetime (yrs)		GWP's	
		20 yrs	100 yrs	500 yrs
CO_2		1	1	1
CH_4	12	62	23	7
N_2O	114	275	296	156
CCl_2F_2	116	7100	7100	4100
CHF_3	260	9400	12000	12000
CF_4	50000	3900	22200	32400

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*]

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 ^{o}C?

[*Answer; ΔA = 0.005*]

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*]