

Temperature & Energy

Chapter 2



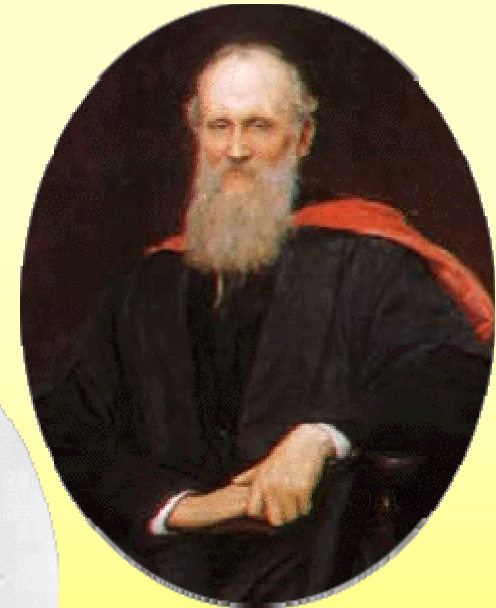
Anders Celsius
1701-1744 Sweden



Joseph Stefan
1835-1893 Austria



Ludwig Boltzmann
1844-1906 Austria



Lord Kelvin (Wm Thomson)
1824-1907 Scotland

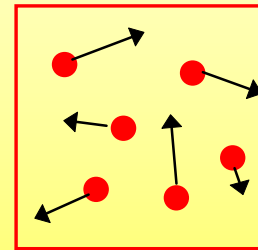


Wilhelm Wien
1864-1928 Germany

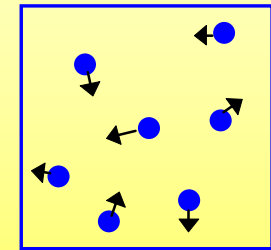
Temperature

- Temperature is a measure of how much energy of motion (**kinetic energy**) the molecules of a material possess

- the higher the temperature, the higher the average speed of the molecules



High temp



Low temp

- at **absolute zero** of temperature, all the kinetic energy of molecules that can be removed has been taken away

- Cold bodies can't heat hotter bodies

Temperature Scales

💧 Usual temperature scale is °C (*degrees Celsius*)

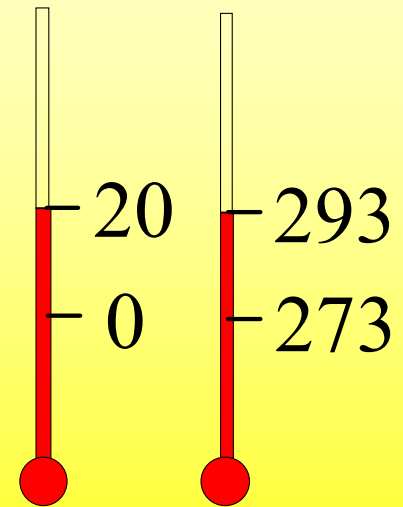
➤ e.g. 20°C; 0°C, etc. [page 27/29]

💧 In basic relations in physics, temperature is measured **from absolute zero**, in K (*degrees Kelvin*)

➤ e.g. 293 K; 273 K

💧 General conversion:

$$K = ^\circ C + 273$$



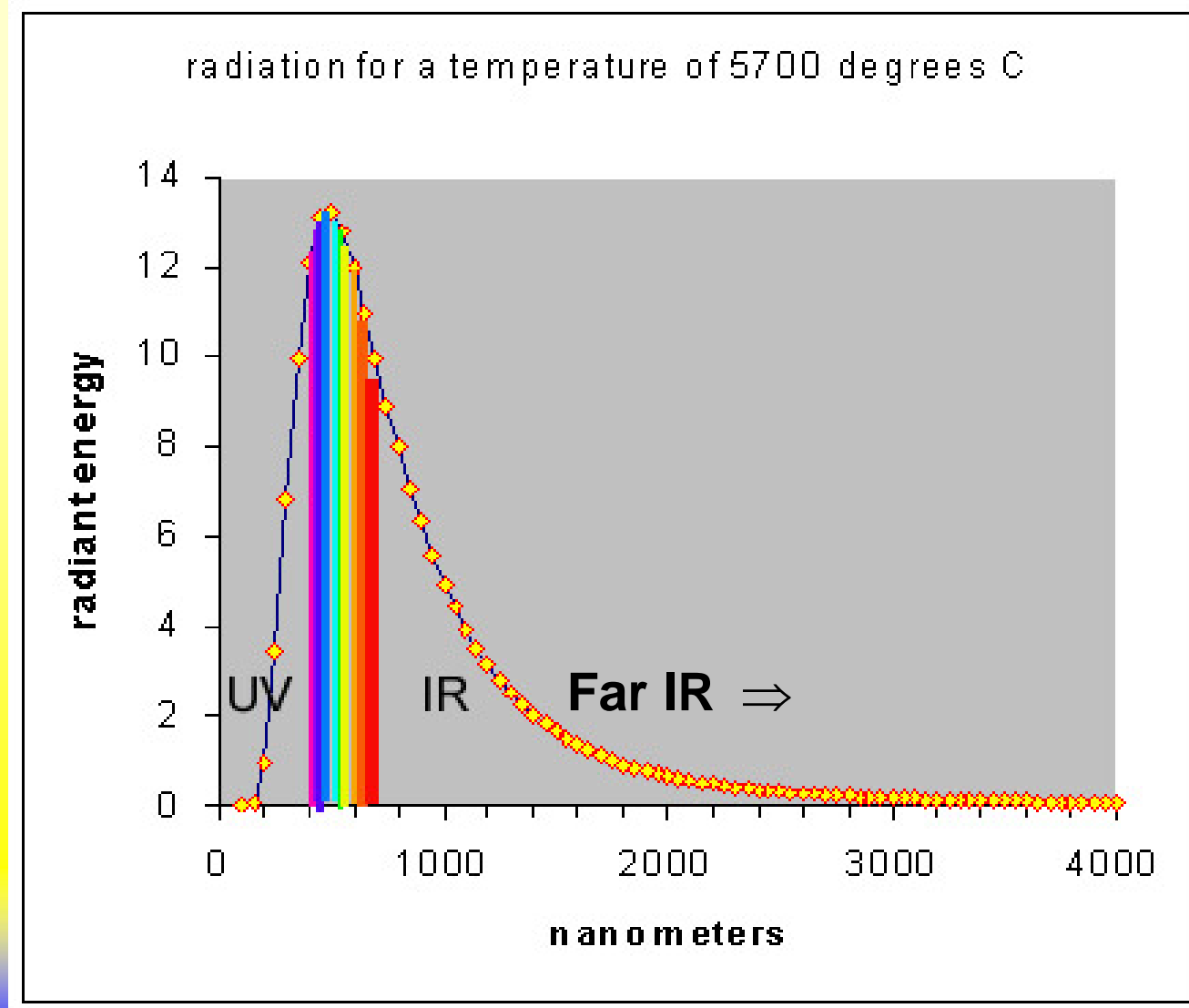
Celsius Kelvin

The Sun's Radiation

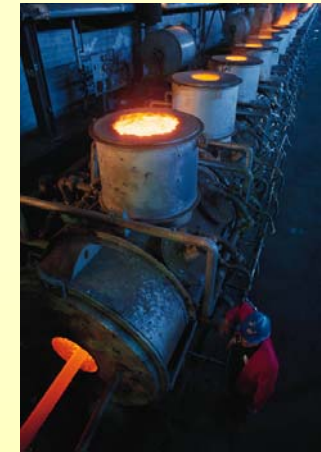
- 💧 Radiation from the Sun keeps us and the weather going
- 💧 UV (ultra-violet), visible and IR (infra-red) radiation are all important
- 💧 Hot bodies usually radiate with a characteristic spread of electromagnetic energy known as **blackbody radiation** [figure 2.9]
 - all bodies radiate electromagnetic energy; what counts is the difference between radiation received and radiation emitted

Blackbody Radiation

💧 Figure 2.9
simplified



What is a Blackbody?



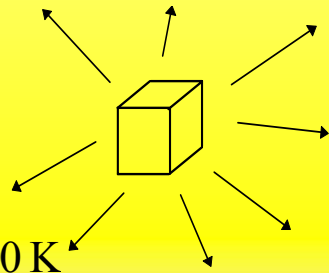
- 💧 A blackbody is one that absorbs completely any radiation that falls on it
 - a glowing coal fire or the Sun are good approximations to a blackbody
- 💧 Most bodies don't absorb all the radiation that falls on them (this a major reason why bodies are coloured)
 - their radiation is described as blackbody \times *an emissivity*, which is a factor ≤ 1 (that may vary with wavelength)

Total Radiant Energy

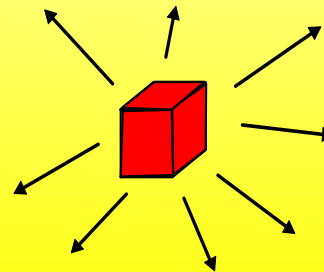
- The total radiant energy (E) emitted per m² of surface per second depends on a blackbody's absolute temperature (T) [page 34/36]

- $E = \sigma T^4$, where σ is $5.67 \times 10^{-8} \text{ Wm}^{-2}\text{K}^{-4}$

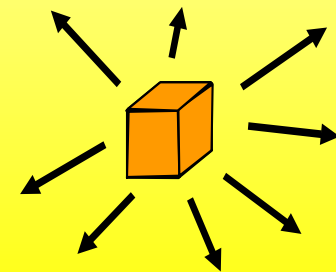
➤ this is called the **Stefan - Boltzmann Law** and σ is *Stefan's constant*



blackbody at 300 K
emits 450 W m^{-2}



Hot coal 1100 K
emits 83 kW m^{-2}

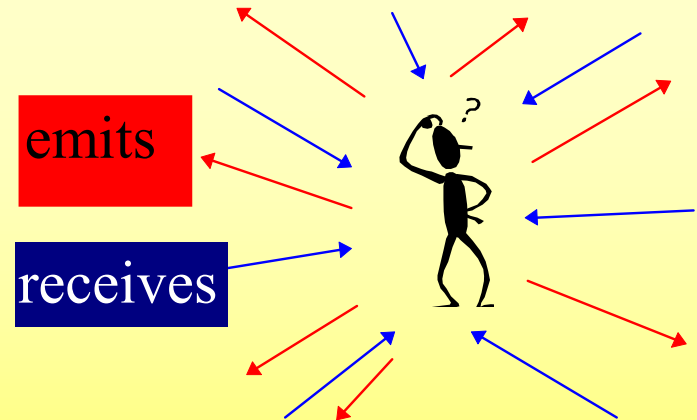


Sun at 6000 K
emits 73 MW m^{-2}

Radiation Example

- Non blackbodies typically emit at 0.1 to 0.9 rate of blackbodies

- A blackbody at blood heat of 37°C (310 K) in surroundings at 0°C (273 K):



- blackbody emits energy $E = \sigma \times 310^4 = 524 \text{ Wm}^{-2}$
- blackbody receives energy $E = \sigma \times 273^4 = 315 \text{ Wm}^{-2}$
- net loss of energy = $524 - 315 = 209 \text{ Wm}^{-2}$, which is quite a rate of loss of energy. A person of surface area 2 m^2 emitting at 0.2 blackbody rate loses 88 W

Global Warming Requirement



- If the earth were a blackbody at 288 K and you heated it by 1 K, then you would need to provide 5.4 Wm^{-2} to sustain the increased radiation
 - 27.6 W m^{-2} for a 5 K temperature increase
- The Earth is not a blackbody but what is its average emissivity?
 - the answer depends on the surface cover (e.g. ice or soil, trees or corn, etc.)
 - the answer is crucial to models of global warming

Wavelength of Maximum Radiation (λ_{\max})

- Hot bodies emit the maximum amount of radiation at a wavelength that is inversely proportional to their absolute temperature
- Wien's Law:** [page 34/36]

$$\lambda_{\max} = \frac{3000}{T}, \lambda \text{ in } \mu\text{m}, T \text{ in K}$$

- e.g. Sun at 6000 K, $\lambda_{\max} = 0.5 \mu\text{m}$ (*green*)
- e.g. us at 300 K, $\lambda_{\max} = 10 \mu\text{m}$ (*far infrared*)

Long and Short Wave Radiation

- Hot Sun emits most of its radiation as *short-wave radiation* [page 35/37], transmitted by the atmosphere

- UV - 7%
- visible - 44%
- near IR - 37%

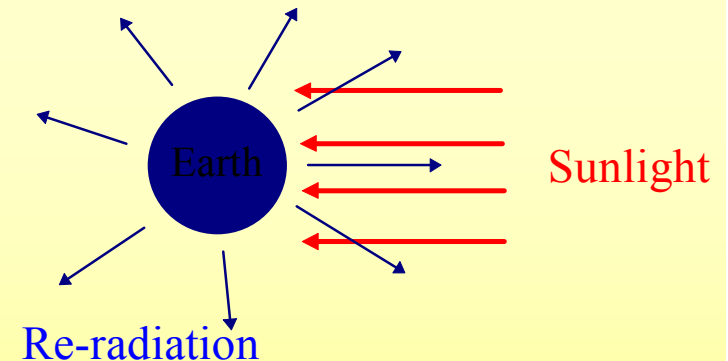


- Far infrared, longer wavelengths than $1.5 \mu\text{m}$, is known as *long-wave radiation*

- Sun emits 11%
- Earth emits 100%

Radiation Balance

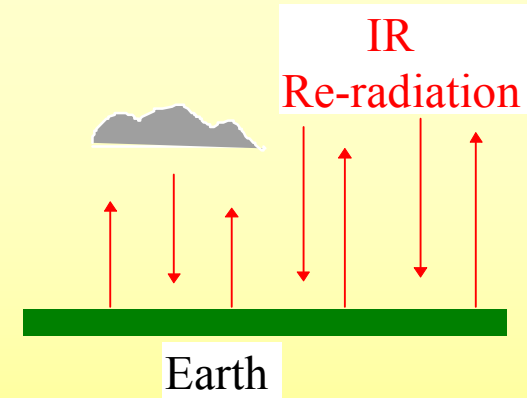
- The Earth receives the Sun's energy from one direction and radiates it back into space in all directions



- Energy balance gives the Earth's **radiative equilibrium temperature** as 255 K (-18°C)
- The average temperature on the Earth's surface is 288 K (15°C)
- The difference is caused by the **atmospheric greenhouse effect**

Greenhouse Effect

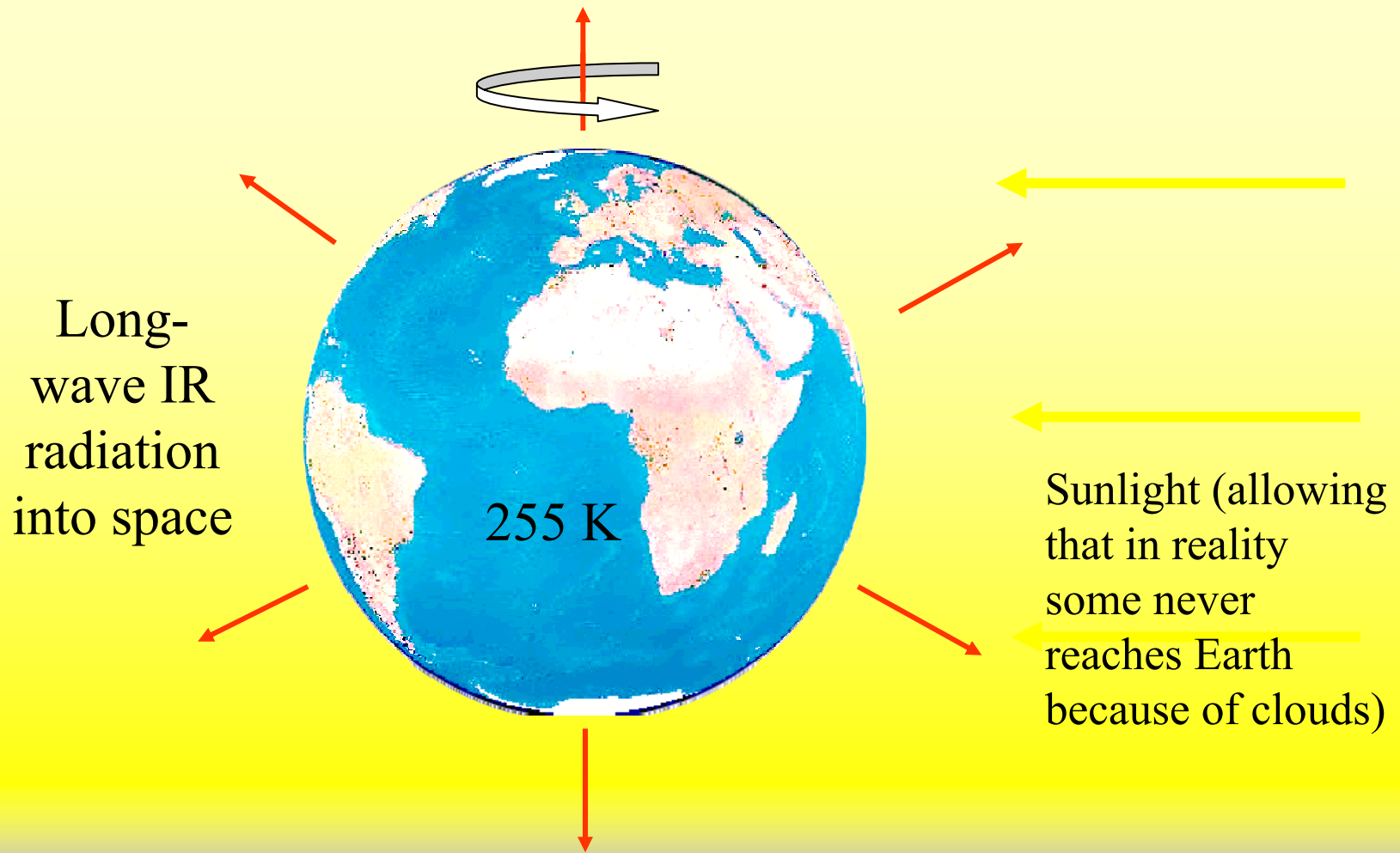
- Caused by the absorption of escaping long-wave radiation by H_2O , CO_2 , CH_4 , N_2O , O_3 & CFCs and its re-radiation back to the surface [page 38/40, figure 2.12]



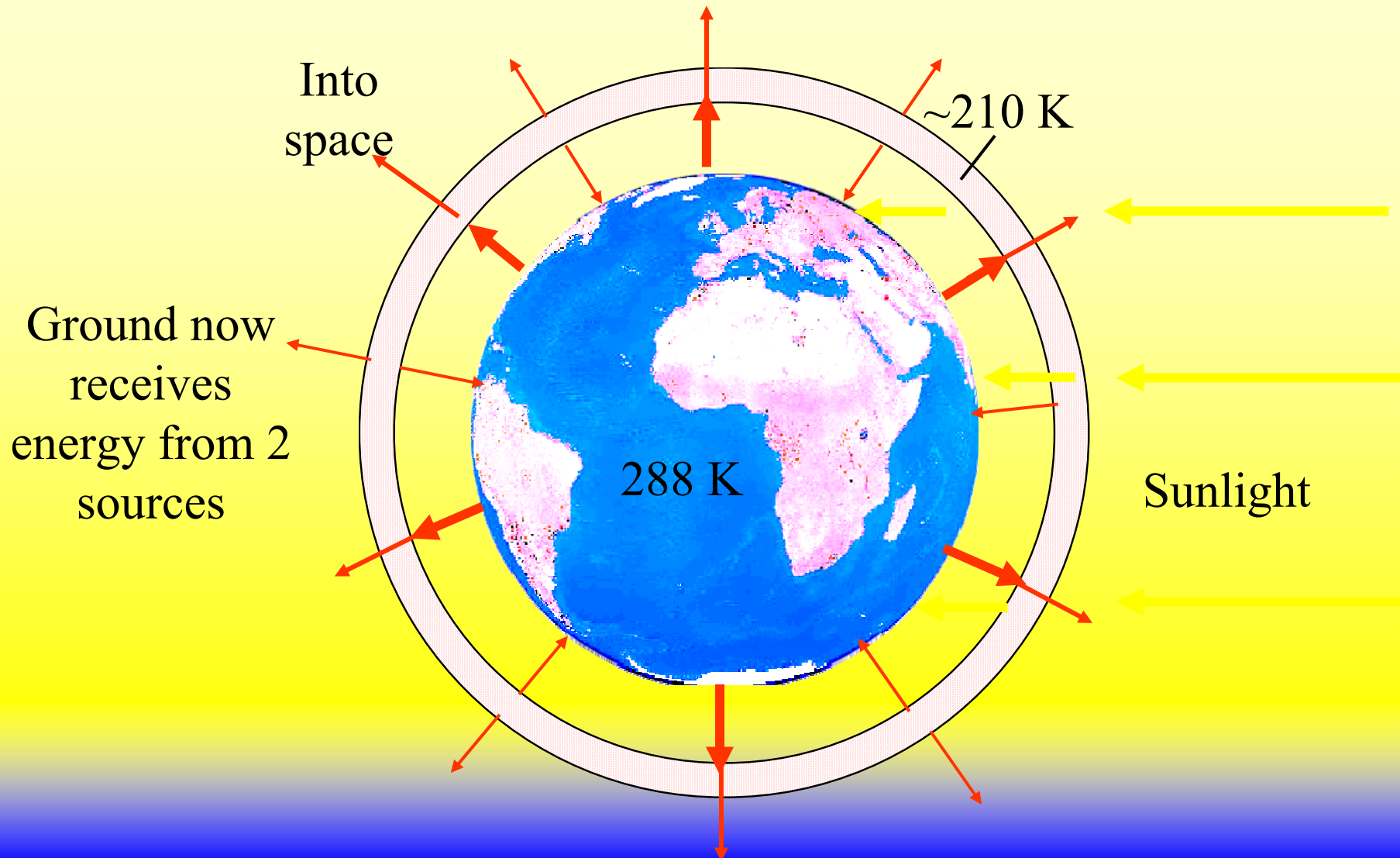
- These *greenhouse gases* make the atmosphere almost opaque to longwave radiation and effectively screen the Earth's surface from the cold of space, raising the temperature by 33°C

Earth from Space

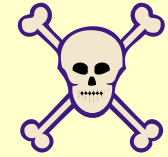
No atmosphere



Add some atmosphere partly absorbing IR



The Media's Greenhouse Effect



- Overall warming of the Earth due to increased absorption and re-radiation of IR back to the Earth

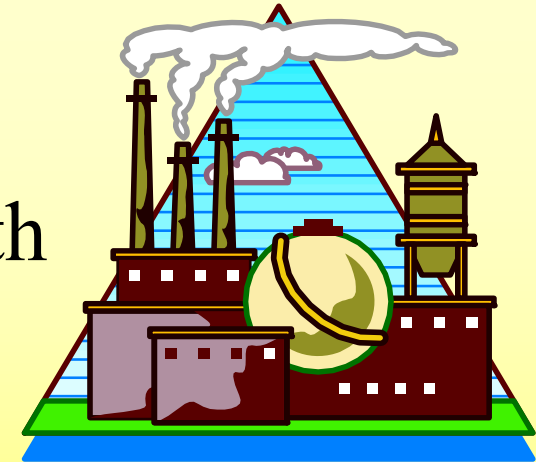
- best estimate of observed warming is $\sim 0.6^\circ - 0.8^\circ\text{C}$ for 20th century

- predicted $2^\circ - 5^\circ\text{C}$ for this one

- global climate changes will be caused by a few $^\circ\text{C}$ rise

- Emphasis on CO_2 is an oversimplification

- climate change is about more than CO_2



Sun's Short-wave Energy

- 30% goes back into space

 - 20% from clouds

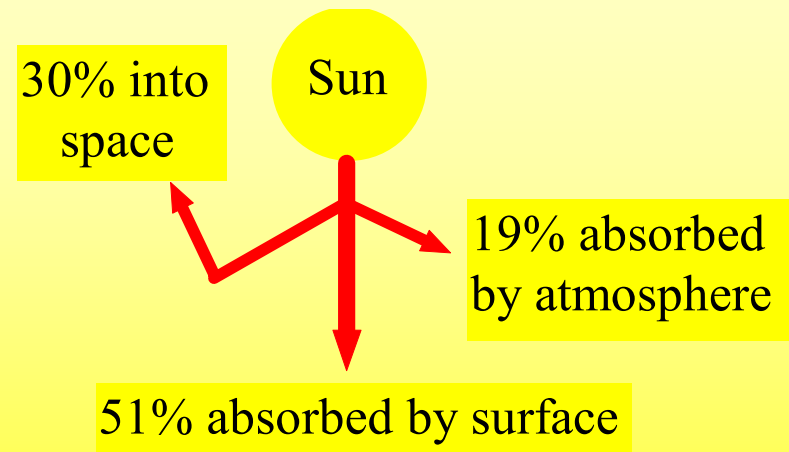
 - 6% from atmosphere

 - 4% from surface

 - Earth's **albedo** is 0.3

- 19% absorbed by clouds

- 51% absorbed by Earth's surface



Ground - Atmosphere Energy Balance

- The Earth's surface receives 147% of the Sun's incident radiation

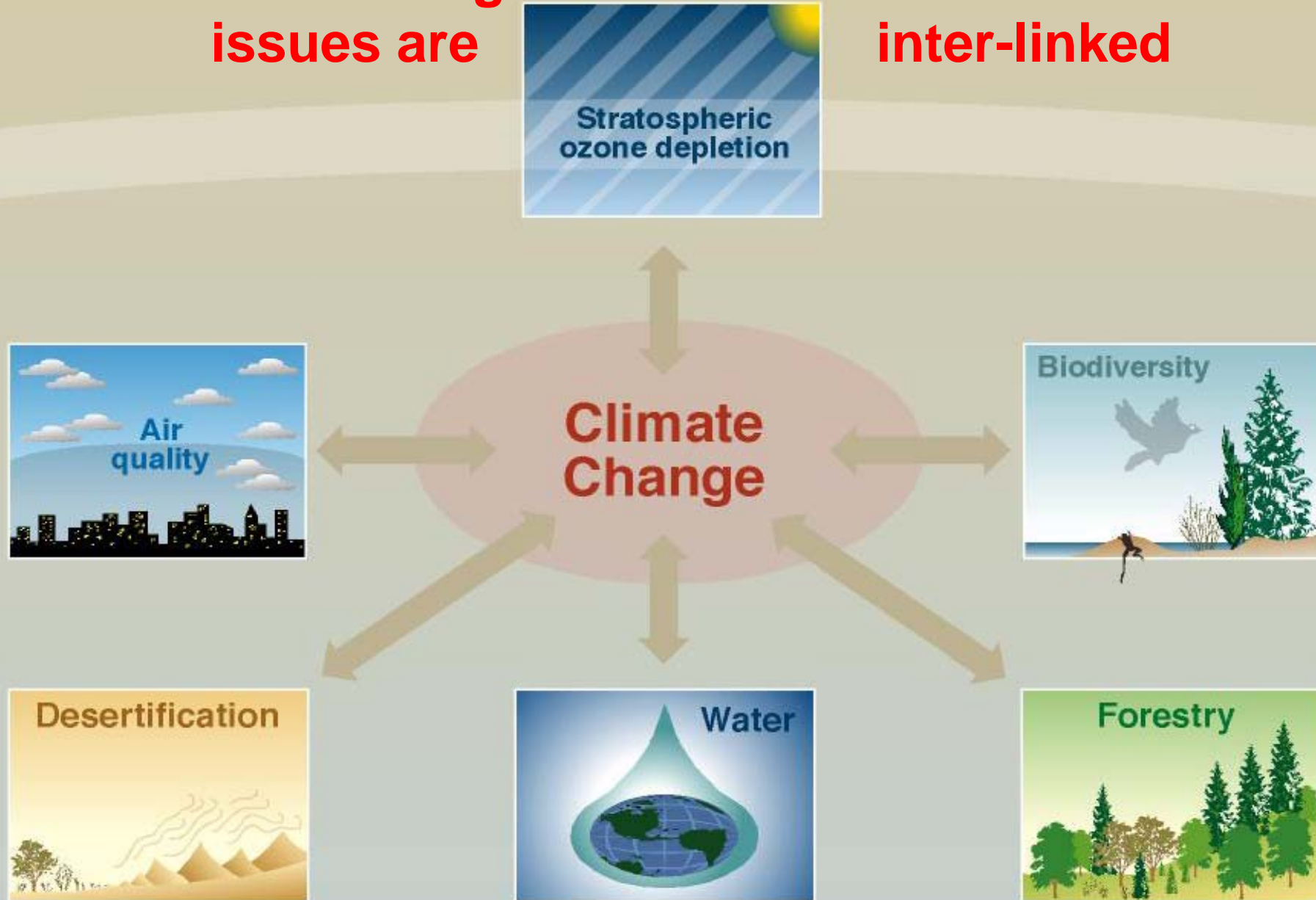
- 51%, only, comes directly from the Sun

- 96% comes from IR re-radiated by clouds and atmosphere [figure 2.16]

- ✿ 96% = 47% IR from ground, 19% from Sun; 30% latent heat and convection



Climate change and other environmental issues are inter-linked



Courtesy: IPCC, see the next chapter