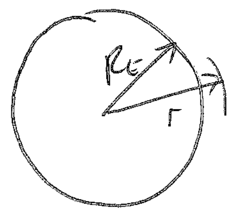
ENVIRONMENTAL PHYSICS

Atmosphere and oceans. In the next 9 lectures, we will study the structure and dynamics of the Earth's atmosphere and oceans, and how these result in the weather we see all around us.

1. Summary of atmospheric properties

a) Size of the Earth and Atmosphere



Radius of the Earth $R_E = 6.37\times10^6$ m

Mass of the Earth $M_E = 6\times10^{24}$ kg

acceleration due to gravity $g(r) = \frac{GM_E}{r^2}$

At Earth's surface, $g_0 = g(r=R_E) = 9.81\,m/s^2$

$$\frac{g(r)}{g_0} = \frac{GM_E/r^2}{GM_E/R_E^2} = R_E^2/r^2$$

Most weather in lowest 10km of the atmosphere (TROPOSPHERE)

$$\frac{g(10km+R_E)}{g_0} = \frac{R_E^2}{(R_E+10km)^2} \simeq 0.997$$

0.3% smaller

$\Rightarrow$ g almost constant

b) Rotation

Diameter of the Earth $d_E = 2\pi R_E$

Rotates once in 24hrs

$\Rightarrow$ at the equator the Earth is rotating at a speed

$$V_{eq} = \frac{2\pi R_E}{24hrs} = \frac{2\pi\times6.37\times10^6}{24\times60\times60} = 470\,m/s$$

($\simeq$ 1000 mph)

$\therefore$ Rotation effects (e.g. Coriolis force) are important.

c) <u>Pressure</u>

Mean sea-level pressure 1013.25 mb
$\sim 10^5$ Pascals (Pa, N/m^2)

(1mb $\simeq$ 100 pascals)

Pressure has units of Force/Area, so 10^5 Newtons per m^2 or $10\ N/cm^2$. Since $F = mg$, and $g \simeq 10$, this is roughly the weight of $1\ kg/cm^2$

We can use this to estimate the mass of the atmosphere

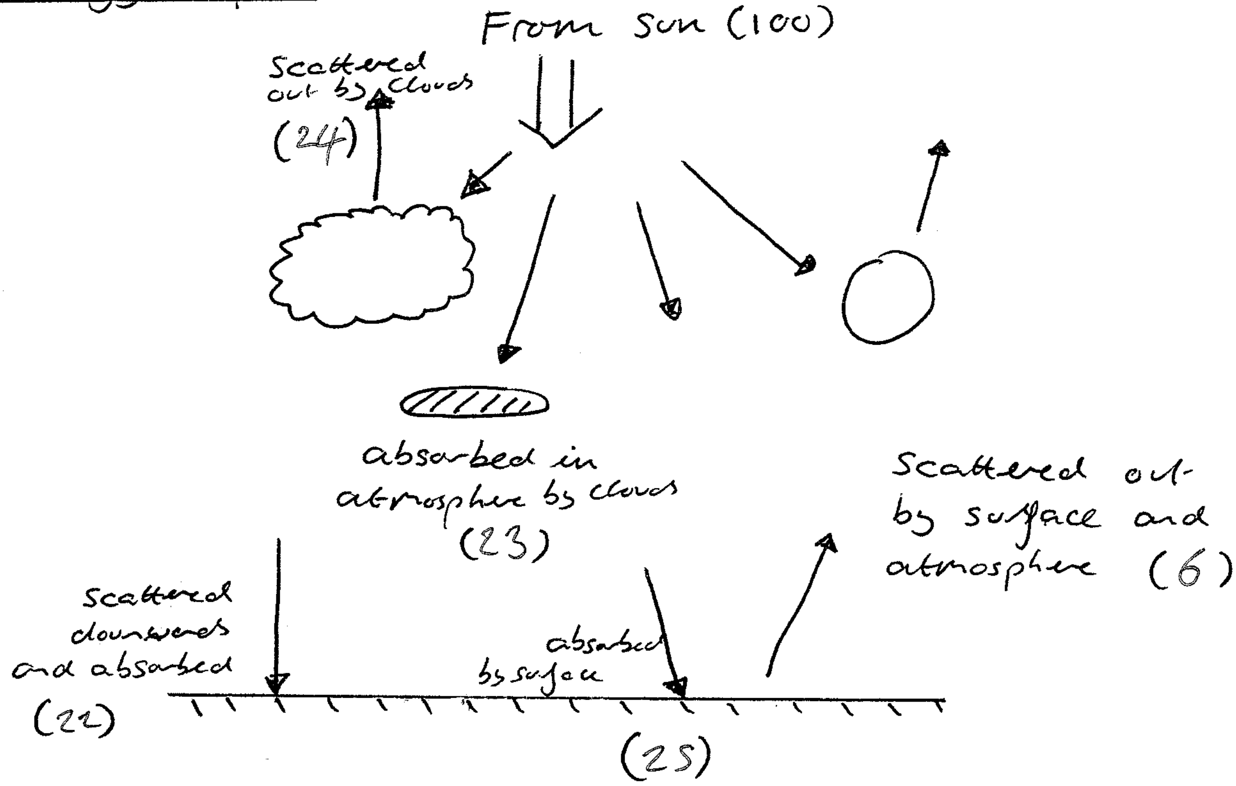
$$\simeq \text{Mass per unit area} \times \text{area of Earth} = 10^4 \times 4\pi R_E^2 \sim 5 \times 10^{18}\ kgs$$

(10^4 ↑ kg/m^2)

or about 1 millionth (10^{-6}) of the mass of the Earth

The oceans are much heavier, around 1.4×10^{21} kg (0.023% of M_E)

d) Energy input



[Fig 4.4, p51 of The Physics of Atmospheres]

⇒ ~30% scattered back out

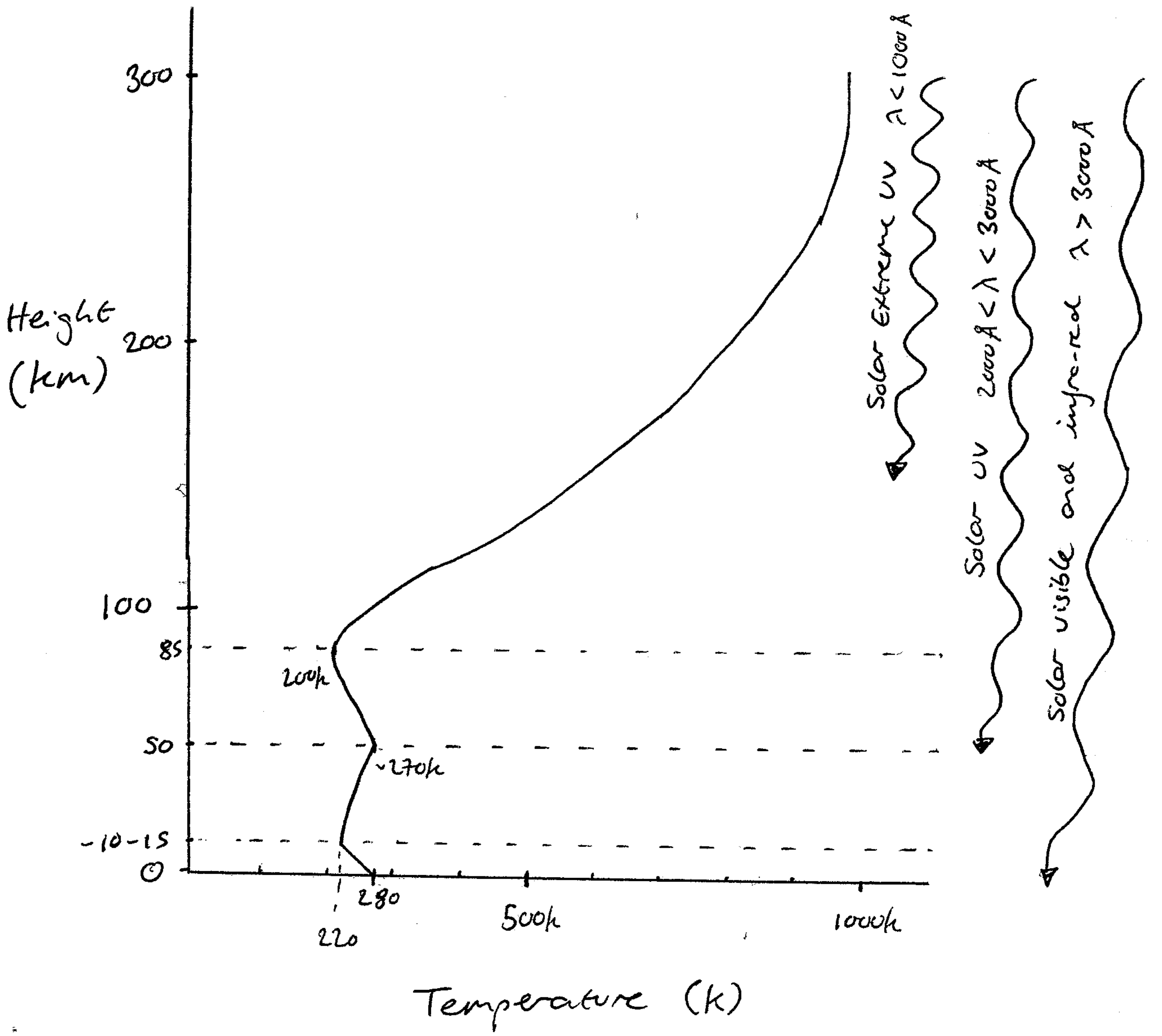
~47% absorbed by surface

Atmosphere is mainly heated from below

e) Temperature of the Atmosphere

Mean surface temperature ~ 280k

As heated from below, expect T to fall as you go higher. It does, but only up to ~10-15km, where it rises again!



<u>Troposphere</u>: Contains ~85% of the mass of the Atmosphere, almost all water, and essentially all weather
→ Most of the course concerned with this region.

Fluids (liquids, gasses) heated from below will tend to convect
→ Lots of interesting dynamics as hot air rises and convects round the atmosphere.

<u>Stratosphere</u>: Temperature rises with height, due to absorption of UV radiation by Ozone.

~~For~~ Chapman (1930)

$$O_2 + \nu \longrightarrow O + O$$

$$O + O_2 + M \longrightarrow O_3 + M$$

needs oxygen, UV light, and a third body (M)

- At high altitude, total density (M) and Oxygen density (O_2) too low → little O_3 above mesopause
- At low altitude UV light blocked by atmosphere above.

⇒ Peak in O_3 concentration around 25 km heats the stratosphere, so temperature rises with altitude up to the stratopause at ~50 km

- Fluids heated from below tend to convect (vertically unstable), whilst those heated from above are stable.

→ No weather, little vertical motion in stratosphere

→ Excellent flying conditions

Mesosphere:

Unlike in the stratosphere, there is little solar heating in the mesosphere. Instead, radiative loss from CO_2 acts to cool this region.

The mesopause is the boundary between the mesosphere and thermosphere and is where the temperature is a minimum. This is the coldest place on Earth, reaching as low as -100°C (173 K).

Thermosphere:

Very low density region in which many atoms are ionised (gain or lose electrons so they have a net charge) by extreme UV and the charged particle wind from the sun. This ionised region is a plasma and is known as the ionosphere. It reflects radio waves, making long-distance radio communication possible.

Interaction of charged particles with the air in the thermosphere can cause it to glow - the Aurora Borealis, or Northern Lights

Mixing of gasses

The composition of dry air is

Molecule	Atomic weight	fraction of molecules (%)
N_2	28	78
O_2	32	21
Ar	40	0.93
CO_2	44	325 parts per million (ppm)
Ne	20	18 ppm
He	4	5 ppm
CH_4	16	3 ppm
H_2	2	0.5 ppm
O_3	48	0 - n ppm

Why is there any Hydrogen at all? Why does it not just 'float' upwards?

→ In the lower part of the Atmosphere the distance a molecule can travel between collisions is short (~ 68 nm at sea level)

$$\lambda \simeq \frac{1}{\sqrt{2}\, n \sigma}$$

↑ cross section (σ)

Exponential decrease of density with height.

Gasses are mixed by turbulence faster than they can separate through diffusion. This region below ~100 km called the HOMOSPHERE. because the composition of air is the same at all altitudes.

→ At high altitude the density is low and so the mean free path λ becomes large (~10 km at 500 km up)

So the components of the air can separate. This region called the HETEROSPHERE

Happens around 105 km up $\lambda \sim 1$ m

→ Boundary between Homosphere and Heterosphere called the

Summary of Lecture I

- The Atmosphere is a thin layer of gas surrounding the Earth
- Rotation of the Earth is important for the dynamics
  → Coriolis force
- Most of the energy from the sun is absorbed at the Earth's surface → atmosphere heated from below

The atmosphere can be divided into 4 regions, according to the temperature variation with altitude

- Troposphere: T falls with height, driven by heating from below and convection. Ends at the tropopause where there is a minimum in temperature.
- Stratosphere: T increases with height due to heating by absorption of UV radiation by Ozone. Reaches a maximum in temperature at the stratopause.
- Mesosphere: T falls again with height, though not as steep as in the troposphere. Minimum T at the Mesopause.
- Thermosphere: very low density region heated by UV radiation and the solar wind. T increases with height. ~~outwards~~ ionised gas forms the ionosphere, which reflects radio waves.

Atmosphere can also be divided into two regions

1. The Homosphere in which gasses are mixed
2. The Heterosphere where gases can separate diffusively