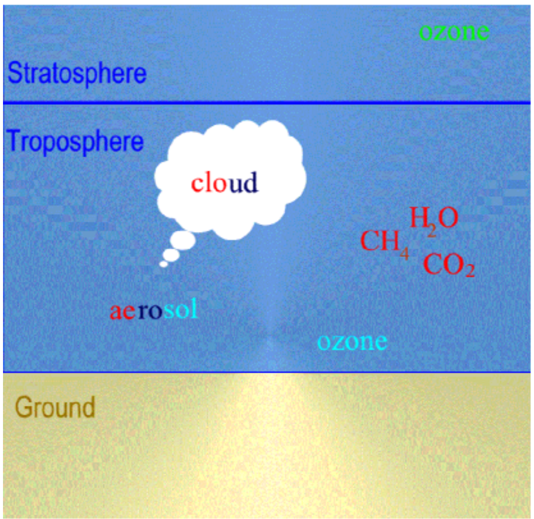
The Atmosphere

- Atmospheric composition
- Measures of concentration
- Atmospheric pressure
- Barometric law

Literature connected with today's lecture:
Jacob, chapter 1 - 2
Exercises:
1:1 – 1:6; 2:1 – 2:4

The Atmosphere



- The atmosphere – Thin "skin" of air surrounding the planet
  - Description
  - Role of natural atmosphere
  - Effects of changed composition

- Atmospheric change
  - Climate
  - UV protection
  - Acidification
  - Health

Composition of the Atmosphere

Dry atmosphere (excl. H_2O):

Gas	**Mixing ratio (mole/mole)**
Nitrogen (N_2)	0.78
Oxygen (O_2)	0.21
Argon (Ar)	0.0093
Carbon dioxide (CO_2)	365×10^{-6}
Neon (Ne)	18×10^{-6}
Ozone (O_3)	$0.01\text{-}10 \times 10^{-6}$
Helium (He)	5.2×10^{-6}
Methane (CH_4)	1.7×10^{-6}
Krypton (Kr)	1.1×10^{-6}
Hydrogen (H_2)	500×10^{-9}
Nitrous oxide (N_2O)	320×10^{-9}

Dry atmosphere:

- Dominated by nitrogen and oxygen
- Noble gases, in particular argon
- Conc. ($O_2 + N_2 + Ar$) ≈ 1 mole/mole
- Remaining components trace gases: E.g. Carbon dioxide, ozone, methane

Humid atmosphere:

- Water vapour: Varies, up to approx. 0.03 moles/mole

Calculation Example: Calculate the density of dry air at $T = 280$ K and $P = 1000$ hPa!

The atmosphere an ideal gas (in most cases): $PV = nRT$

Density:

$\rho = m/V = nM/V$

From the gas law: $n/V = P/RT$ =>

$\rho = MP/RT$

Air is a mixture of gases – average molar mass: $M_a = 29{,}0$ kg/kmole

Gas constant: $R = 8314{,}3$ J/(kmole K)

Insert numbers:

$\rho = M_aP/RT = 29{,}0*1000*100/(280*8314{,}3) = 1{,}25 \text{ kg/m}^3$

Atmospheric Concentration of Species

Expressions atmospheric concentration:

Number concentration:
- number of moles or molecules of type X per volume unit of air

Mass concentration:
- mass of X per volume unit of air

- Air compressible ⇒ These measures of concentration change with local atmospheric pressure

Mixing ratio:
- (No. moles of X)/(No. moles air molecules)
  - Or: mass X/mass air
- Unaffected by expansion/compression

- Trace gases ⇒ small numbers
  - ppm (parts per million): 10^{-6}
  - ppb (parts per billion): 10^{-9}
  - ppt (parts per trillion): 10^{-12}
- Kinds of mixing ratios:
  - ppb**v** (v = volume) based on number
  - ppt**m** based on mass

Example helium:

[He] = 5.2 10^{-6} mole He / mole air = 5.2 ppmv

Mixing ratio

- C = moles of X / total No. moles
- $C = n_x/n$

Apply the gas law: n = PV/RT ⇒

- $C = (P_xV_x/RT_x)/(PV/RT)$
  - $T_x = T$; $V_x = V$ ⇒

- $C = P_x/P$ = (partial P of X) / (total P)

Example:
The mixing ratio of He is 5.2 ppmv.
Calculate the He partial pressure at sea level!

Average sea level atmospheric pressure P = 1013 hPa

$C_{He} = n_{He}/n = P_{He}/P \Rightarrow$

$P_{He} = C_{He} \cdot P =$

$= 5.2\text{x}10^{-6} \cdot 1013 \text{ hPa} = 0.53 \text{ Pa}$

Exercise 2-1 in Jacob: The atmospheric CO_2 concentration has during the industrial era increased from 280 to 400 ppmv. How large is this increase expressed as mass of atmospheric carbon?

$$C = \frac{n_C}{n_a};$$ n_C and n_a are No. moles CO_2 and air molecules

$$\Delta C = \frac{n_{C2}}{n_a} - \frac{n_{C1}}{n_a} = \frac{\Delta n_C}{n_a}$$ ΔC = 400 – 280 ppmv = 120 ppmv = 120 x10^{-6}

Increase of the carbon mass:

$$\Delta m_C = \Delta n_C M_C = \Delta C n_a M_C = \Delta C \frac{m_a}{M_a} M_C$$

M_C = molar mass of carbon;
m_a = mass of the atmosphere;
M_a = average molar mass of air
Δm_C = increase of the carbon mass

With known m_a: Δm_C = 250 billion tonnes = 250x10^{12} kg

Problem

How can we calculate the mass of the atmosphere?

Hint: The pressure at a level is caused by the weight of the overlying atmosphere

Exercise 2-1 – Continued: How can the mass of the atmosphere be calculated?

Gravitational field and no other forces affecting the pressure:

The pressure at a given level is caused by the weight of the overlying air ⇒

Force: $m_a g = A_{earth} P$ where $A_{earth} = 4\pi R^2$

Average pressure at surface (P): 984 hPa

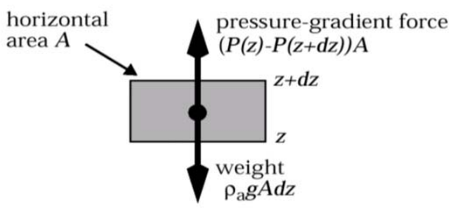
Radius of the earth (R): 6400 km

Reorganize:

$m_a = 4\pi R^2 P/g = 5.2 \times 10^{18}$ kg

Atmospheric Pressure – Dependence on Altitude

Vertical element dz:



Equilibrium: The gravimetric force is balanced by the force from a pressure gradient

Gravimetric force = Gradient force

$-g\rho_a A dz = (P(z+dz)-P(z))A = dPA$

(A = horizontal surface area)

$dP = -\rho_a g\, dz$

From the ideal gas law:

$\rho_a = PM_a/(RT)$

$dP = -PM_a/(RTg)\, dz$

Rearrange:

$dP/P = -M_a/(RTg)\, dz$

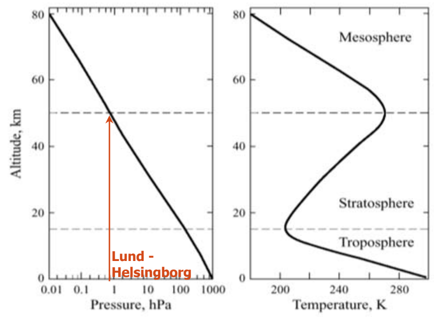
Approximation: T independent of z ⇒

Barometric law:

$$P(z) = P(0)e^{-M_a gz/RT}$$

Vertical Profiles in the Atmosphere

- The pressure decreases exponentially with altitude
  - Example: at 50 km 0.1% of the pressure at the surface



Temperature profile:

- Troposphere
  - T decreases with z
  - Earth's surface warm due to absorption of solar radiation
  - Cooling with altitude due to adiabatic expansion
- Stratosphere
  - T increases with z
  - Ozone absorbs solar radiation and heats the stratosphere
- Mesosphere
  - T decreases with z

Exercise 2:3 Calculate the altitude that divides the mass of the atmosphere in two equal halves (Assume T constant at 260 K)!

$m_a g = 4\pi R^2 P \Rightarrow m_a \sim P \Rightarrow m_a/2$ appears at $P/2$

Use the barometric law:

$P(Z) = P(0)e^{-M_a gz/RT}$ and find $P(Z) = P(0)/2$

$P(Z)/P(0) = e^{-M_a gz/RT} = 0.5$

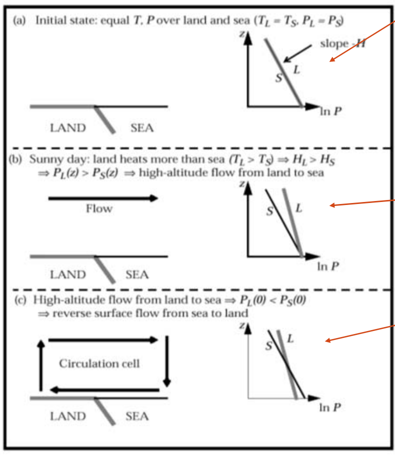
Logarithm at both sides:

$-M_a gz/RT = \ln(0.5)$

Reorganize:

$z = -RT\ln(0.5)/M_a g = 5.27$ km

Sea-Breeze



- Initially: $T_L=T_S$; $P_L=P_S$; no wind
- Solar heating of land strongest:
  - Water has higher heat capacitivity
  - Evaporation of H_2O cools
- $P(z) = P(0)\exp(-M_a gz/RT)$
- ⇒ Difference in vertical pressure gradient
  - $P_L - P_S$ increases with altitude
  - High altitude wind from land to sea
- ⇒ Air column over land decreases
  - ⇒ $P_L < P_S$
  - Low altitude wind from sea to land
- Circulation cell:
  - 10km horizontally, 1km vertically