Meteorology: an introduction to weather, climate and the environment

by

Dr John S. Reid

Fellow of the Royal Meteorology Society

Department of Physics

University of Aberdeen

Introduction

- Course hand-out
  - scope of course
- Course text-book
  - *Meteorology Today* by C. Donald Ahrens
    - [p 5 or page 6/7/8 → 6th ed'n/7th ed'n/8th ed'n page numbers]
  - first-class book

    Buy it!

200 Years of Observations

- Cromwell Tower observatory (1868) was part of the first British national met network

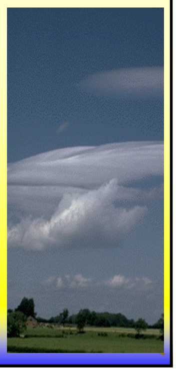
Our Solarimeter

- George Aubourne Clarke

Earth's Atmosphere - chapter 1

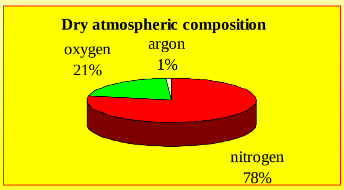
- Earth's atmosphere is very thin
  - 99% of atmosphere is within 30 km of sea-level [page 2]
  - all weather is well within this height
- Earth's atmosphere does contain a lot of molecules: about 10^{44} mols
  - 1 breath ≈1 litre ≈10^{22} mols [p 5/4/4] Each breath contains over a million molecules breathed
  - 1 lifetime ≈10^{8} litres

    real historical character



Atmospheric Composition

- The atmosphere is not a fixed set of molecules
  - exchange between land, sea, living things and atmosphere; also between 'space' and atmosphere



- Dry atmosphere: 78% nitrogen (N_2); 21% oxygen (O_2); 1% argon (Ar) [page 3]

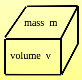
Composition: the rest

- Trace gases: carbon dioxide (CO_2) 380 ppm; methane (CH_4) 1.7 ppm; nitrous oxide (N_2O) 0.3 ppm
  - ppm stands for *parts per million* in terms of numbers of molecules
  - rate increase CO_2 about 2 ppm/year
  - more than 50 times CO_2 in oceans than in atmosphere
- Variable element:

  water (H_20) 0 - 4%
  - with 4% water, the % of N_2 and other gases reduces
- Earth's early atmosphere

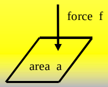
Structure of Atmosphere

- The atmosphere gets less dense as you go up



$$density = \frac{mass}{volume} = \frac{m}{v} \text{ in kg m}^{-3}$$

- The **pressure** at any level is caused by the weight of air in a column above [page 8/9/9]



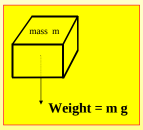
$$pressure = \frac{force}{area} = \frac{f}{a} \text{ in N m}^{-2}$$

Units of Pressure

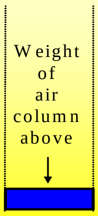
- Mks unit of pressure: Pascal = 1 N m^{-2}
- Meteorologist's unit: mb (*millibar*) = 100 Pa ≡ 1 hPa
- Sea level pressure is about 1000 mb
- **Isobars** are lines of constant pressure
- Barometers may use: mm of Hg = 1.33 mb (*millimetres of mercury*) 1 mm Hg ≡ 1 torr

Pressure Decreases with Altitude

- Weight is proportional to mass



- g is acceleration due to gravity (~9.81 m s^{-2})
- Weight of all the air above produces air pressure
  - density and pressure generally vary together; see fig. 1.7/1.7/1.8



Exponential Fall of Pressure

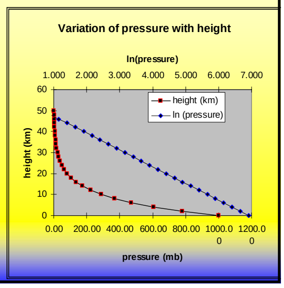
- Atmospheric pressure falls almost exponentially with height

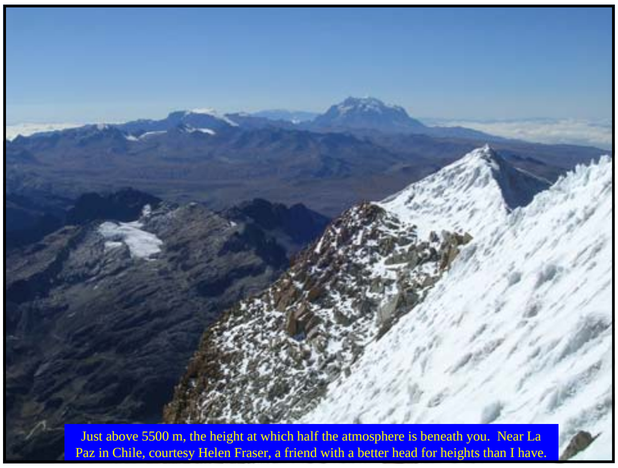
$$P(h) = P(0)e^{-h/H}$$

P pressure; *h height*; *H* is a *constant* 'scale height' at which the pressure drops by a factor of 'e'

- If *H* = 8 km and ground level pressure is 1010 mb, what is the pressure outside an airliner flying at a height h of 11 km?

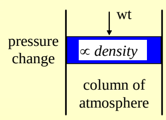
$$P(h) = 1010\,e^{-(11/8)} = 255\,mb$$





Just above 5500 m, the height at which half the atmosphere is beneath you. Near La Paz in Chile, courtesy Helen Fraser, a friend with a better head for heights than I have.

Why does pressure fall exponentially?



- There are 2 lines to the argument
  - *hydrostatic equilibrium* requires:

    $change\ in\ pressure \propto density$
  - *gas law* requires:

    $density \propto pressure$
  - combining these two gives:

    $change\ in\ pressure \propto pressure$

  which is the fundamental rule underlying exponential change

Edmund Halley in 1686 appreciated the exponential decrease of pressure with height

Consequences of exp decay of atmosphere


Auroral rays

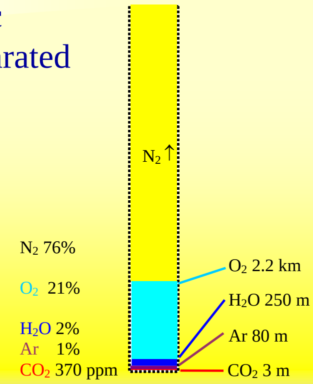
- Most of a planetary atmosphere is close to the ground
- The scale height H depends on molecular weight

$$H \approx RT / Mg$$

- ➢ *R gas constant*; *T Temperature*; *M molecular weight*; *g gravitational constant*
- ➢ light gases have larger scale height H and therefore you expect the outer atmospheric layers to be atomic O and then helium and hydrogen, which they are!

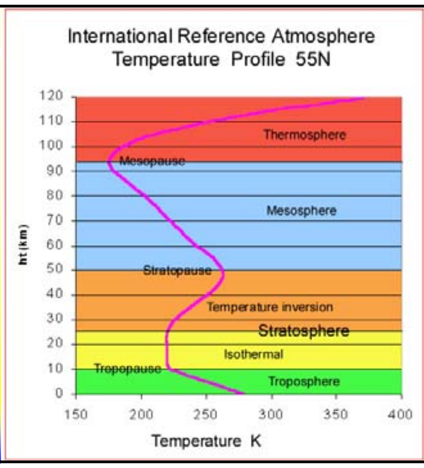
Atmospheric Constituents Separated

- Graphic showing heights of columns of different gases in atmosphere if gases were separated



Annual average (cospar data)

See fig. 1.9/1.9/1.10



Troposphere


Ice particle haloes; courtesy Bienkowski

- The region around the Earth closest to the ground [p. 10/10/11]
- The temperature decreases with increasing height
  - ➢ **lapse rate** about 6°C - 10°C per km
  - ➢ at about 10 km, temp around -60°C
- Includes 80% of atmosphere
- Weather occurs in the troposphere
- Top of region is the **tropopause**


Sundogs and halo at Balmedie beach 02/02/2008; Courtesy Martyn Gorman

Stratosphere

- **Isothermal layer** (i.e. constant temperature) up to a height of 25 km
- **Temperature inversion** up to 50 km, where temperature is about 0°C
- Heating caused by ozone UV absorption
- Top of stratosphere is the **stratopause**

Mesosphere & Above

- 'Middle Sphere' - from 50 km to ~90 km
- Temperature falls steadily with height to about -80°C at the **mesopause**, where the pressure ~0.01 mb
- Noctilucent clouds
- Higher still:
  thermosphere
  exosphere

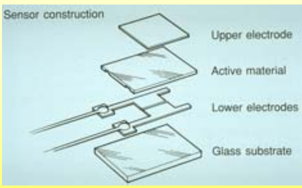
Mesospheric clouds (noctilucent clouds): courtesy M Gadsden

Radiosondes

- They carry instruments to measure the vertical structure of atmosphere: temperature, pressure and humidity up to 30 km [page 14]
- Measurements returned by radio
- Tracking balloon position will give the vertical profile of winds, too
  - a wind tracking balloon is called a **rawinsonde**
- A graph showing all results is called a **sounding**

Radiosonde Sensors

- Humidity sensor



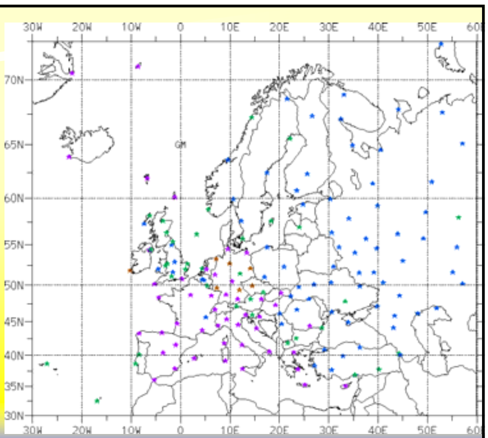
- Pressure sensors
  - silicon technology:
    - pressure changes electrical capacitance

Radiosonde Telemetry

- Transmitter operates at high frequencies

Radio-sondes

- Stations releasing daily radiosondes



Courtesy: http://www.meteo.uni-koeln.de/meteo.php?show=En_We_We