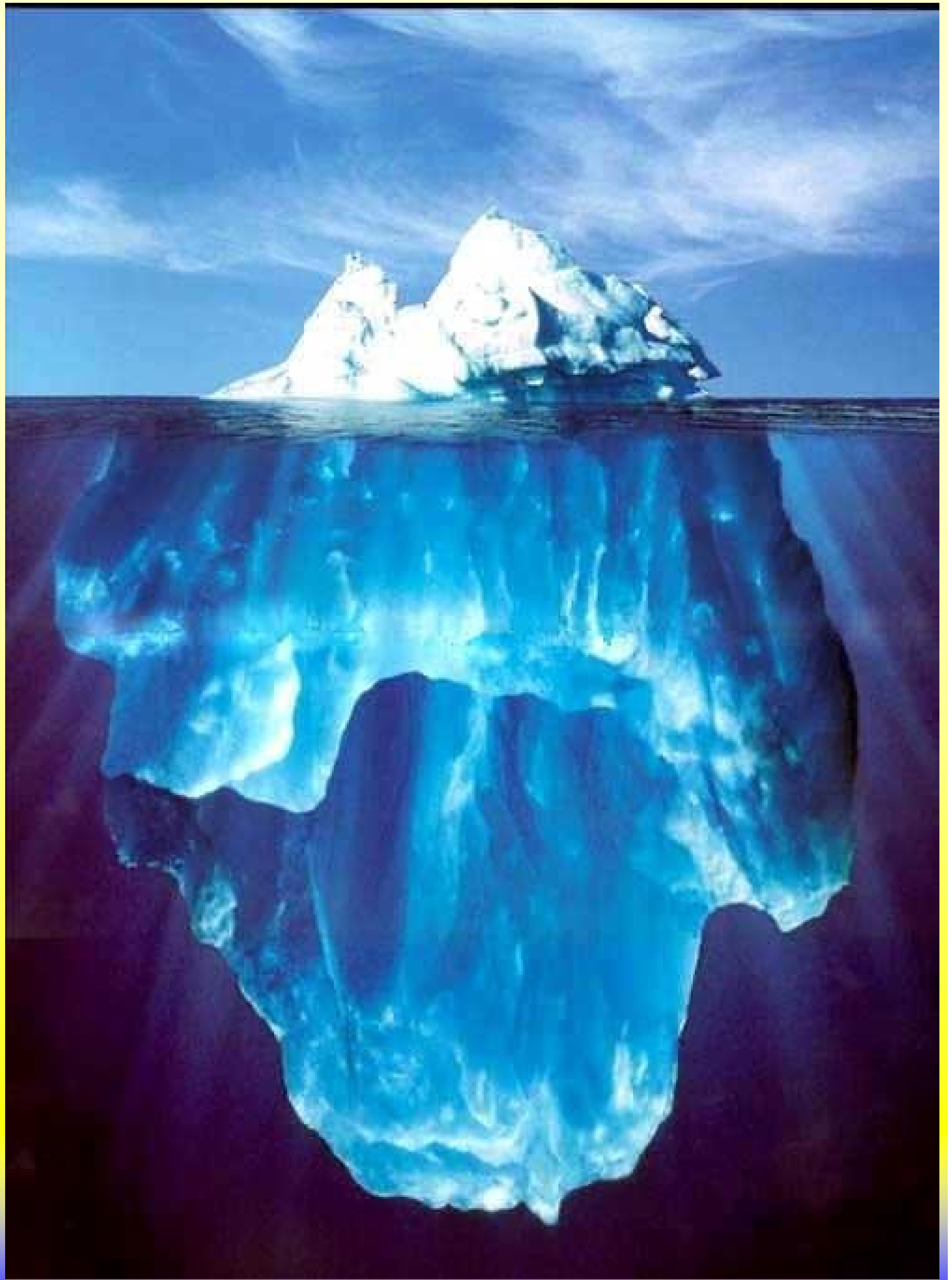
Water

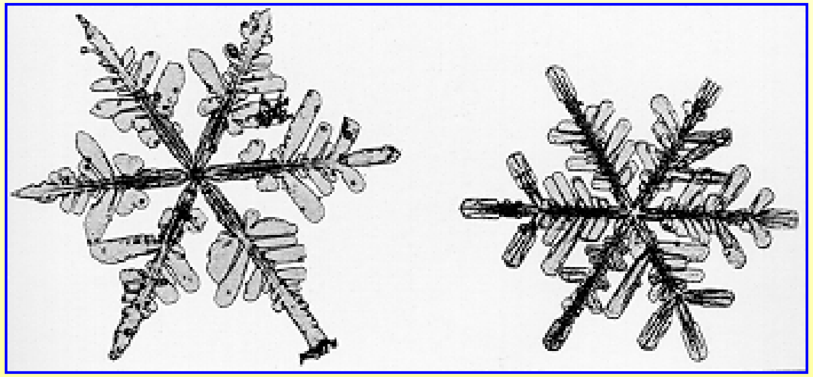
- 300 million tons of ice that fell as snow→
- Atmospheric water exists in all 3 phases:
  - vapour
  - liquid
  - solid

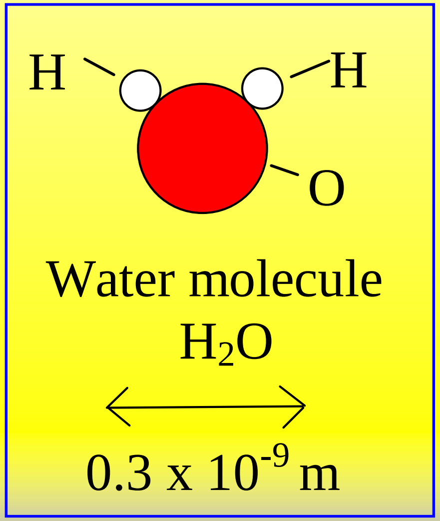


Picture courtesy Global Marine Drilling, Newfoundland

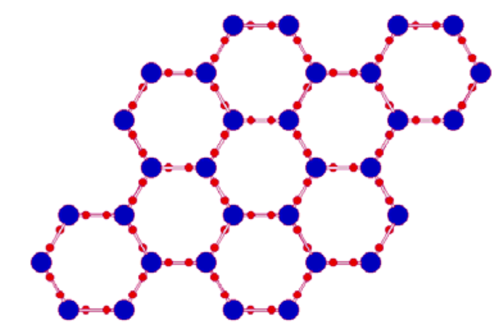
Water in the Atmosphere

- 3 **phases:**
  - vapour (gas)
  - liquid (drops)
  - solid (ice)
- Most important difference between phases: amount of energy and motion of water molecules
  - remember **latent heat**



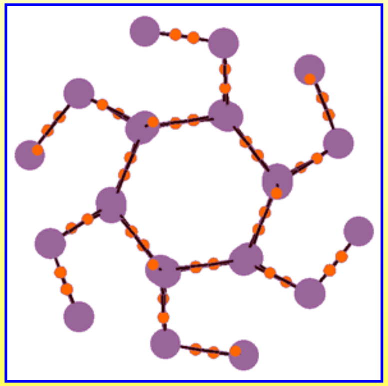


Solid, Liquid, Vapour



normal crystalline ice

- Most solids are crystalline, with molecules ordered in a highly symmetric repeated pattern
  - the 3D arrangement in a solid is the one that minimizes the energy at a given temperature and pressure

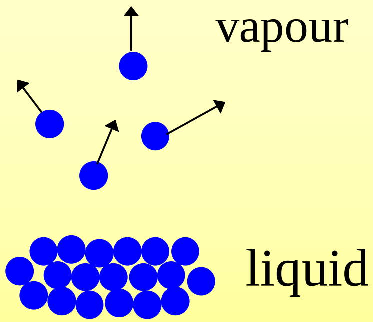


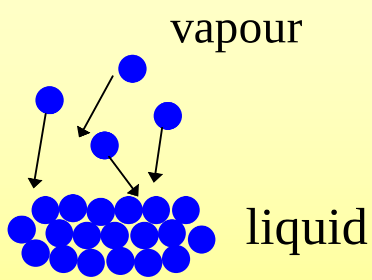
unusual ice

- In liquids, molecules are still close together but move relative to each other
- In the vapour, even neighbouring molecules are many diameters apart

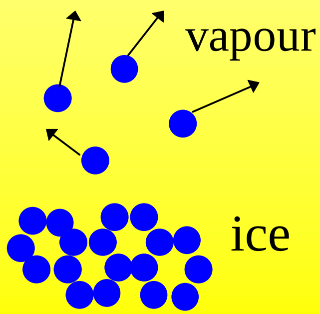
Phase Changes

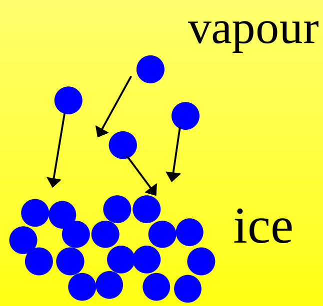
- Evaporation ⇔ Condensation





- Sublimation ⇔ Deposition



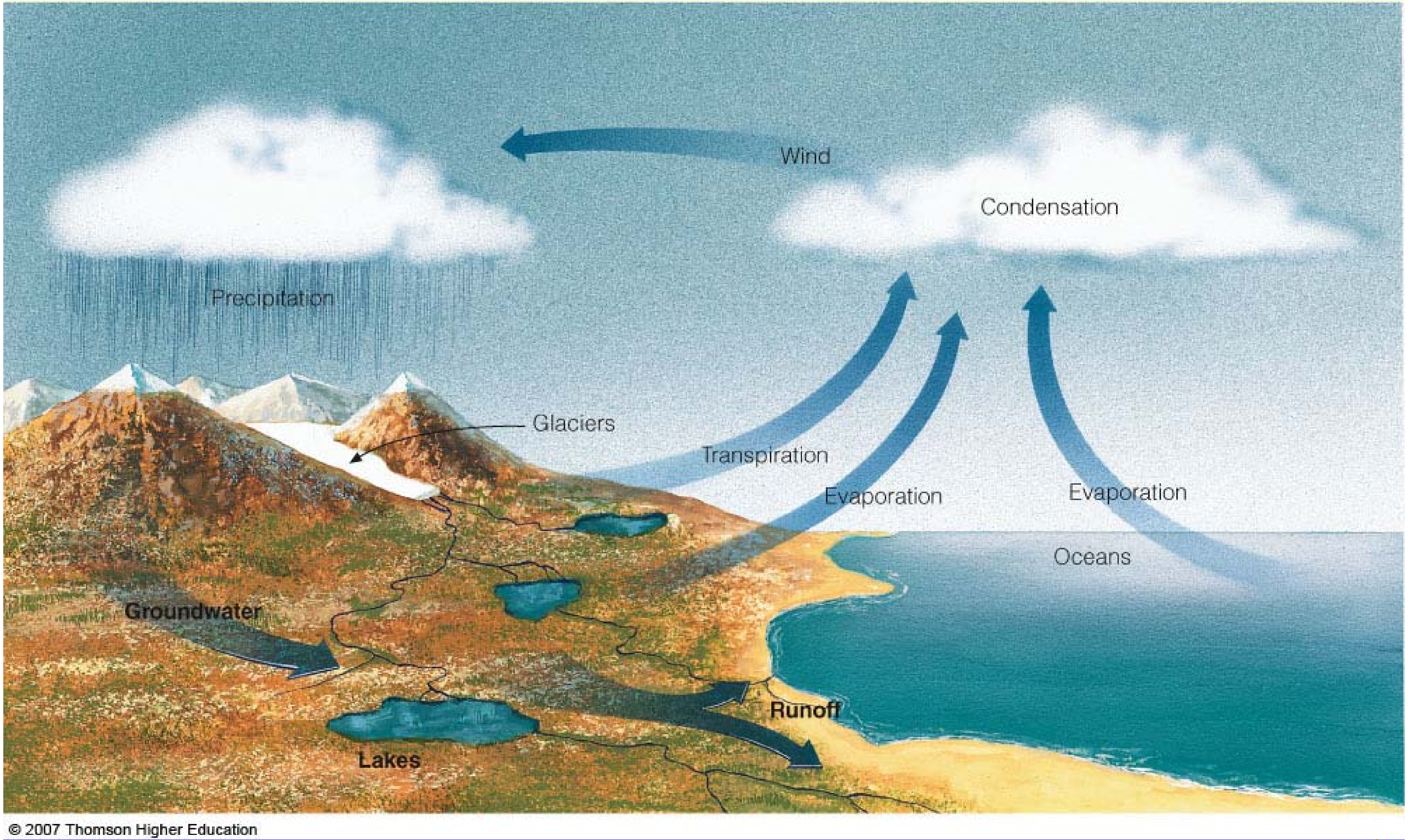


The Hydrological Cycle

- Circulation of water via the atmosphere [fig. 5.5/5.5/4.5] Total water vapour in atmosphere is equivalent to ~1 week's rainfall over world
  - sea: **evaporation** (solar energy) 85% of water to atmosphere
  - atmosphere: **condensation** (latent heat); **precipitation**
  - land: **runoff** to sea
  - direct evaporation from ground and lakes + **transpiration** from plants (15% water into atmosphere)

South of France

Ahrens' hydrological cycle



Courtesy: Thomson Higher Education

Measuring Water Vapour: Humidity

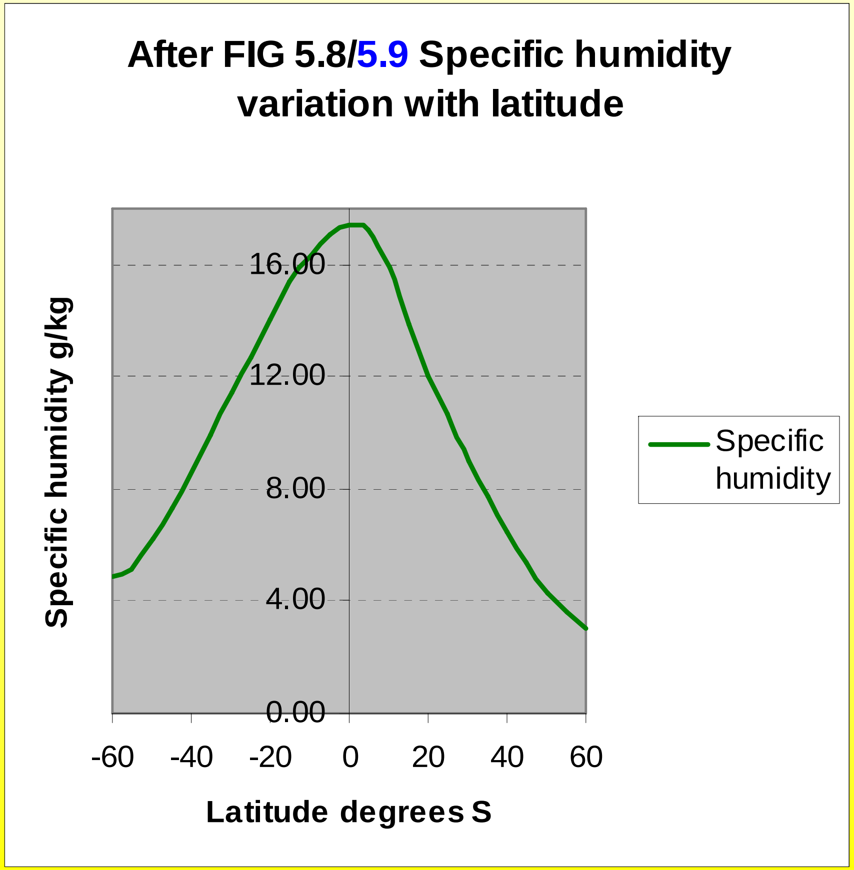
- Humidity is measured in several ways
- **Specific humidity**: [page 109/113/89]

$$Specific\ \ humidity = \frac{mass\ \ of\ \ water\ \ vapour}{total\ \ mass\ \ of\ \ air}$$

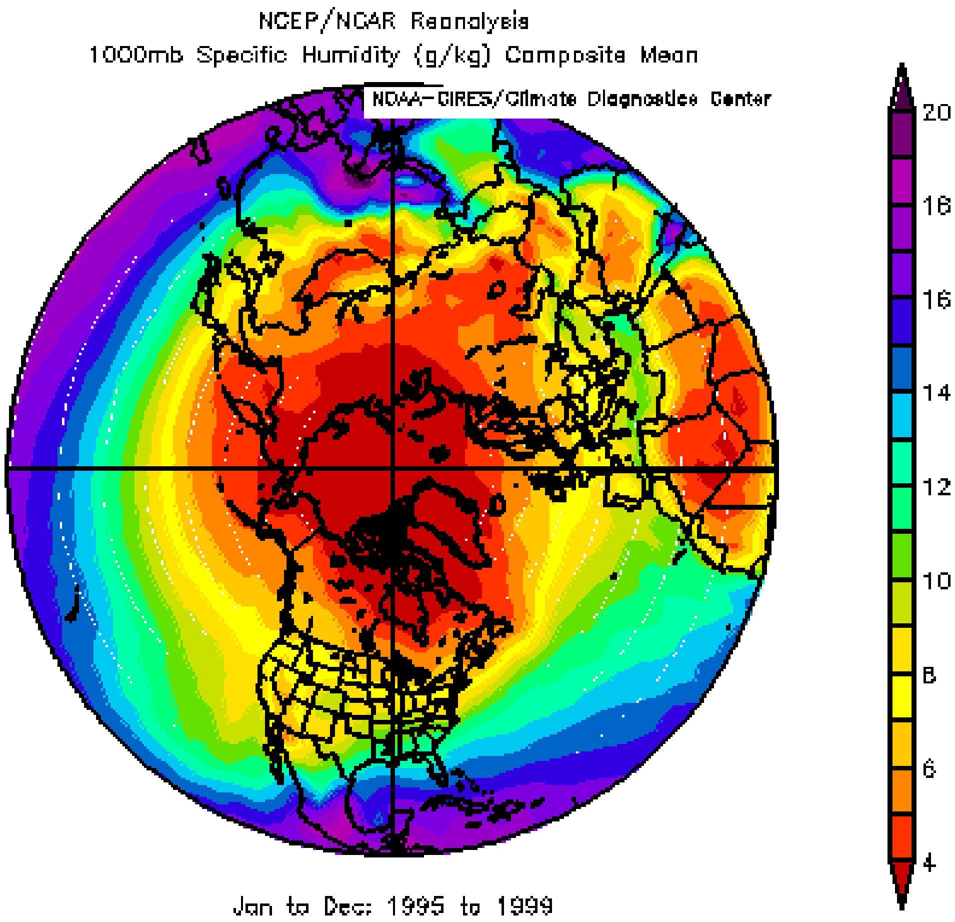
  - e.g. specific humidity of 10 g kg^{-1}
- **Parcels of air** move along, or up and down, keeping more or less the same composition
  - a parcel of air preserves its *specific humidity*

Average Specific Humidity

- Fig 5.9/5.9/4.9 shows that across the globe, averaged over the year, the specific humidity decreases from equator to pole
  - greater heat at equator evaporates more water
  - cooler polar air is saturated with less water vapour

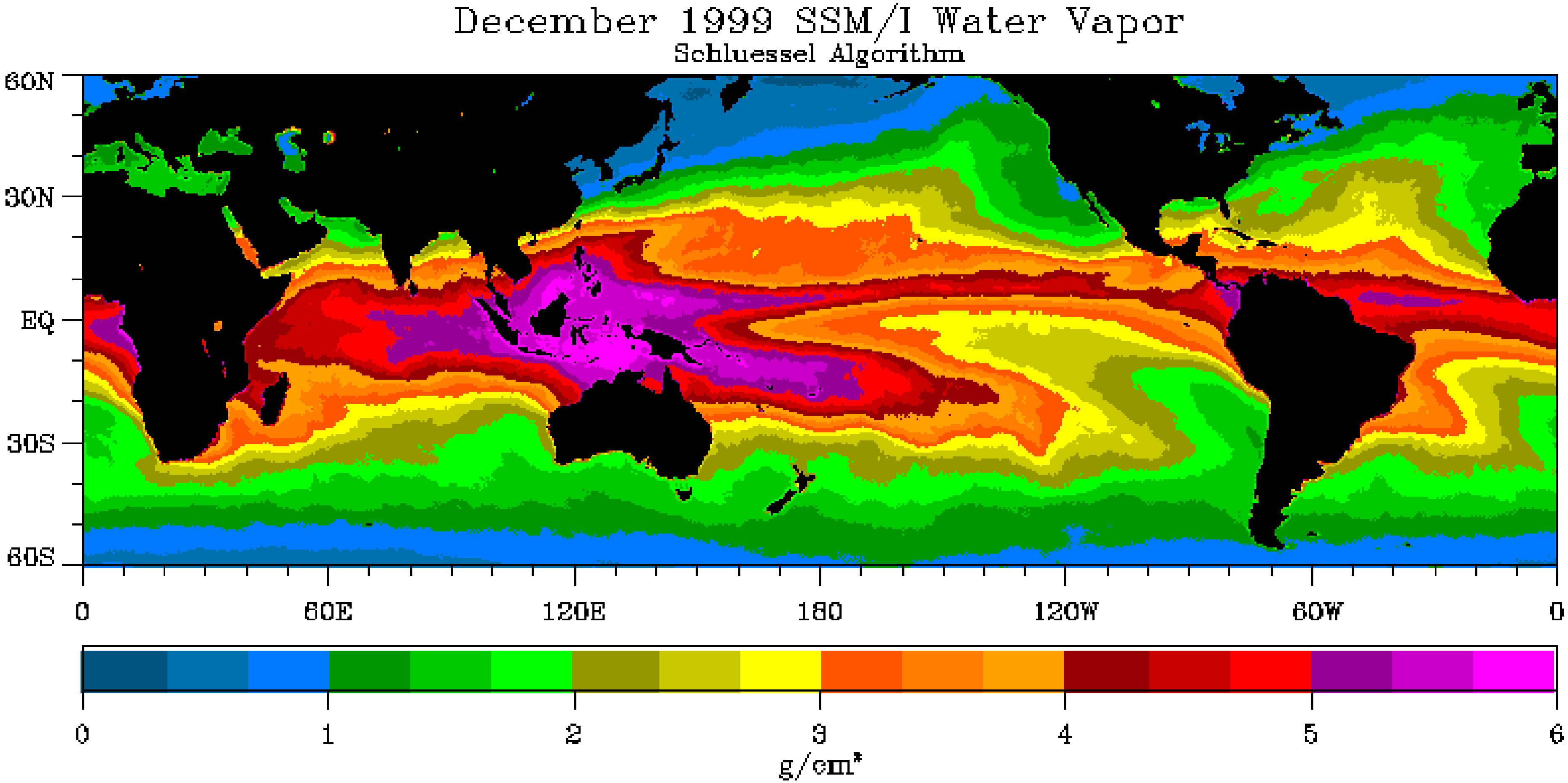


Graphic Example of Specific Humidity



- Northern hemisphere 5 year average of specific humidity from satellite observations
  - note the modifying influence of the continents

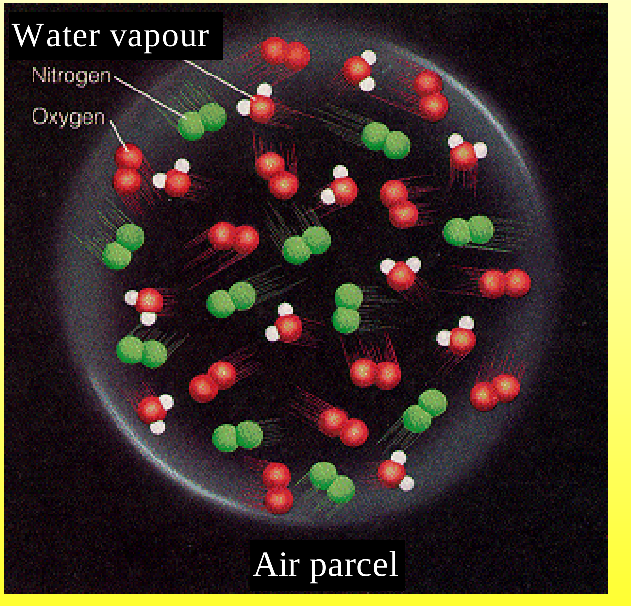
Water Vapour Content



- Typical monthly water vapour column plot from satellite observations

Vapour Pressure

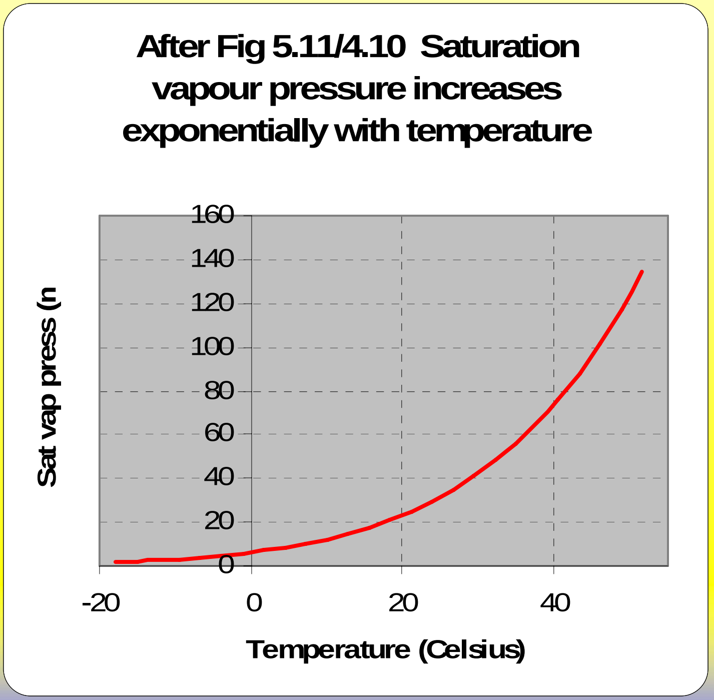
- A measure of the amount of water vapour in the atmosphere is the pressure that the water molecules alone exert – **water vapour pressure** [page 110/114/90]



- The fraction of pressure exerted by one gas in a mixture of gases depends on the fraction of molecules of the one gas
    - e.g. if the total atmospheric pressure is 1000 mb and there is 1% of water by number of molecules, then the ***water vapour pressure*** is 1% of 1000, i.e. 10 mb

Saturation Vapour Pressure

- **Saturation vapour pressure** is the maximum vapour pressure of water at a given temperature [fig. 5.12/5.10/4.10]
  - if any more water is added, condensation takes place



Iceland

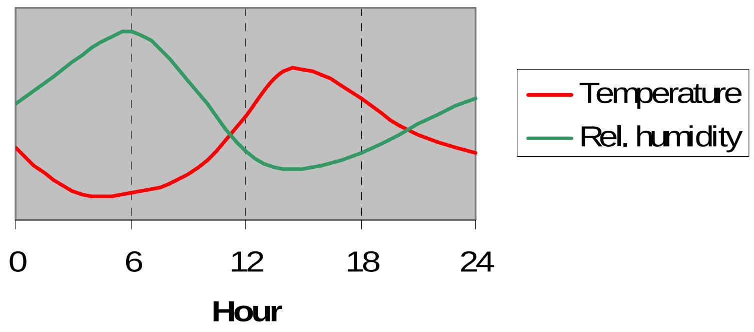
Relative Humidity

- The most common measure of water vapour in the atmosphere is **relative humidity** [p. 112/117/93]

$$\text{Relative humidity} = \frac{\text{actual vapour pressure}}{\text{saturation vapour pressure}} \times 100\%$$

- relative humidity is the % ratio of: *content/capacity*
- relative humidity is what we naturally sense
- if a packet of air cools, its relative humidity increases

FIG 5.13/4.12 Daily variation of relative humidity and temperature on a calm day

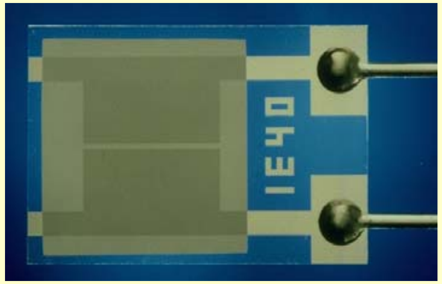


Dew Point

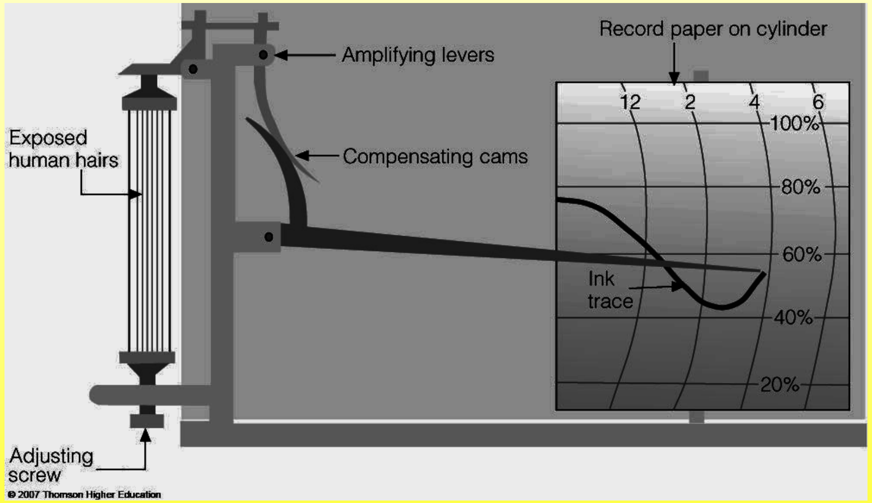
- **Dew point** is the temperature to which a packet of air would have to be cooled for water vapour saturation to occur
  - dew point is useful in predicting how likely fog or cloud, or dew, is to form
  - the **difference between air temperature and dew point** is a measure of the **relative humidity** of air; the **larger the difference**, the **smaller** the relative humidity

Donside

Measuring Humidity



- A device that measures humidity is called a **hygrometer**; sometimes, a **psychrometer**
  - electrical sensor (met it earlier)
  - infrared remote sensor
  - hair hygrometer, 2.5% change in length from dry air to humid air

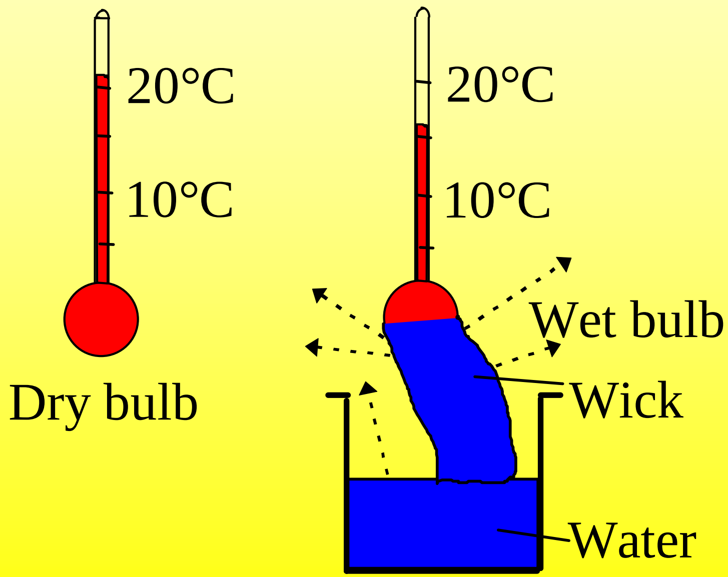


Courtesy Thomson Higher Education

  - measurement by cooling to dew point
- Wet & dry bulb psychrometer (next slide)

Psychrometer

- Device consists of 2 thermometers, one with its bulb covered in a wick dipped in water
- Evaporation from the wet bulb cools one thermometer
- The amount of cooling depends on how far the dew point is below the air temperature



- A look-up table determines the relative humidity (and dew point)

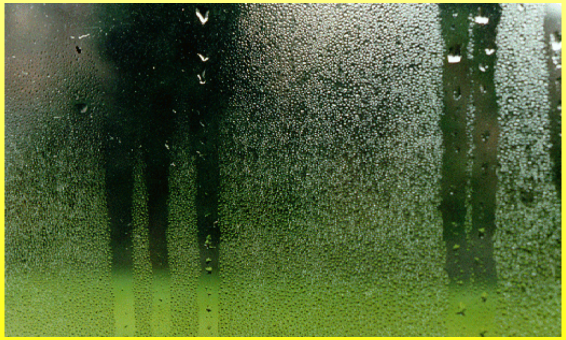
Psychrometer Example

- Take readings
  - dry bulb temperature = 21°C
  - wet bulb temperature = 16°C
  - calculate **depression of wet bulb** as 21 - 16 = 5°C
- Look up Appendix D in Ahrens' textbook
  - tables show dry bulb temperature (downwards) and depression (horizontally)
  - from table D.1, **Dew-point = 13.5°C**
  - from table D.2, **Relative humidity = 60%**
  - note 21°C is between 2 rows: - interpolation needed

Relative Humidity Calculations

- Table 1, page 117/122/98, gives the saturation vapour pressure of water for different temperatures
- *What is the vapour pressure in a room at 21°C and relative humidity 50%?*
  - from table: sat. vap. press. at 21°C = 25 mb
  - hence 50% of 25 mb = **12.5 mb**
- *If the room cools to 8°C, will condensation appear on windows?*

Condensation streaming down a window



  - at 8°C, sat. vap. press. = 10.9 mb; **condensation** ✓
  - (table shows that 12.5 mb is sat. vap. press. at 10.2°C)