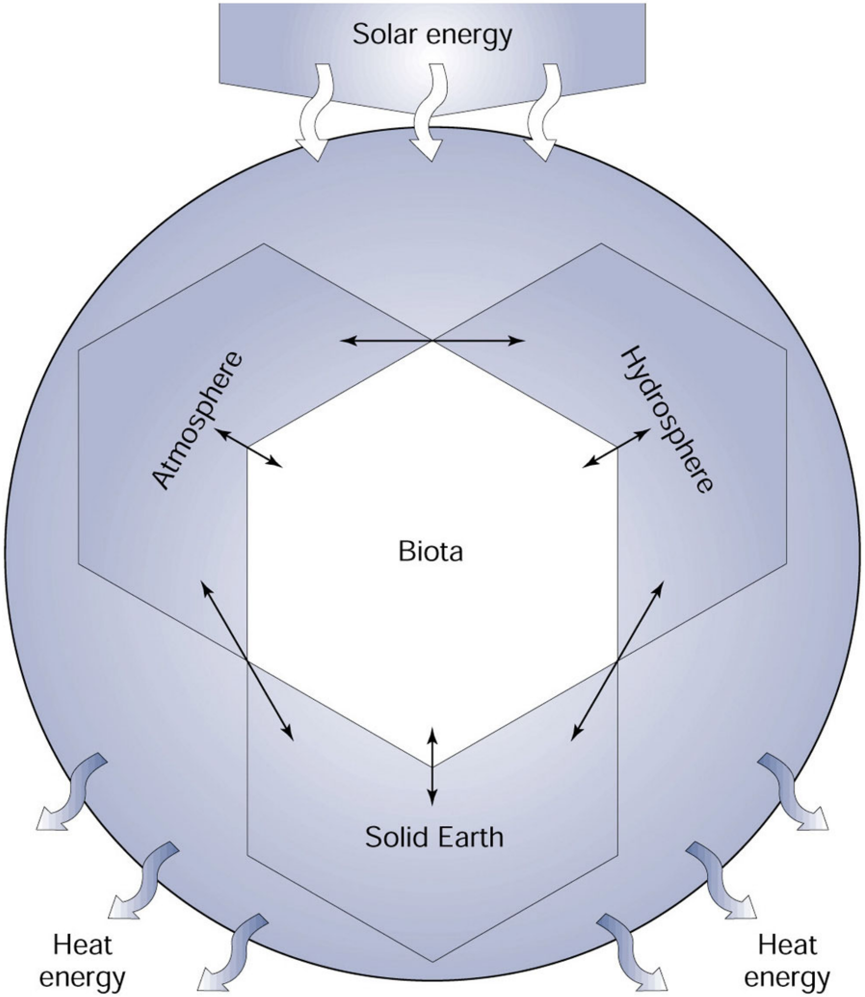
Observations of the Climate System I

Reading: GPC Ch 1

Outline:

- Climate system
- Atmospheric temperature, lapse rate
- Atmospheric humidity, Clausius-Clapeyron relation
- Rainfall, cloudiness
- Sea level pressure
- Hydrostatic balance, relationship to pressure



The (earth) climate system in its most general form consists of **Atmosphere, Hydrosphere (including cryosphere),** Biosphere, Lithosphere and the interactions between them

Climate can be thought of as the **state** of this system at a particular time (dynamical definition of climate: ensemble of all statistical properties of the climate system – all space and time scales)

Another (classical) definition of climate: ***synthesis of weather***

(time mean of variables defining the weather over a given time interval, from years to centuries – typically 30 y)

in a particular region.

No reference to dynamical processes explaining how climate is formed and how it evolves.

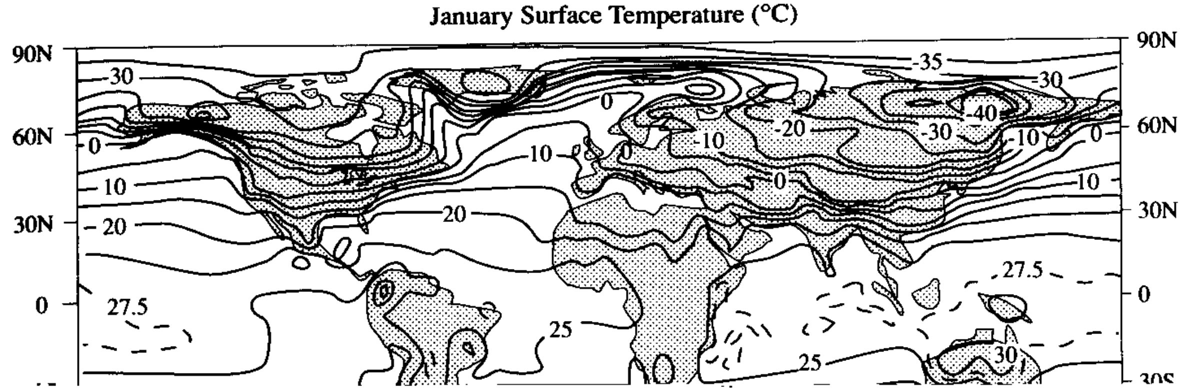
Definitions:

Annual (monthly) mean: average of a quantity over a year (month)

Seasonal or annual cycle: variation over one year

Annual cycle amplitude: (maximum - minimum) of a quantity over the year

Question: what do we measure to know what ‘climate’ is, and why?



Surface temperature

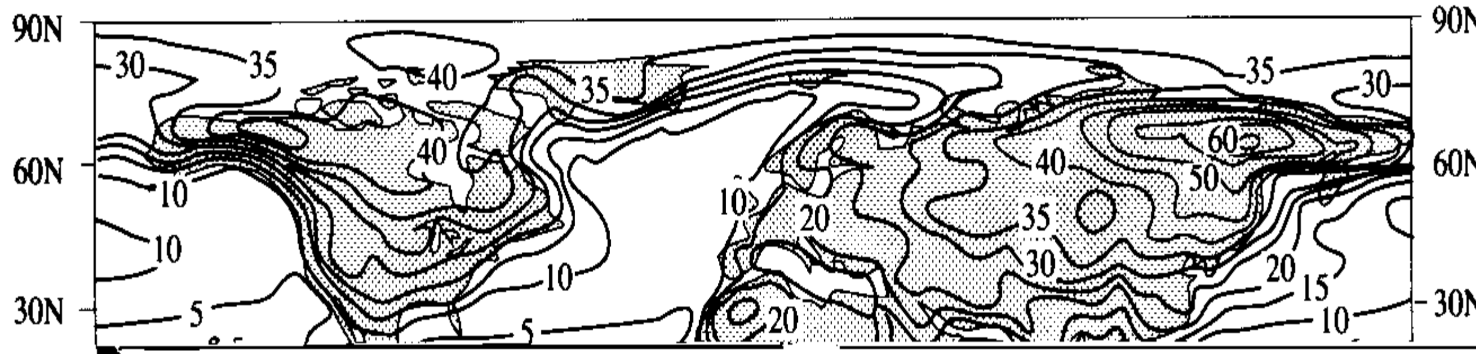
Usually measured in Celsius (degrees C) or Kelvin (K)

1 degree K = 1degree C

0 K = -273.16 C

Annual mean global average surface temperature ~287K

Annual Range of Temperature (°C)



Zonal averaged surface air temperature

Defn: zonal average = average of a quantity over all longitudes

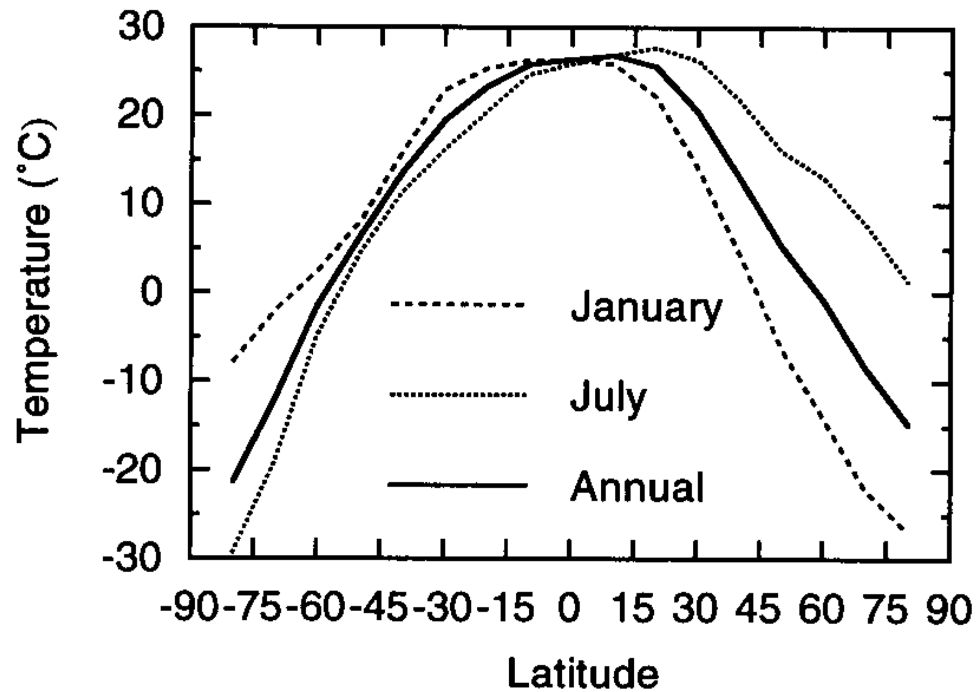
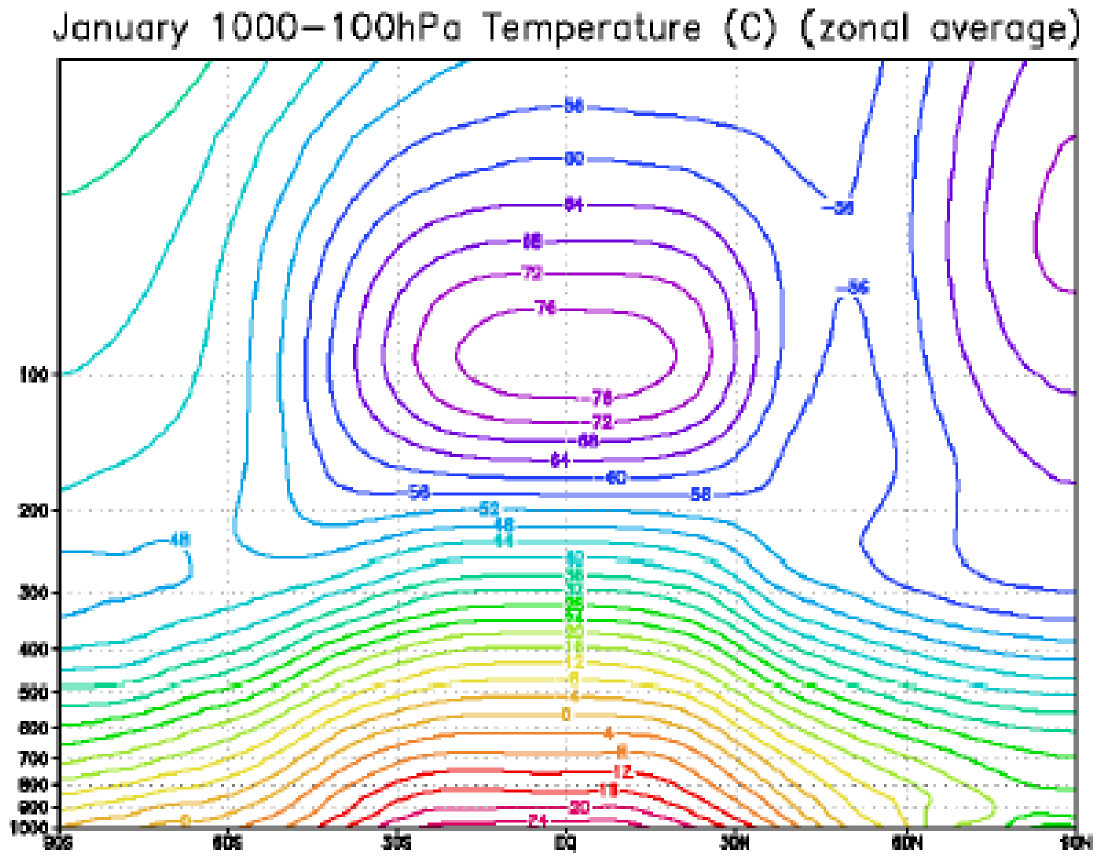


Fig. 1.5 Near-surface air temperature as a function of latitude for January, July, and annual-average conditions. [Data from Oort (1983).]

Zonal averaged January air temperature

Note: height here is expressed in pressure units (mb) - we’ll explain why later.



http://www.egs.uct.ac.za/workshops/mm5/Module_notes/S1/obsclimate.html

Defn: rate of change. Suppose $T(z)$ is temperature with height

define: *change* $\Delta T = T(z_2) - T(z_1)$ and

rate of change (with height) $\Delta T/\Delta z = (T(z_2) - T(z_1)) / (z_2 - z_1)$

$\Delta T/\Delta z$ is usually denoted dT/dz

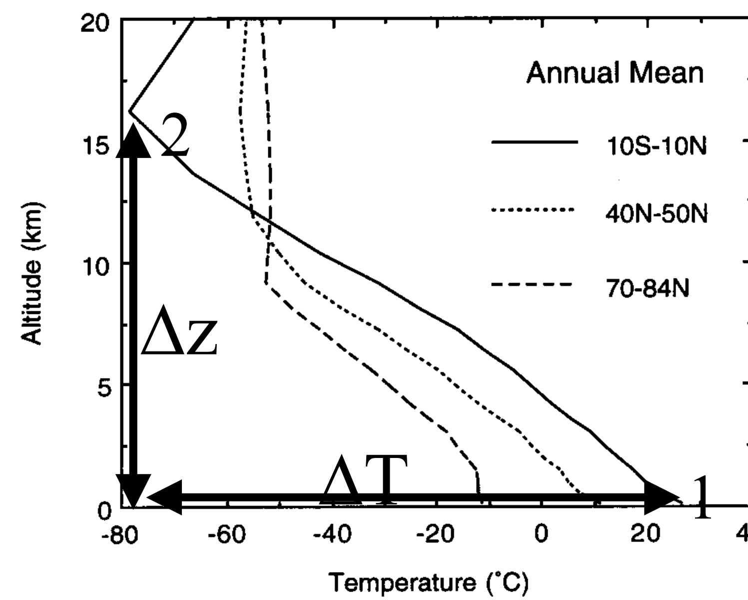
Ex: Calculate the rate of change of temperature with height 10S-10N for the troposphere:

$\Delta z = z_2 - z_1 = 17\text{-}0\text{km} = 17\text{km}$

$\Delta T = T_2 - T_1 = -80\text{C} - 27\text{C} = -107\text{C}$

$\Delta T/\Delta z = (-107\text{K})/17\text{km}$

$= -6.3$ K/km



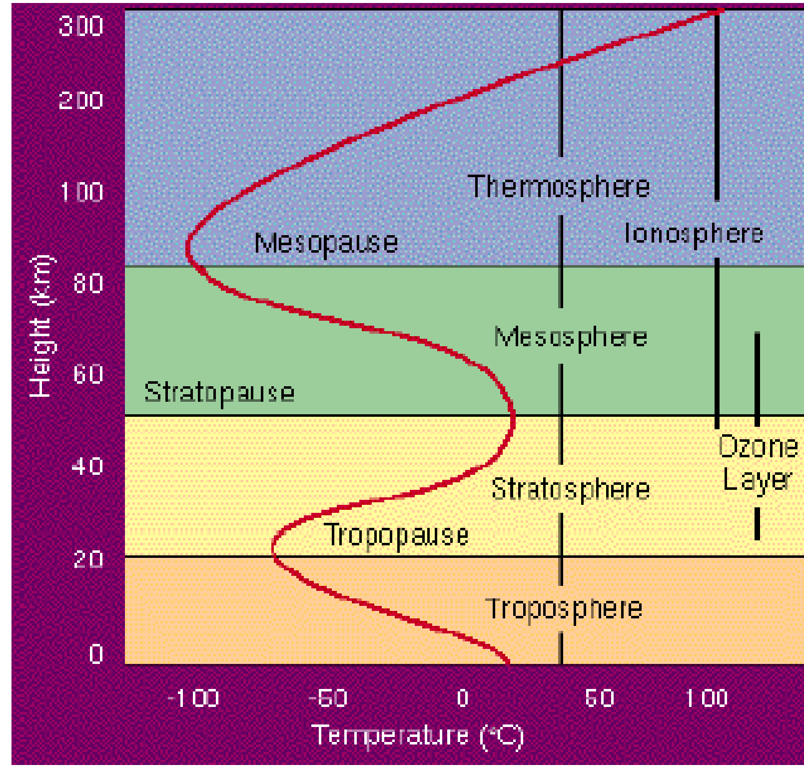
Annual-mean temperature profiles for the lowest 20 km of the atmosphere in three
'rom Oort (1983).]

Typical Atmospheric temperature with height

- Four 'layers': Troposphere, stratosphere, mesosphere, thermosphere
- **Defn: Lapse rate** is rate of change of temperature with height, multiplied by -1

$$\Gamma = -\Delta T/\Delta z$$
$$= -dT/dz$$

- ~6.5 K/km in troposphere



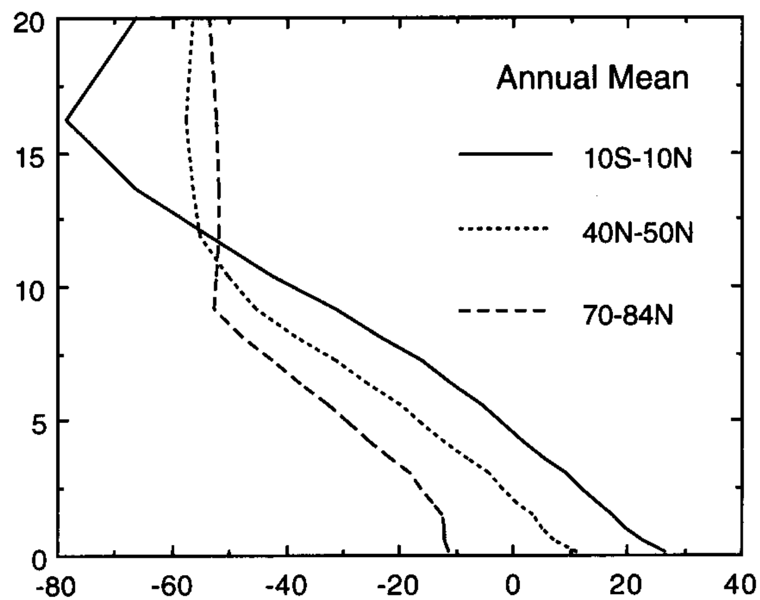
It's important to appreciate how thin the atmosphere is relative to the earth diameter

Tropopause: ~15km

Radius of earth: ~6356km

Troposphere thickness ~ 0.24% earth radius!

http://www.atmosphere.mpg.de/enid/1lq.html



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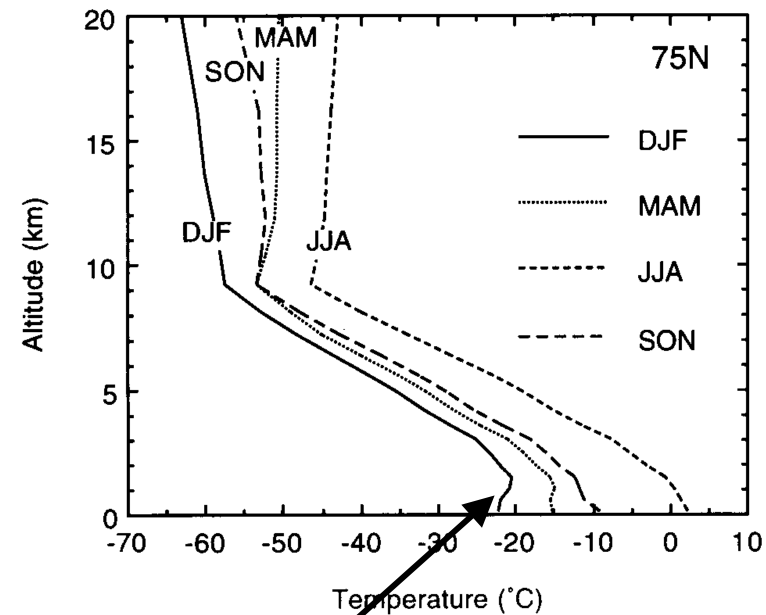


g. 1.4 Seasonal variation of temperature profiles at 75°N. [Data from Oort (1983).]

Lapse rate varies in latitude and season

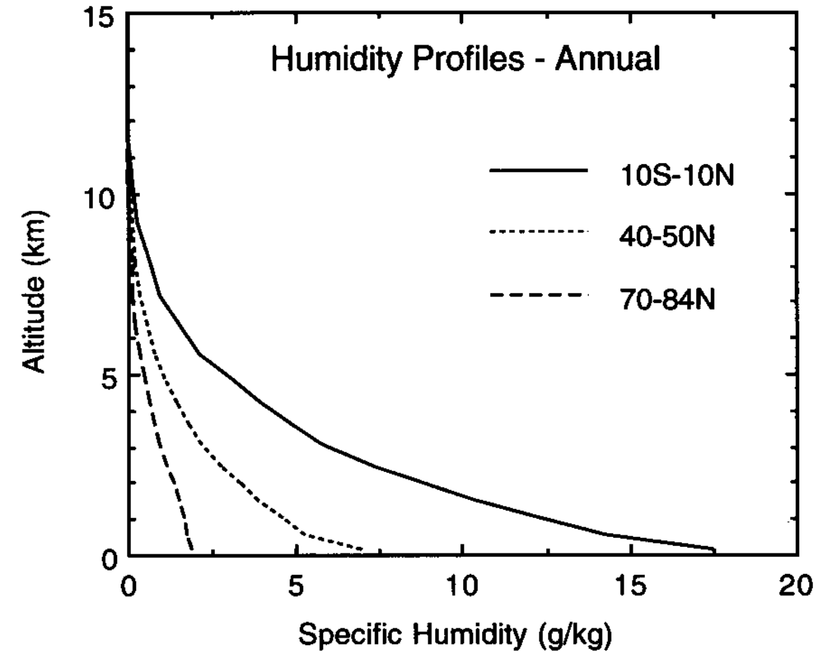
Def: temperature inversion= region of negative lapse rate

Atmospheric humidity

Moisture in the air is generally confined to the lowest few kilometers of the atmosphere

Def: specific humidity = ratio of the mass of vapor in a certain volume to the total mass of air and vapor in the same volume.

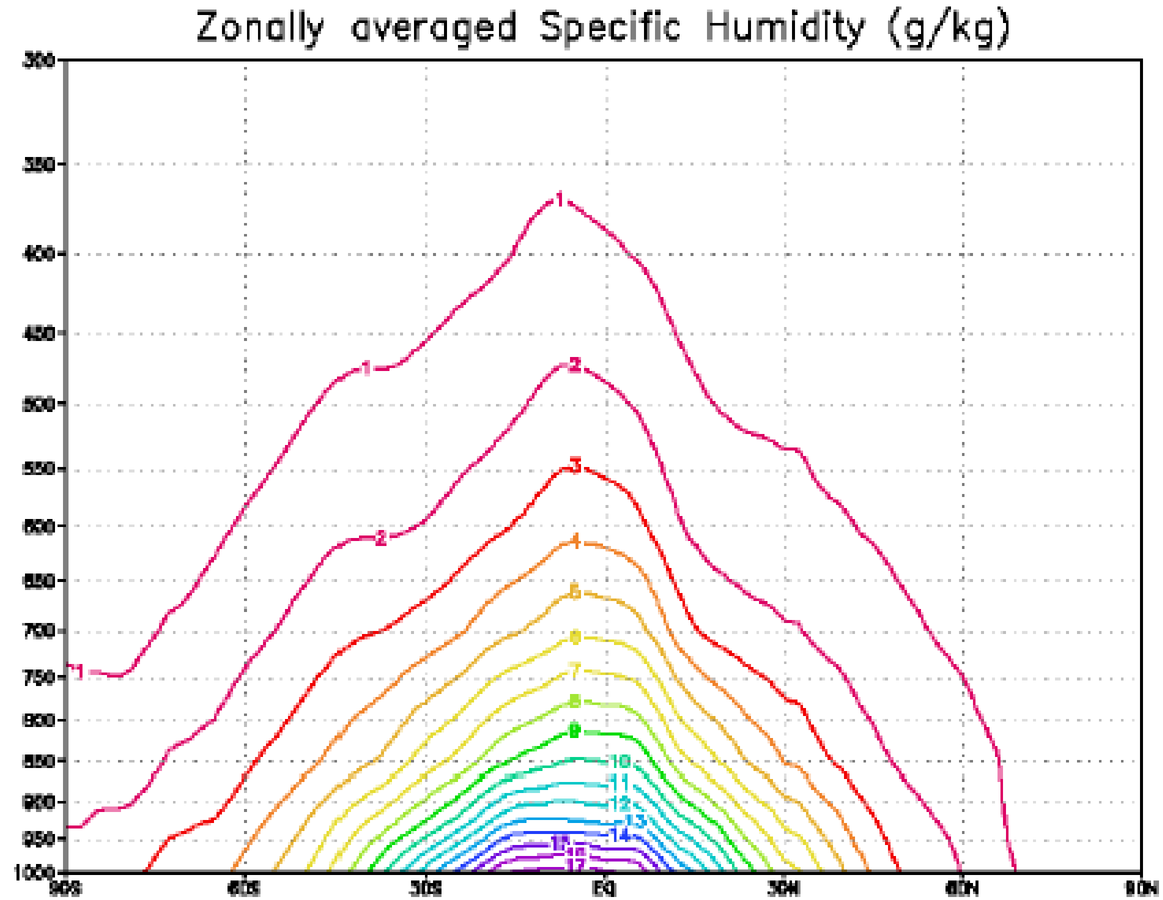
Specific humidity is often reported in (g/kg)



:ific humidity or mass mixing ratio of water vapor for annual-mean l on the equator, 45°N and 75°N. [Data from Oort (1983).]

January zonal mean specific humidity.

How does it compare to zonal mean temperature?



http://www.egs.uct.ac.za/workshops/mm5/Module_notes/S1/obsclimate.html

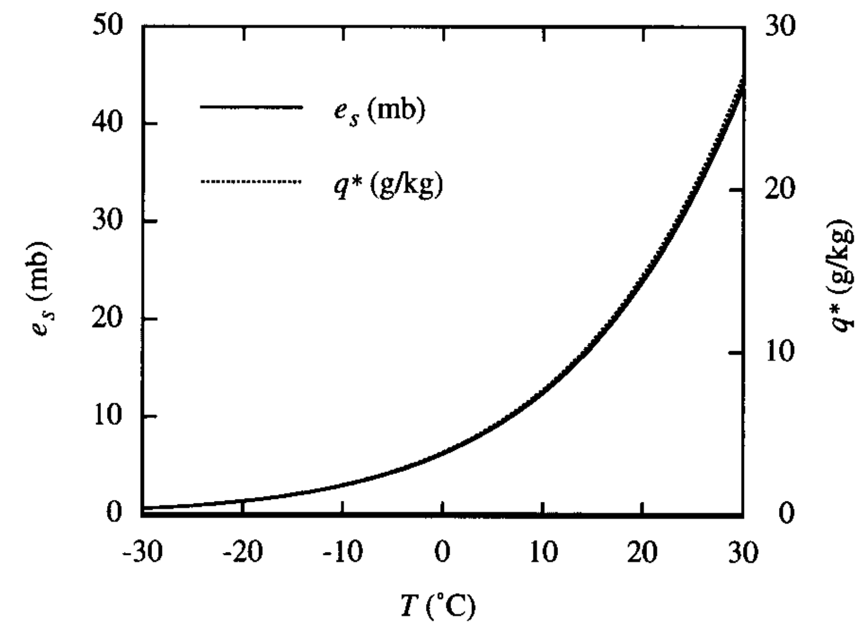
Clausius-Clapeyron Relation (GPC appendix B)

Defn: vapor pressure is the pressure exerted by the (water) vapor. It is a measure of how much vapor is contained in the air.

Saturated vapor pressure (specific humidity) is the maximum amount of vapor the air can hold.

It is a function of air temperature.

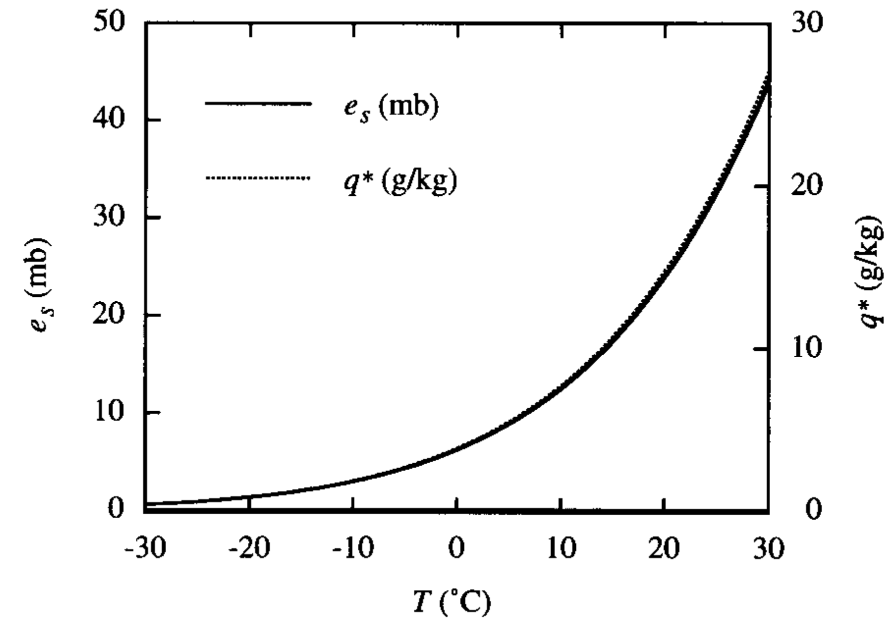
The **Clausius-Clapeyron** relationship gives the saturation vapor pressure as a function of temperature.



ation vapor pressure and specific humidity as junctions of tempe

A very important property (for climate) is that the saturation specific humidity increases nonlinearly with increasing temperature.

At typical earth temperatures, a 1% change in temperature of ~3K implies about a ~20% change in saturation vapor pressure



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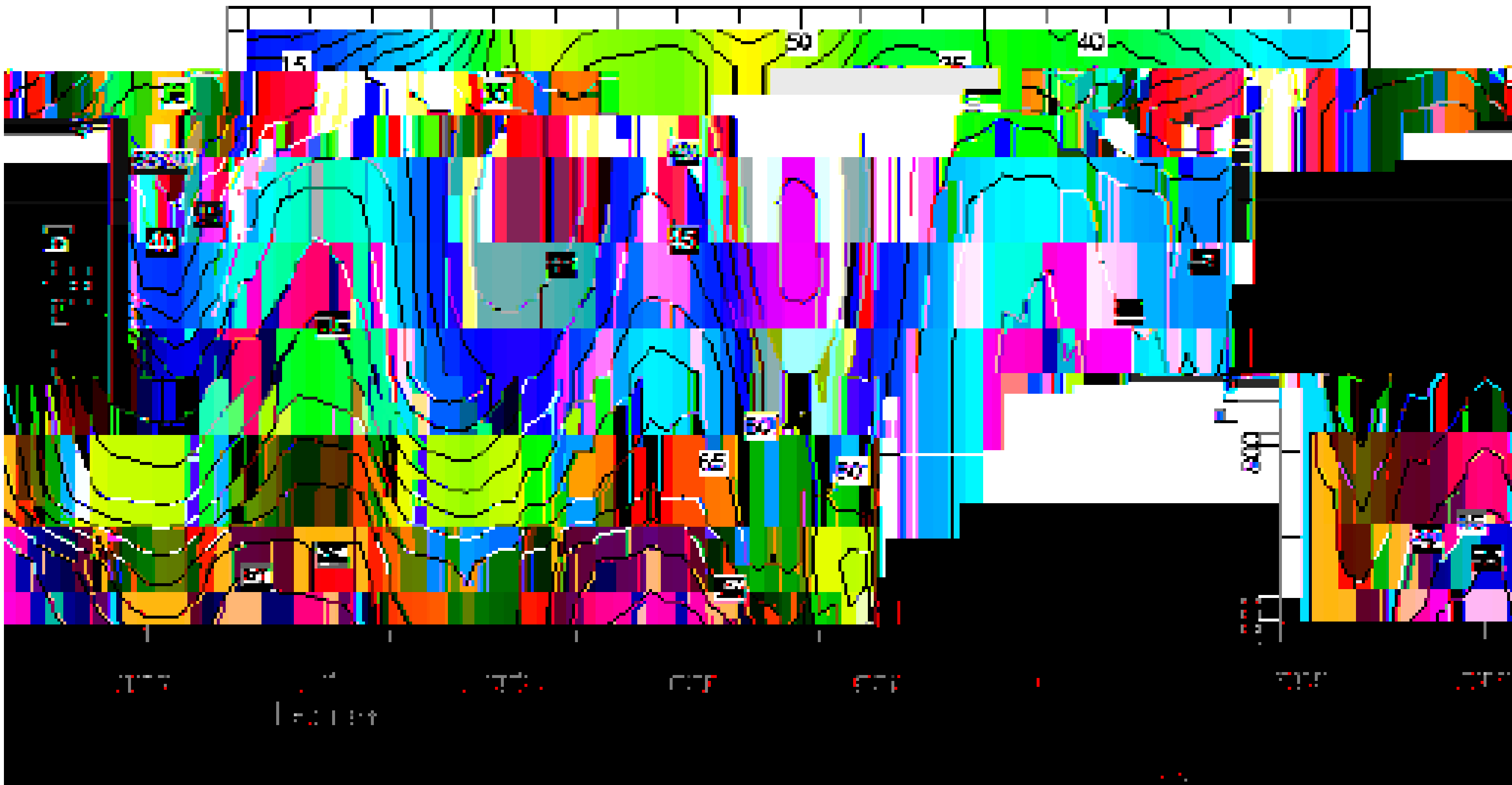
Defn: Relative humidity

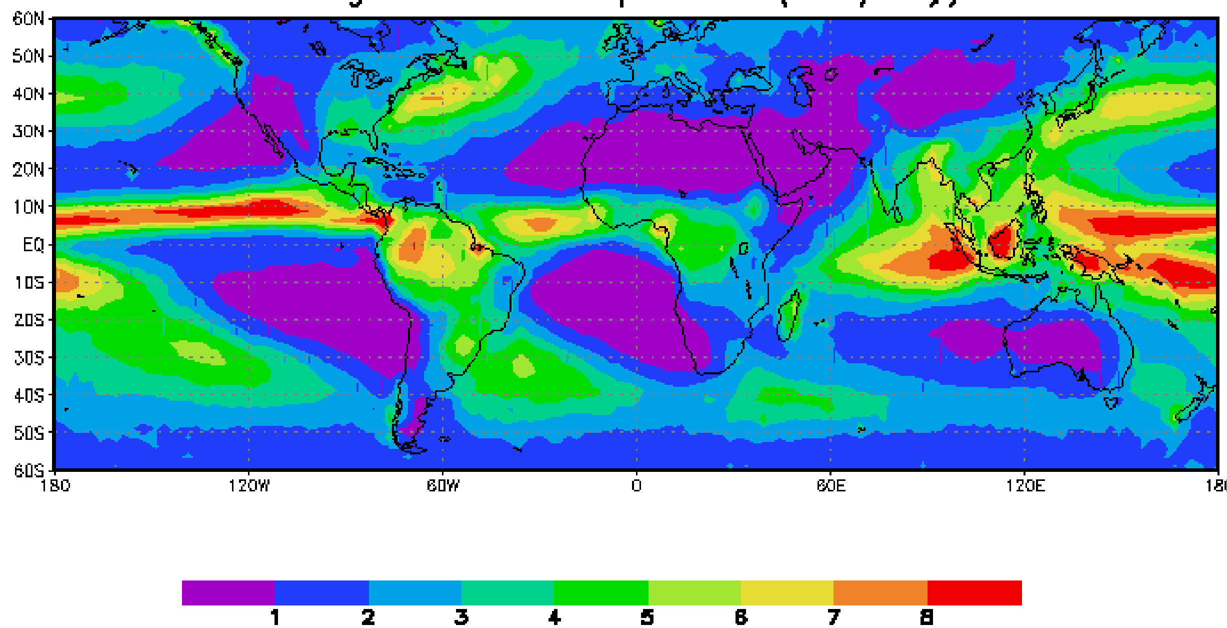
= (specific humidity/saturation specific humidity) x 100%

Expressed as a percentage

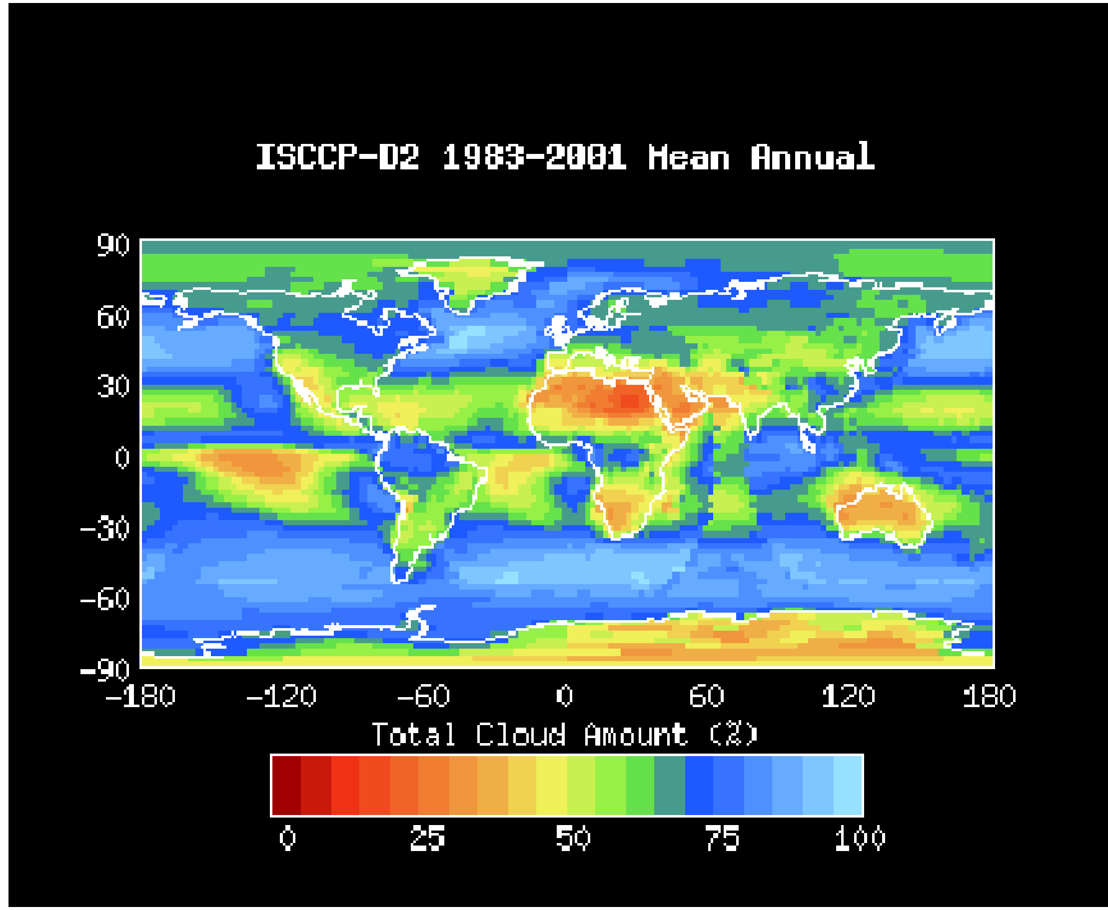


Rainfall: measured in mm/day. Note that rainfall is concentrated in two latitudinal bands of the earth: 1) the tropics 20S-20N (known as the intertropical convergence zone (ITCZ); and 2) the midlatitudes (around 45N and S). The subtropics (around 30N and S) are generally dry.

Annual Average GPCP Precipitation (mm/day): 1987–99



Cloudiness: measured as a percentage covered of the area. Regions that are rainy are cloudy, but some dry regions (like off the western coasts of the Americas in the subtropics) are cloudy but dry.



(http://isccp.giss.nasa.gov)

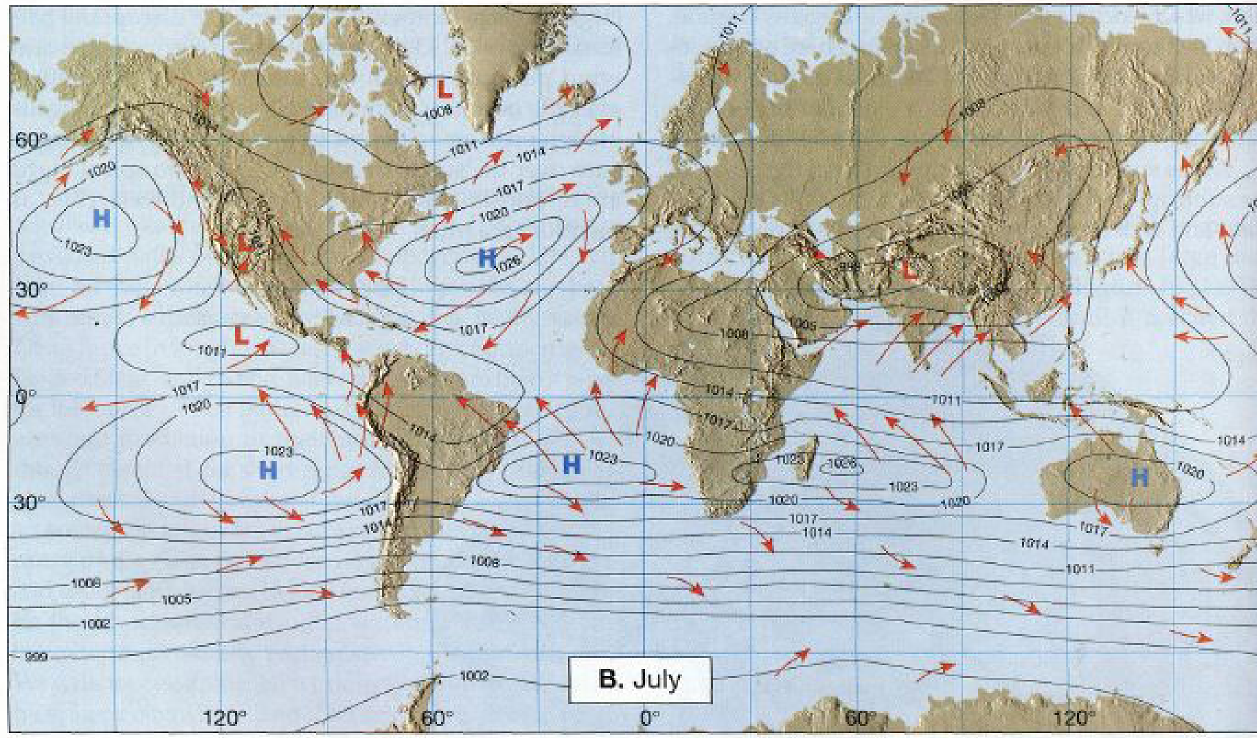
Sea level pressure

The pressure of the air at sea level. Note that the pressure is the weight of the air above per unit area. 'H' denotes pressure maxima ('highs').

Units: 1Pascal (Pa) = 1 N/m^2

Conventionally reported in millibars:

1mb = 100Pa

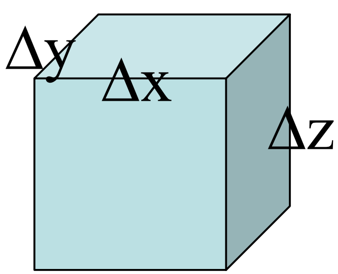


Hydrostatic balance

Concept of **Balance:** Suppose X is a property that generally changes with time because of various ‘forces’ that act on it. X will stay constant only when the various forces applied to it cancel (are ‘balanced’): i.e.

$\Delta X/\Delta t$ = (sum of forces on X) = 0

Now: it is useful to visualize air as infinitesimal parcels with dimensions $(\Delta x, \Delta y, \Delta z)$ and mass Δm (= $\rho \Delta V$ where ρ is the air density):

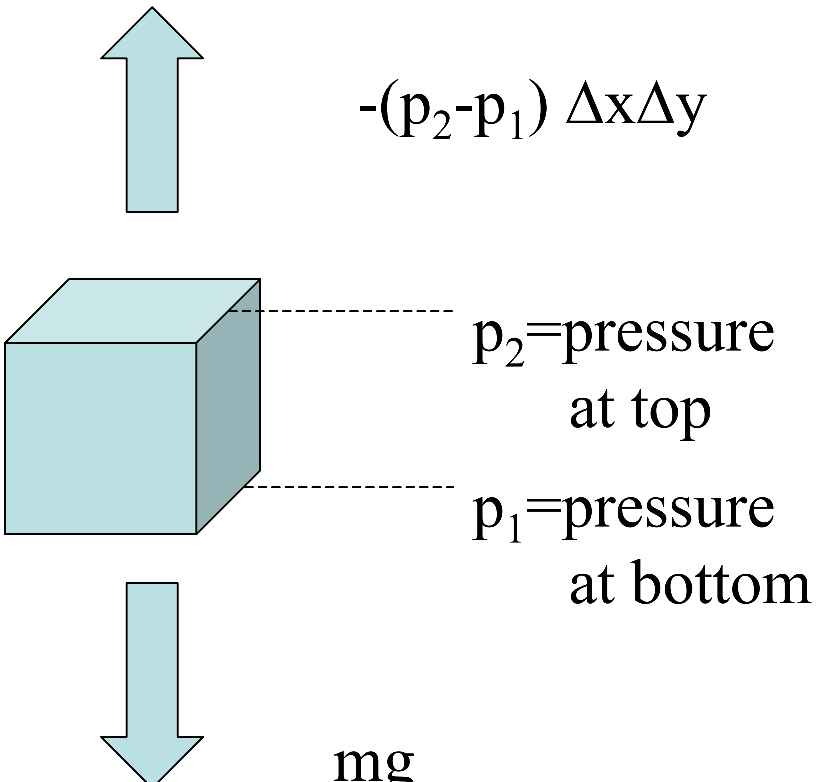


Newton’s 2nd law (“F=ma”) states that the sum of all forces on the parcel equals the mass times acceleration on the parcel (a=dv/dt)

$$\sum(\text{all forces on parcel}) = \Delta m \, dv/dt$$

Hydrostatic balance comes about when the the vertical forces on the air parcel sum to zero - air isn't accelerating vertically. This is generally a good approximation for the air in the atmosphere.

i.e. $\sum$(all forces on parcel) = m dv/dt = 0



$\therefore -(p_2-p_1)$ x area - mg = 0

Divide both sides by volume ΔV to obtain

$\Delta p/\Delta z = -\rho g$ or
$dp/dz = -\rho g$

Note what the relationship is saying: its saying that the change of the air pressure going up with height depends on the density of the air (and the acceleration due to gravity): $dp/dz = -\rho g$

Ideal gas law gives (for an 'ideal' gas) the density ρ of the gas as a function of its pressure (p) and temperature (T):
$\rho = p/RT$ or $p = \rho RT$ where R is the gas constant which varies with the type of gas. For the dry atmosphere, R = 287 J/(K kg). For water vapor it is 461 J/(K kg).

Given the ideal gas law and the assumption of a constant air temperature (OK to first approximation), one can obtain a simple expression for the change of air pressure as a function of height (next slide)

$$g = -\frac{1}{\rho}\frac{dp}{dz} \tag{1.2}$$

For an ideal gas, pressure (p), density (ρ), and temperature (T) are related by the formula

$$\boxed{p = \rho RT} \tag{1.3}$$

Ideal gas law

where R is the gas constant. After some rearrangement, (1.2) and (1.3) yield

$$\frac{dp}{p} = -\frac{dz}{H} \tag{1.4}$$

where

$$H = \frac{RT}{g} = \text{scale height} \tag{1.5}$$

If the atmosphere is *isothermal*, then the temperature and scale height are constant and the hydrostatic equation may be integrated from the surface, where $p = p_s = 1.01325 \times 10^5$ Pa, to an arbitrary height, z, yielding an expression for the distribution of pressure with height.

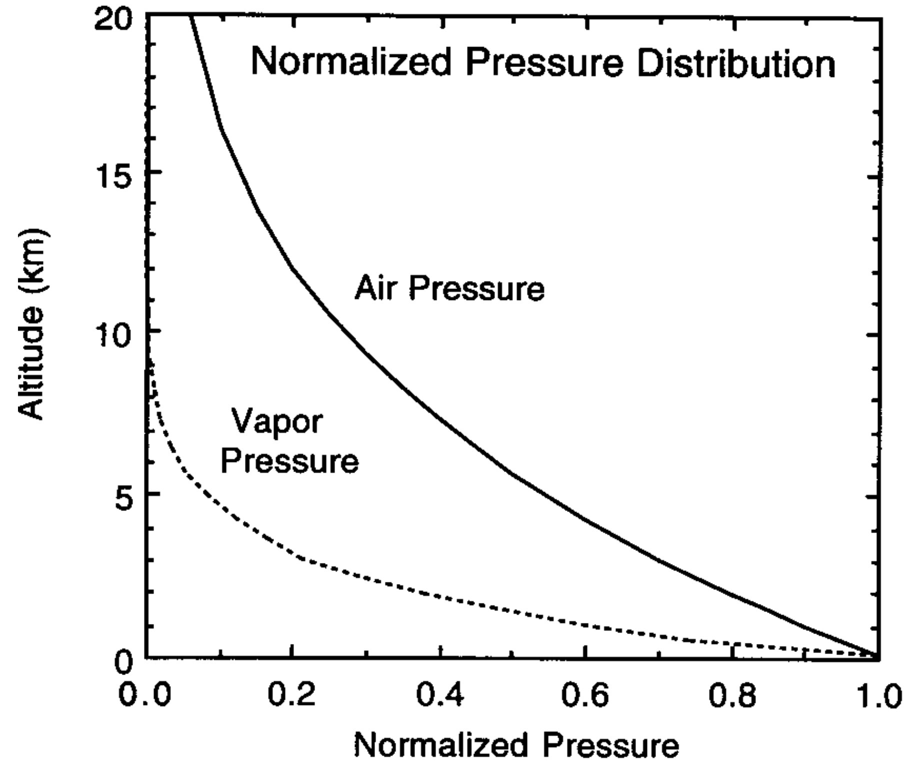
$$\boxed{p = p_s e^{-z/H}} \tag{1.6}$$

The pressure thus decreases exponentially away from the surface, declining by a factor of $e = 2.71828$ every scale height. The scale height for the mean temperature

Pressure is related to height

Observed *normalized* pressure (meaning air pressure divided by the pressure at the surface) distribution as a function of height.

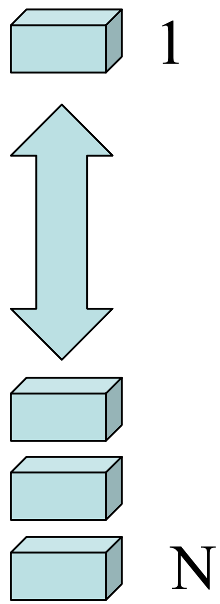
Note that the monotonic relationship between height and pressure allows us to use pressure as a measure of height.



l distributions of air pressure and partial pressure of water vapor as functions of alti- annually averaged conditions. Values have been normalized by dividing by the sur- !5 and 17.5 mb (millibars), respectively.

We now show that surface pressure is equivalent to the weight of the air above. Divide up the atmosphere above into air parcels (below) with unit horizontal area, and sum all the individual masses

Top of atmos



Sfc

$\sum^{N}_{1} \Delta m_i = - \sum^{N}_{1} \Delta p_i/g$ by the hydrostatic balance

Note that when you sum the RHS the pressures at the interfaces of the individual parcels cancel except for the pressure at the very top and bottom:

mass of column = $-(p_{top}-p_{sfc})/g$ but $p_{top}=0$ Pa so

p_{sfc} = mass of column x g = weight of column (with a unit horizontal 'footprint')