Conduction, Convection and Sensible and Latent Heat

So far we have only considered transfer of heat through the atmosphere by radiative processes.

Energy may also be transferred through *conduction* and *convection*.

Conduction:

The process of conduction occurs by the transfer of kinetic energy from one molecule to an adjacent one. The process will be most efficient when the molecules are tightly constrained in solids and especially when there is a defined structure to the material such as a metal. Gases, including air, have low thermal conductivities and so the atmosphere is a poor conductor of heat. Although conduction can be neglected in the atmosphere it the main mechanism by which heat is transferred away from the warm surface through the underlying layers of soil or rock.

Convection 1:

Convection occurs much more efficiently than conduction in fluids as warmer parts of the mass can mix much more rapidly with cooler parts and transfer heat. This transfer of heat on the macroscale is far faster than transfer on the molecular scale and makes this process extremely important when considering heat transfer in the atmosphere.

Heat is exchanged between the Earth's surface, which is radiatively heated, and the lowest layer of the atmosphere by conduction at the molecular level. The heating of the air causes density changes in the fluid and locally the air expands. This makes the warmed parcel more buoyant and may in itself cause the parcel to mix through the bulk of the air above, a process known as *free convection.*

However, the atmosphere is continually stirred by large scale winds generated by pressure gradients and motion around and over mountain ranges and as a result the air above becomes mixed. This process forces the heated air close to the ground to mix through the air and warm the whole air mass. Hence, this process is known as *forced convection*.

Convection 2:

Convection then mixes parcels of warm and cold air together and so changes the temperature of the two parcels. The warm parcel loses heat as it cools and the colder parcel gains heat as it warms.

Enthalpy, or specific heat, is transferred along this temperature gradient. The specific heat content of a parcel of air of unit mass is defined as c_pT, where c_p is the specific heat at constant pressure and T is the temperature of the parcel.

Energy may be transferred indirectly, without changing the temperature of the air parcel, through a change in phase of water in the atmosphere, otherwise known as *latent heat*.

Large amounts of heat are required to change liquid water to water vapour and the same amount of energy is released when water vapour condenses and a cloud forms.

Convection 3:

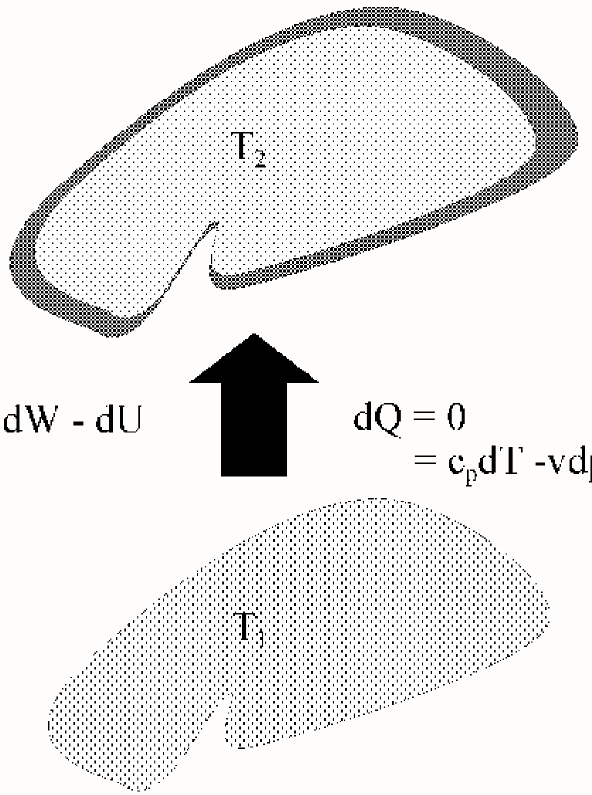
Cloud formation releases energy and so will have an effect on the temperature profile compared to the dry atmosphere.

The *latent heat of vapourization*, L, is the energy required to convert 1 kg of liquid water to water vapour at the same temperature: at 0 °C $L=2.5\times10^{6}$ J kg^{-1}.

The latent heat of melting is the energy required to melt 1 kg of ice to form liquid water. At 0 °C this is around 3.3×10^{5} J kg^{-1}.

We will now look in more detail at the effects sensible and latent heats have on the temperature structure of the troposphere.

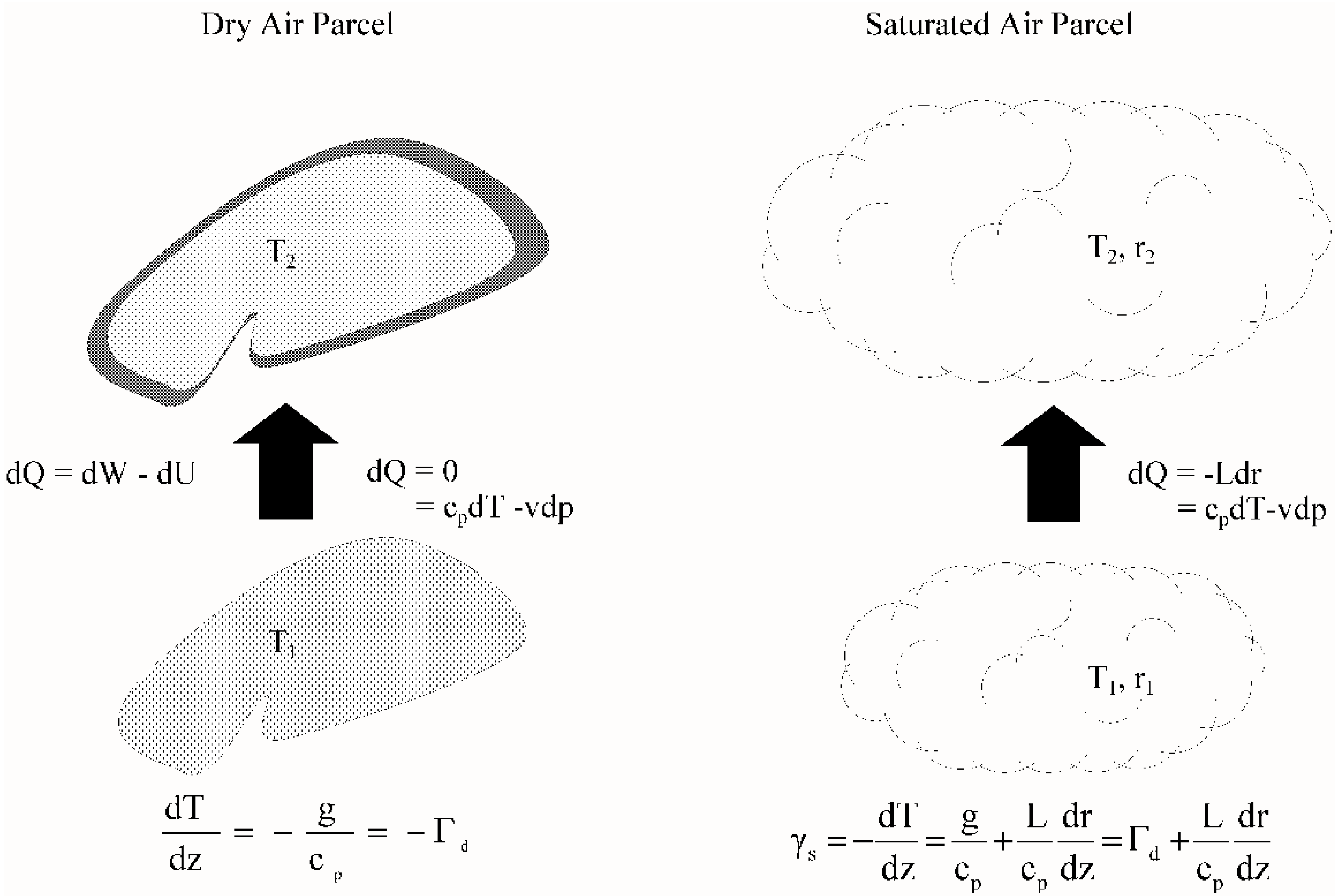
Dry Air Parcel

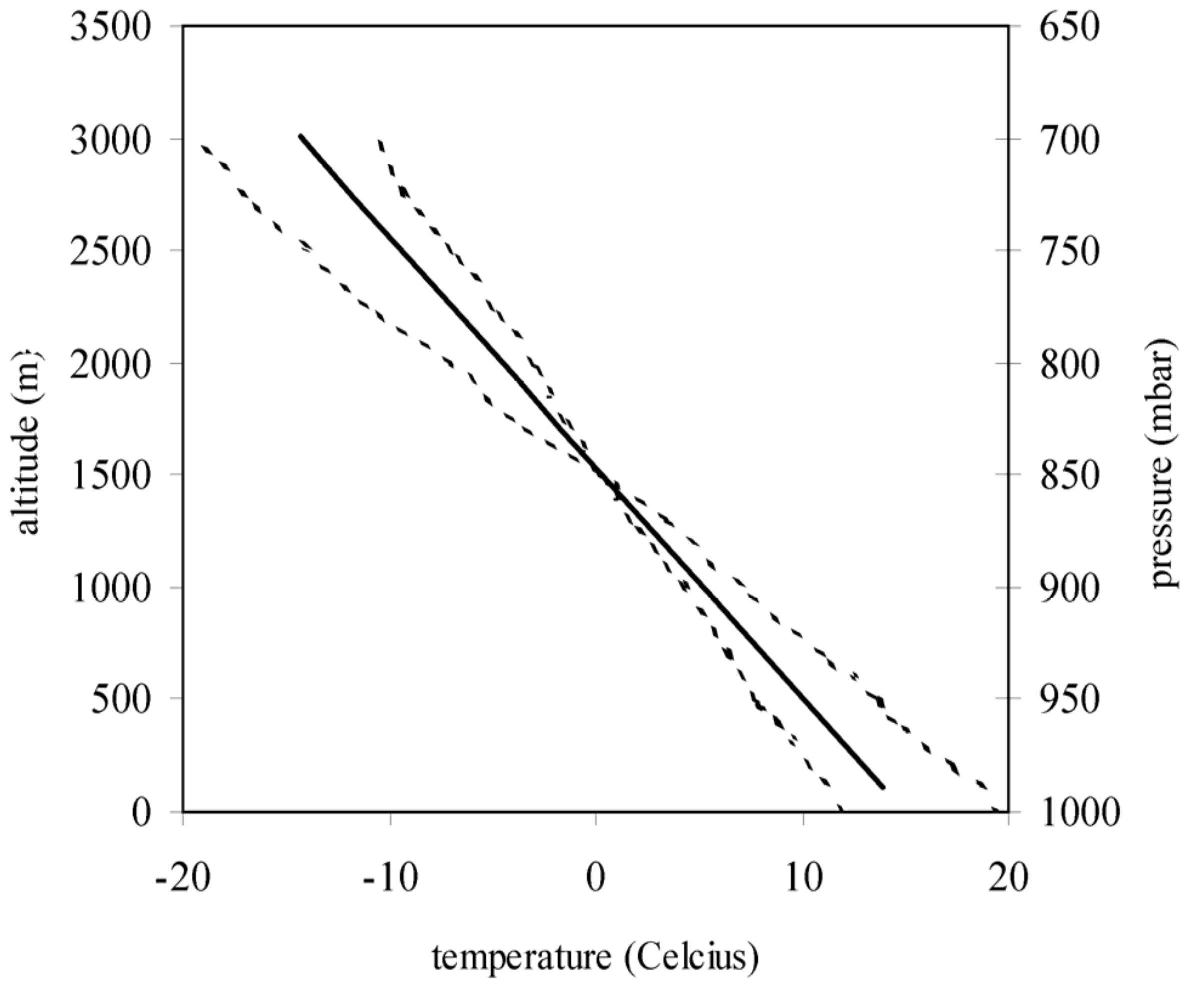


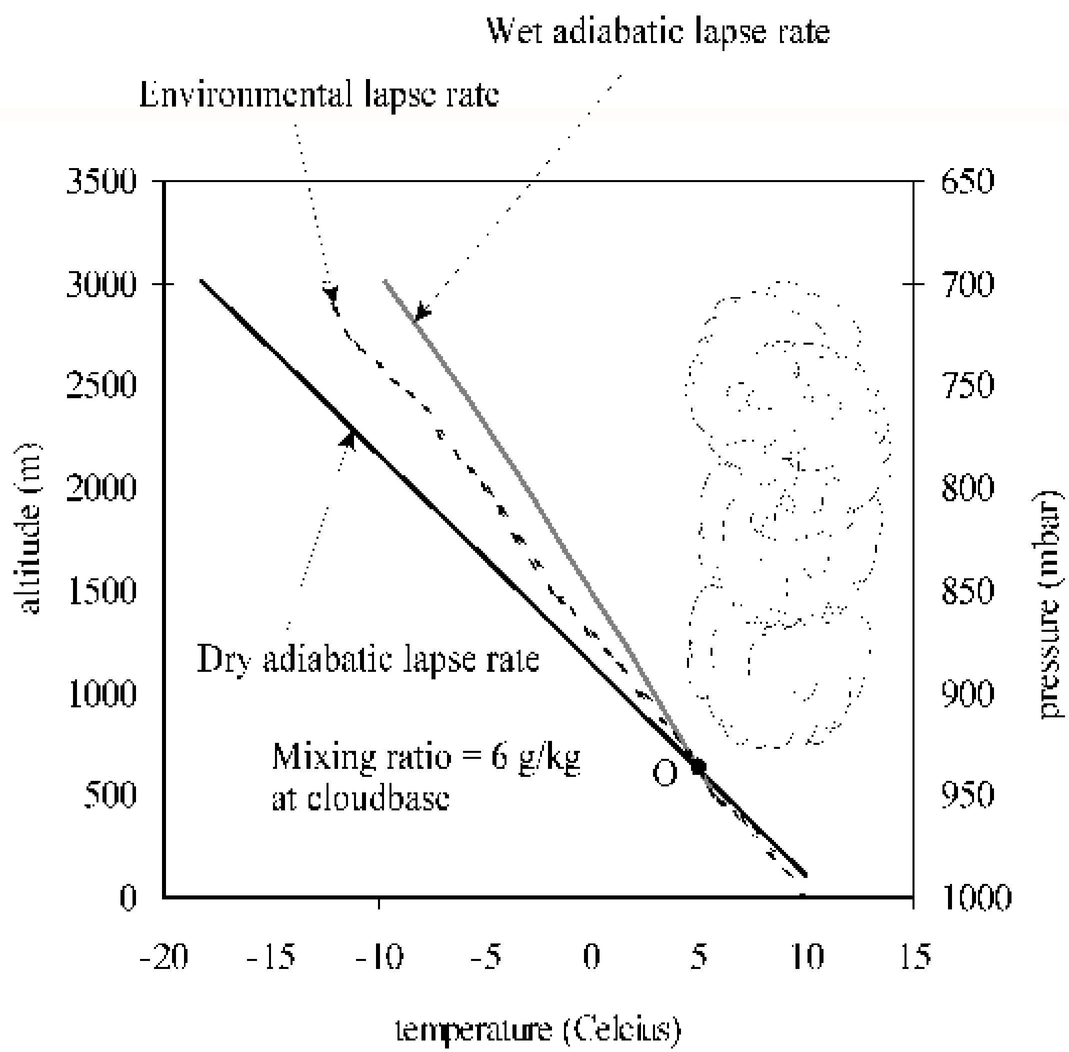
$$dQ = dW - dU$$

$$dQ = 0 = c_p dT - v dp$$

$$\frac{dT}{dz} = -\frac{g}{c_p} = -\Gamma_d$$


Dry Air Parcel
Saturated Air Parcel
T_2
T_2, r_2
$dQ = dW - dU$
$dQ = 0$
$= c_p dT - vdp$
$dQ = -Ldr$
$= c_p dT - vdp$
T_1
T_1, r_1
$\frac{dT}{dz} = -\frac{g}{c_p} = -\Gamma_d$
$\gamma_s = -\frac{dT}{dz} = \frac{g}{c_p} + \frac{L}{c_p}\frac{dr}{dz} = \Gamma_d + \frac{L}{c_p}\frac{dr}{dz}$


3500
3000
2500
2000
1500
1000
500
0
altitude (m)
650
700
750
800
850
900
950
1000
pressure (mbar)
-20
-10
0
10
20
temperature (Celcius)


Wet adiabatic lapse rate
Environmental lapse rate
Dry adiabatic lapse rate
Mixing ratio = 6 g/kg
at cloudbase
O
altitude (m)
pressure (mbar)
temperature (Celcius)
3500
3000
2500
2000
1500
1000
500
0
650
700
750
800
850
900
950
1000
-20
-15
-10
-5
0
5
10
15