Lectures on

Meteorology

Lecturer

Dr. Eman Fouad El-Said

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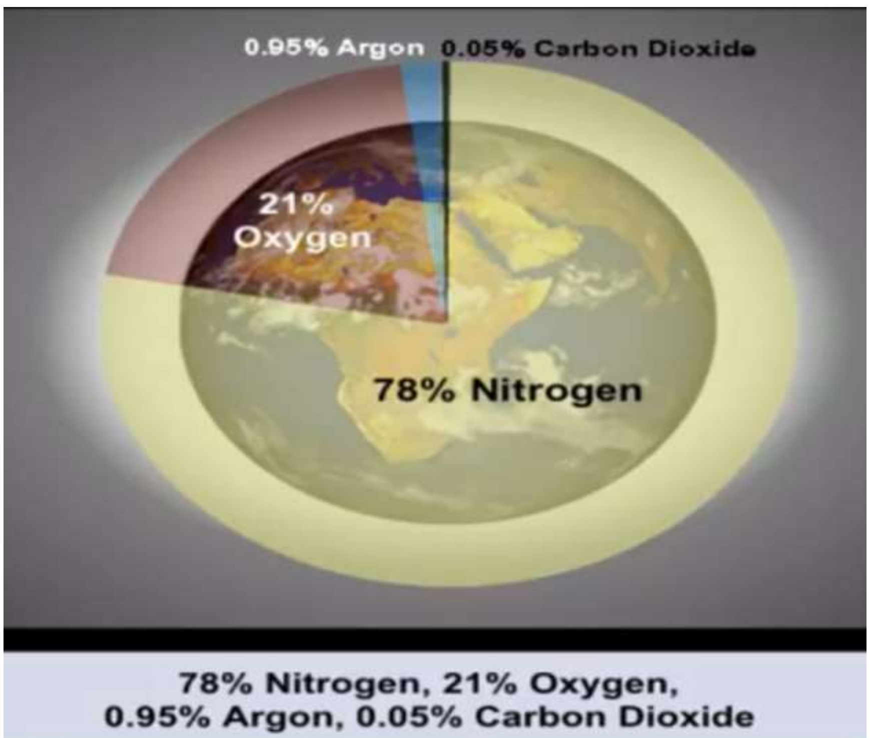
Preface

Dear students, the purpose of our course this year is to provide an introduction to the Meteorology. I hope that I have succeeded in preparing this course and find it easy, understandable and enjoyable as I enjoyed with you during lectures. If there is any comment I would like to hear criticism from my students on my email.

Dr. Eman F. El-Nobi
eman.fouad@sci.svu.edu.eg

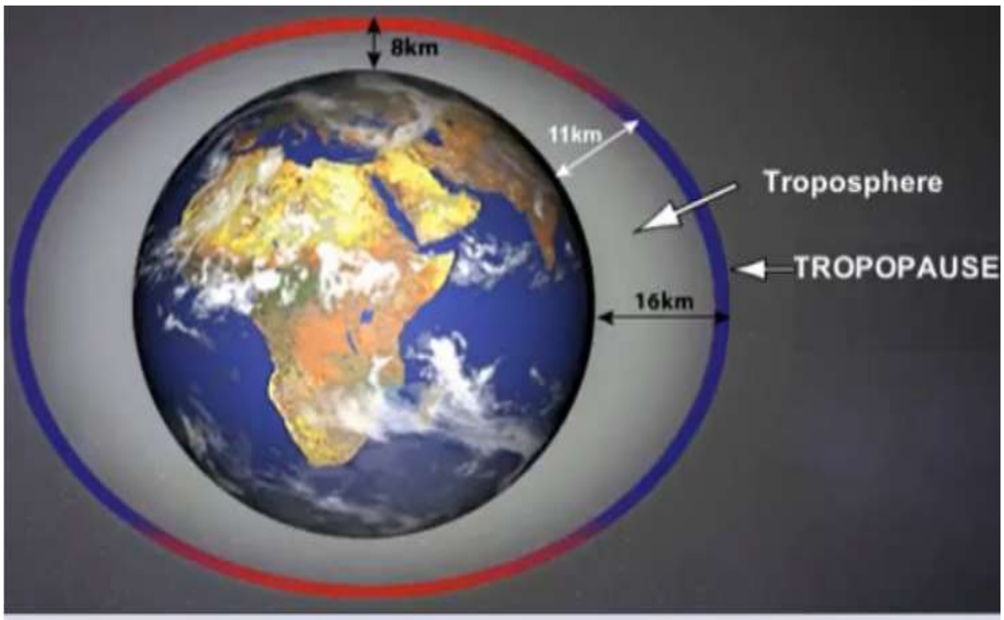
Meteorology Lesson 1 | The Atmosphere

The atmosphere is defined as being a gaseous envelope surrounding a celestial body. In more simple words, the atmosphere is the collection of gases that is held around the earth by gravity. There are various major gases that make up our atmosphere; the most common gas is nitrogen which accounts for about 78 % of the atmosphere. Oxygen is sometimes misconceived as being the most abundant gas but it represents only 21%, just under 1% is argon with carbon dioxide and a few others making up the rest.



There are many more gases that are found in such small quantities that we regard them as trace gases; some of these include Leone, helium, methane, ozone and hydrogen. Water vapor is another gas in the atmosphere, it's found in very small quantities but without it, there would be no weather. So much of our understanding of weather is to do with the behavior of water in our atmosphere; it can become visual to us in many ways such as clouds, rain, snow, hail, frost and so on.

The relative amount of the gases stays very constant up to about 60 kilometers above the earth. There are after gravitational separation alters the composition of the atmosphere. However, there are other changes primarily in temperature that allow us to structure the atmosphere into segments.



The tropopause is typically found at 8km over the poles and 16km over the equator

First of these segments or layers is called the troposphere, this layer is closest to the earth and its defining characteristic is the marked decrease in temperature with height throughout the layer. Where the temperature no longer decreases with height defines the upper part of the troposphere. This upper boundary we call the Tropopause, here temperature is constant with altitude. The thickness of the troposphere and therefore the height of the tropopause is not constant across the earth. Over the poles, the height of the tropopause is about eight kilometers whereas over the equator, it's about sixteen kilometers. The average height is 11 kilometers which is found at about 45 degrees latitude. What controls the height of the tropopause is the general temperature of the troposphere as a general rule the colder the troposphere, the lower the tropopause and vice-versa. The extremes of this are demonstrated very well over the poles and the equator. It follows that, when the troposphere is at its coolest, i.e.; over the poles and in winter then the tropopause would be at its lowest.

However, there are places where the tropopause Folds or breaks. This is where we find a significant difference in the temperature in the troposphere and therefore significant tropopause altitude change. The first of these is at about 40 degrees latitude. the warm air circulating from the equator meets much cooler air circulating from mid-latitudes. This temperature difference in the troposphere causes a height change of the tropopause.

The second tropopause break is at higher latitudes of about 55 degrees, where polar air meets tropical air. This happens along the polar front which we'll talk about much later on again, there's enough of a temperature difference within the troposphere the cause of tropopause height change.

the last of the tropopause break as of even higher latitudes and is evident mainly in the northern hemisphere and in winter, this is where very cold arctic air meets less cold polar air .it occurs typically at about 60 to 70 degrees latitude. The temperature difference here is also enough to cause another tropopause fold or break. if we know that temperature decreases with height, then it follows that the closer the tropopause is to the earth the warmer it will be. over the poles, that tropopause temperature is about -50 degrees Celsius. and over the equator, it's minus 80 degrees Celsius.

As we can see at the tropopause temperature increases with attitude, of course, this is the opposite from what happens at the surface where temperature decreases with latitude. ***Why is the tropopause so important to us?*** Well the tropopause signifies the start of a marked temperature inversion. This effectively limits the vertical movement of air and clouds within our atmosphere. It's useful to know then that the tropopause usually signifies the limit of cloud development; however the tropopause does tell us other things.

As a result of very low densities in the upper atmosphere, the upper winds tend to be very strong and, in some cases, form narrow bands. these are called jet streams, these in themselves can be beneficial if our flight goes in the same direction. but with these jet streams; there is a likelihood of significant turbulence, we call this clear air turbulence or cat.

Having discussed the troposphere and its upper boundary the tropopause will now look at the next layer in the atmosphere called the stratosphere. The stratosphere extends through tropopause up to about 50 kilometers above the Earth's surface. The temperature structure of stratosphere is dominated by the presence of ozone.

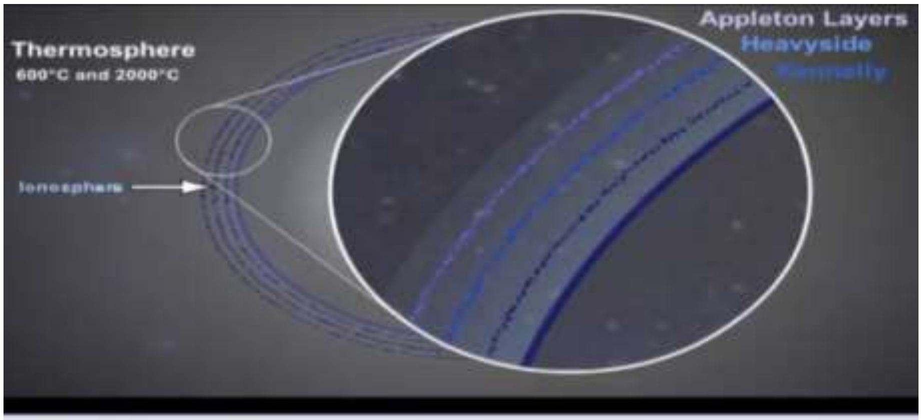
ozone is formed when solar radiation splits oxygen into its two individual atoms, these are then free to combine with others to form the gas ozone. this process releases energy into the surrounding air and therefore heats up the part of the atmosphere where ozone can be found. Concentrations of ozone are at up maximum at around 20 to 25 kilometers above the Earth's surface. due to latitude effects and the depletion of ozone during the polar winter, the temperature through this part of the stratosphere can vary from minus 32 to plus 20 degrees Celsius annually.

Superimposed on the earth is a color representation of ozone depletion. The purple area over Antarctica is showing where we have the greatest amount of depletion. This is due to a number of reasons and the discussion of this is outside the scope of this lesson. Where the temperature starts to fall again signifies the top of the stratosphere and marks its upper boundary, this boundary is called the stratopause.

a bubbler stratopause is a much cooler layer where the temperature continually decreases with height, this layer is called the mesosphere. it usually extends about 80 or 90 kilometers above the Earth's surface. at the top of this layer, we have some of the coolest temperatures encountered.

sometimes as low as minus 180 degrees Celsius the upper boundary to the mesosphere is called the **mesopause**, above the mesopause is a layer called the ***thermosphere***.

this zone is characterized by a rapid rise in temperature up to about 200 kilometers, temperatures here can be between 600 and2,000 degrees Celsius.

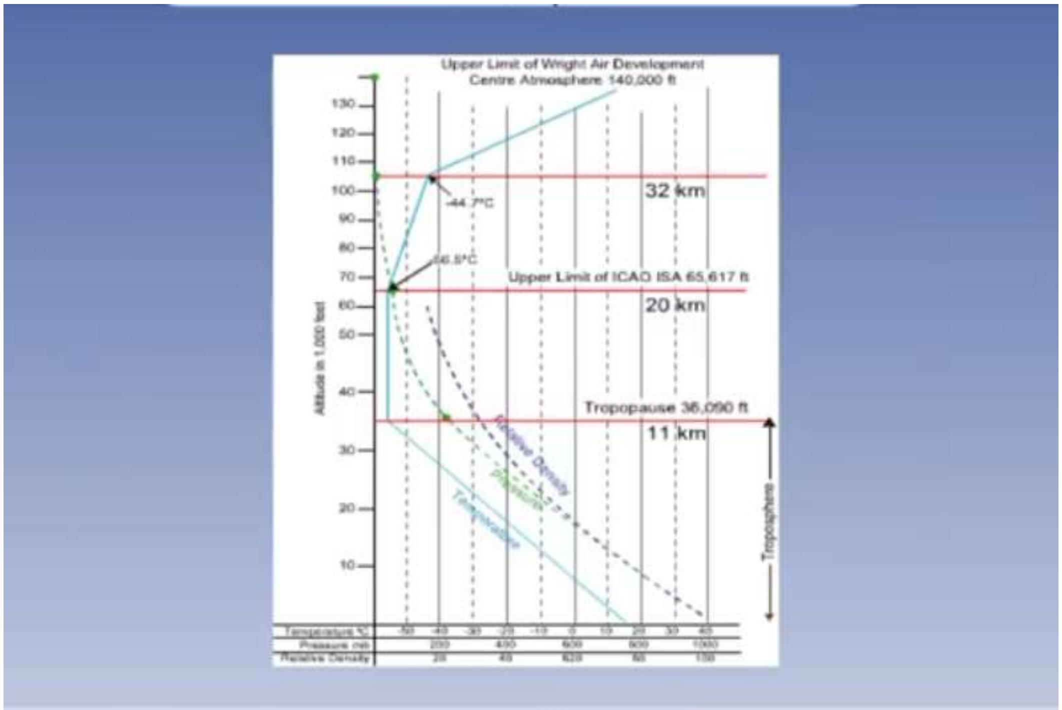


Within the ionosphere we have the Kennelly, Heavyside and Appleton layers

lower part contains a zone called the ionosphere, where we can have such high ionization levels that long wave radio waves can be reflected back to earth. where this reflection is at a maximum is at roughly 110 ,160 and 250-kilometer levels, these are respectively called the Kennelly, Heaviside and Appleton layers.

The upper part of the them known as the **exosphere,** this layer starts at about 700 kilometers above the Earth's surface and is highly tenuous and undefined. All the layers we have analyzed being defined by their unique temperature profiles. however most of our flying and our weather is contained within the first two layers of the atmosphere namely the troposphere and the stratosphere.

within these two layers we have many properties which are important to us like density, pressure and temperature. however, our atmosphere is so very variable from day to day, it's been necessary to construct a model atmosphere at the help in calibration of instruments and aircrafttesting.



This model is known as The ICAO International Standard Atmosphere (ISA)

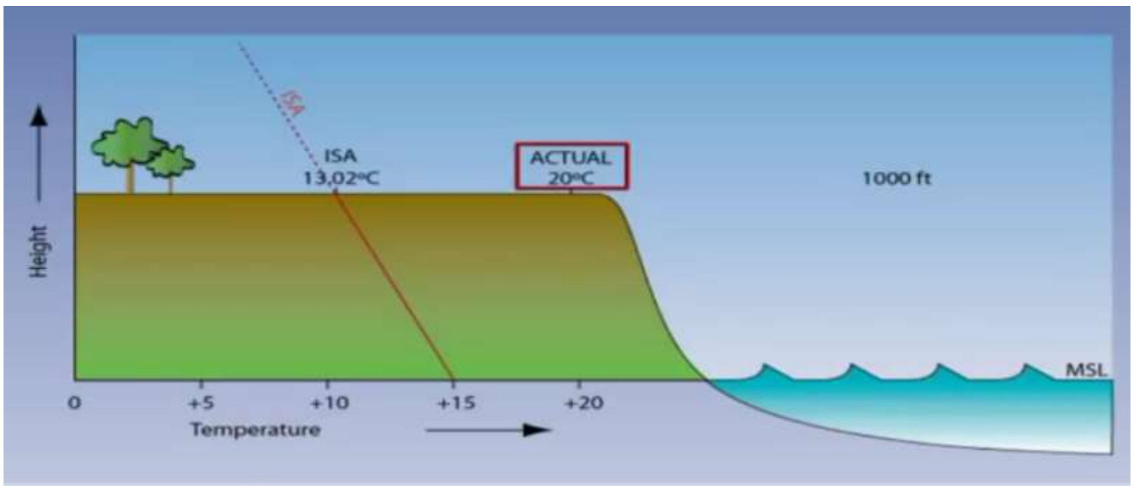
this model Atmos known as the ICAO international standard atmosphere or (ISA). sometimes referred to as Eisha. however, the model only extends to 32 kilometers which is about 105 thousand feet above mean sea level.

ISA assumes that at mean sea level the temperature is 15 degrees Celsius, pressure is one zero one 3.2 hector Pascal's, and the density is 1225 grams per cubic meter. from the surface up to 36,000 and 90 feet or 11 kilometers, the temperature decreases at a constant rate of 1.98 degrees Celsius per thousand feet or by 0.65 degrees Celsius per 100 meters.

the temperature decreases down to minus fifty-six point five degrees Celsius, this is where we find the tropopause in ISA and the temperature no longer decreases with altitude. from this point onwards, we have the stratosphere and ISA assumes the temperature within the first part of this layer remains constant at minus fifty-six point five degrees Celsius, up to 20 kilometers or sixty-five thousand six hundred and seventeen feet. from 20 kilometers and upward to 32 kilometers, we have a gradual increase in temperature by 0.3 degrees Celsius per 1000 feet or 0.1 degrees Celsius per 100 meters.

if you remember this is the part of the stratosphere that contains the gas ozone, which causes the surrounding air to warm. all aircraft instruments are calibrated to ISA. therefore, it's essential to know just how much the actual atmosphere on a given day differs from ISA. the simplest method we use to analyze this difference is through comparing the real temperature to the standard ISA temperature. this is known as the ISA **deviation** .in other words, how much the real atmosphere deviates from the standard atmosphere.

let's recap the ISA lapse rate within the troposphere. remember, we said ISA assumes that the sea level temperature is 15 degrees Celsius, the temperature then fell by 1.9 8 degrees Celsius per thousand feet.

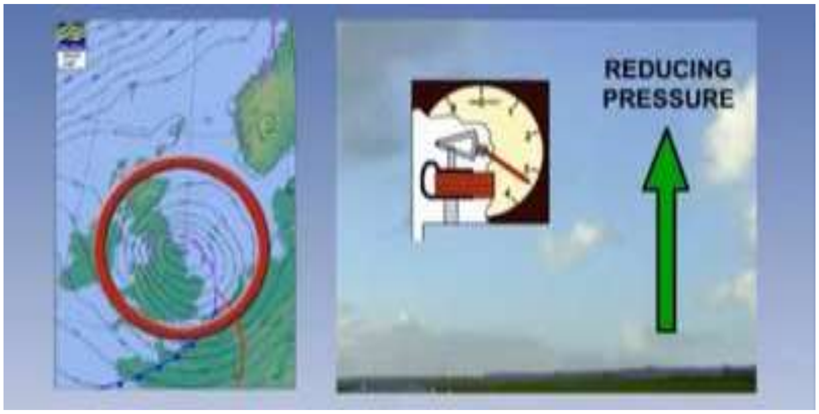


For 1000ft AMSL the ISA temperature is 13.02°C but the actual temperature is 20°C

in the diagram we can see that at an airfield 1000 feet above sea level. the ISA temperature should be 13 point zero 2 degrees Celsius, but the actual is much hotter than the standard hotter than ISA. the real atmosphere is a simple mathematical calculation, shows that the atmosphere is six point nine eight (6.98) degrees Celsius hotter than ISA. the representation of this in important the best way to understand it is by reading the ISA deviation backwards. we can say that; the real atmosphere is six point nine eight (6.98) degrees Celsius hotter than ISA

Meteorology Lesson 2 | Pressure, Part 1

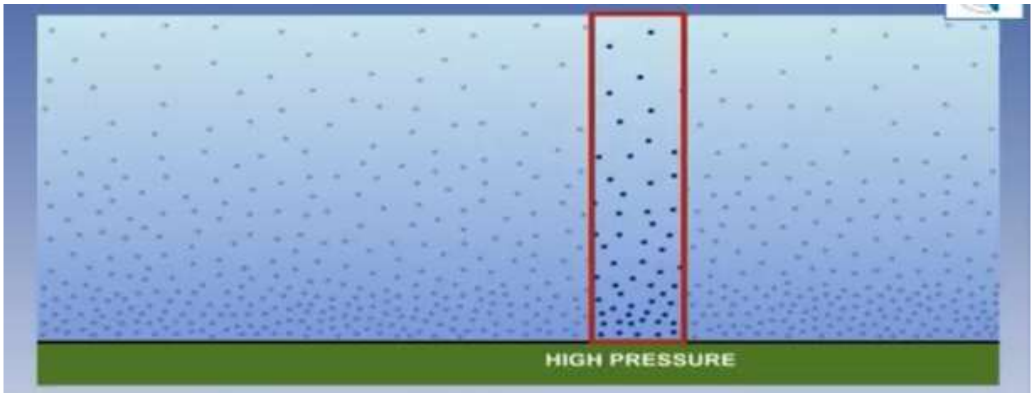
pressure is well-known to be a fundamental part of meteorology. many years ago scientists saw a strong relationship between the distribution of pressure and the weather.



this led to one of the simplest instruments called the barometer which many households use for ornamental purposes. these were developed well before the 19th century but are still used today. over the years more complex instrumentation have been developed to measure atmospheric pressure to the degree of accuracy required for aviation.

the forces generated by horizontal pressure differences give rise to horizontal air movement and therefore winds. the vertical variation of pressure gives us the ability to measure the height of an aircraft above a surface.

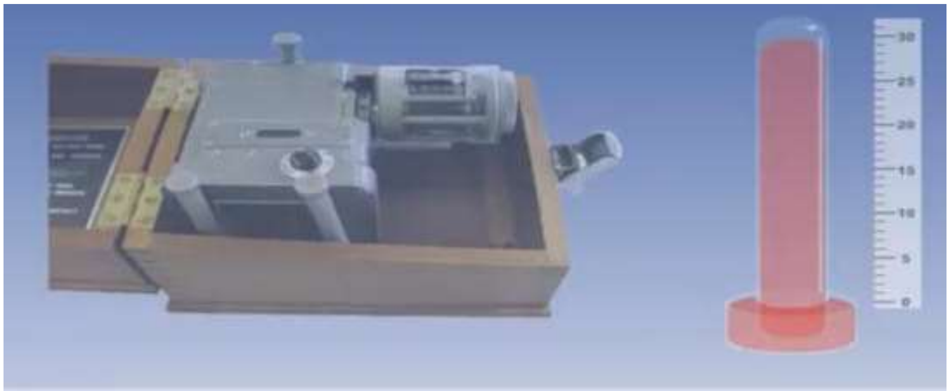
- the instrument that measures this variation is the altimeter as pressure is reduced with height through the atmosphere the altimeter will read a higher value as you can see pressure is fundamental to meteorology and aviation. this lesson aims to give you an understanding of pressure in our atmosphere and its significance to us as aviators.



- what is atmospheric pressure ? the air in the atmosphere is made up of particles and as a result these will be subject to gravity that will tend to pull the particles downwards ; therefore any area on the Earth's surface will have to support the weight of the column of air directly above it. this weight is otherwise known as atmospheric pressure the less air in the column the less the pressure will be at the surface the higher and higher we go in the atmosphere the total amount of air overlying our ski creases therefore the less Knar weight of air above the less the atmospheric pressure so pressure decreases with altitude. we will now look at how pressure is measured and represented in meteorology

- as we mentioned earlier traditionally pressure was measured using an instrument called a barometer there are two types an aneroid barometer and a mercury barometer.

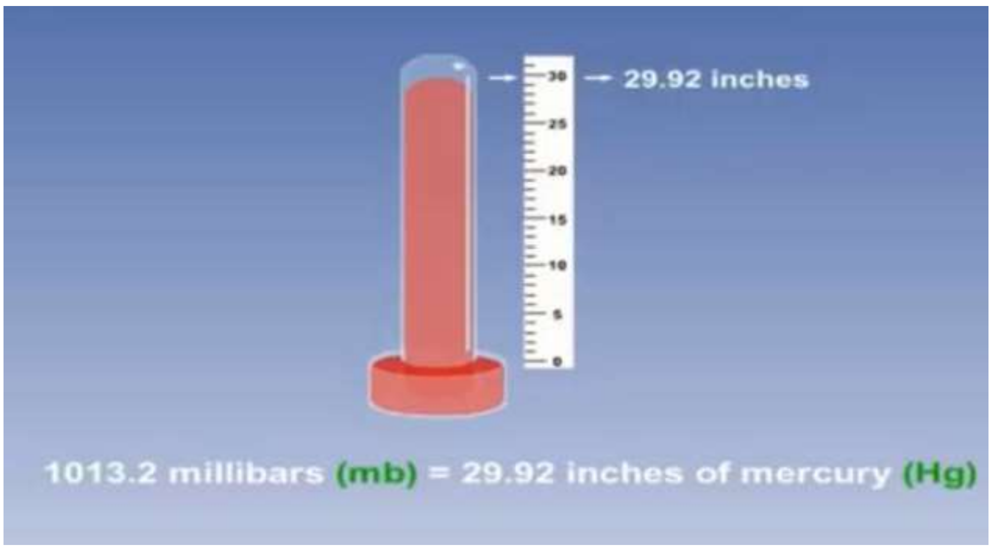
- A mercury barometer consists of an inverted glass cube of mercury with its open end inside a reservoir at the bottom. when high atmospheric pressure is experienced the force or weight of the atmosphere will depress the mercury in the open reservoir and force more of the mercury up into the tube this displacement is traditionally measured in inches the higher the column of mercury the higher the atmospheric pressure.

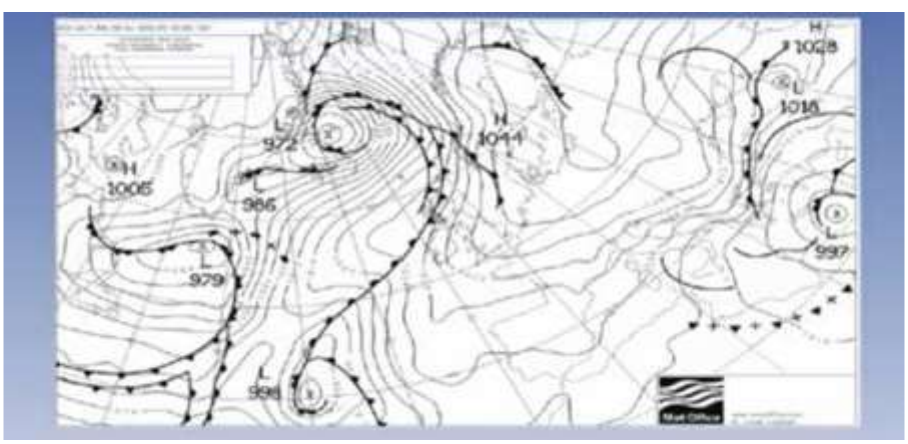


the other type of barometer is non liquid and is therefore called an aneroid barometer these can be less accurate than mercury barometers but are more sensitive to small changes in air pressure an aneroid barometer **measures the effect of air pressure on a metal chamber** from which part of the air has been removed changes in air pressure make the chamber expand or contract moving a needle on a dial the dial may be scaled in millibars inches or millimeters these light and portable barometers are widely used in homes offices and schools and importantly for us in aircraft.

often a special type of aneroid barometer called a barograph is **used to record changes in atmospheric pressure over time** a paragraph includes a pen that records the air pressure on a paper chart mounted on a rotating drum.

going back to the mercury barometer once calibrated the average sea level pressure will displace the mercury from the level in the reservoir by 29.92 inches the United States usually use inches for measuring pressure however elsewhere it is more common to use the millibar or hectopascal to measure atmospheric pressure this uses a different scale but for comparison one thousand and thirteen point two 1013.2 hecto pascals is equivalent to 29.92 inches of mercury in recent years the adoption of the metric. Hecto Pascal has been replacing the millibar however do not worry because the HectoPascal and the millibar use the same scale 1013.2 millibars is also 1013.2 to hecto pascal Infirmary then 29.92 inches of mercury is the same of 1013.2 millibars and 1013.2 hecto pascals. remember from the atmosphere lesson that this is the atmospheric pressure at mean sea level according to ISA .next we will look at horizontal variations and pressure.





- now we need to analyze how we might show pressure variations across a region this is important because then we will be able to identify if one area of a surface is experiencing higher or lower pressure than another area.

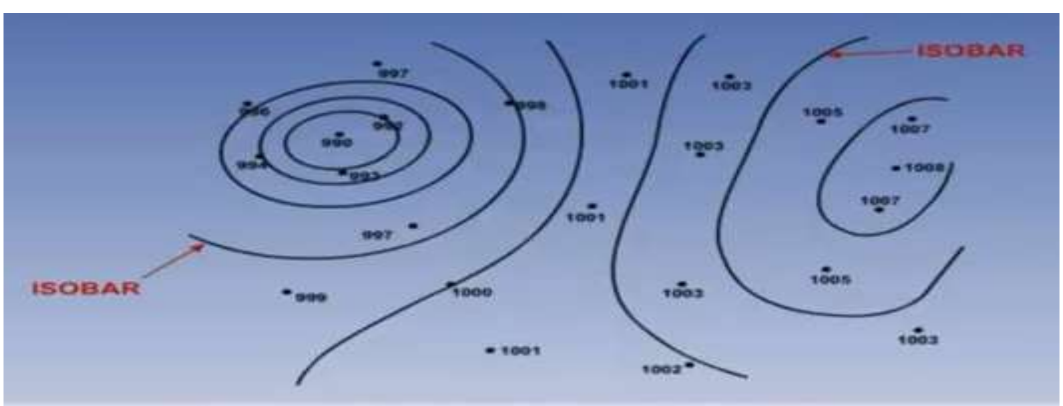
in order to remove the pressure height anomaly ie the vertical pressure variation we wrestled our observations to a common horizontal level usually mean sea level if we look at the diagram we can see various stations reporting their particular pressure values

if we now draw a line connecting all the areas with the same pressure we end up with a pattern of lines over the surface these lines are called isobars and they join places of equal pressure using these pressure values we can identify areas of low and high atmospheric pressure lower value.

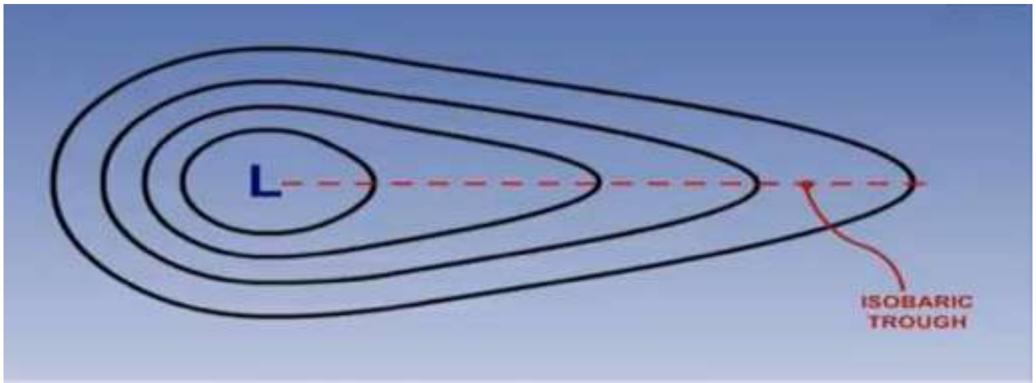
Isobars indicate a low pressure a concentric low value enclosed Aiza bar shows the lowest pressure and reveals the center point , these systems can range from tens of nautical miles wide to hundreds and even a thousand miles wide.

note though that the spacing between the isobars in below can be smaller than those found around high pressures this means that the pressure gradient or the change in pressure with distance can be greater within a low pressure system down in a high pressure system

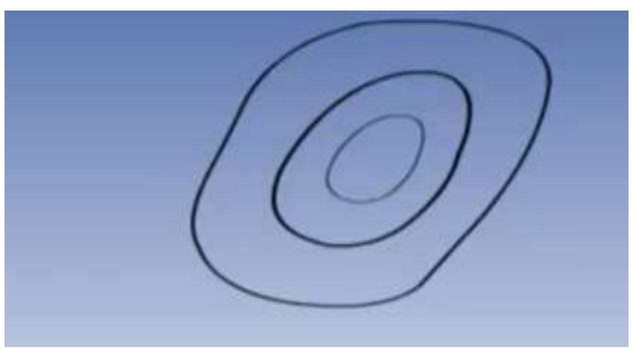
by watching the isobars change shape over time we can see how these systems behave if they were to intensify or deepen we would see new concentric lower-value isobars appearing within the central part of the depression.



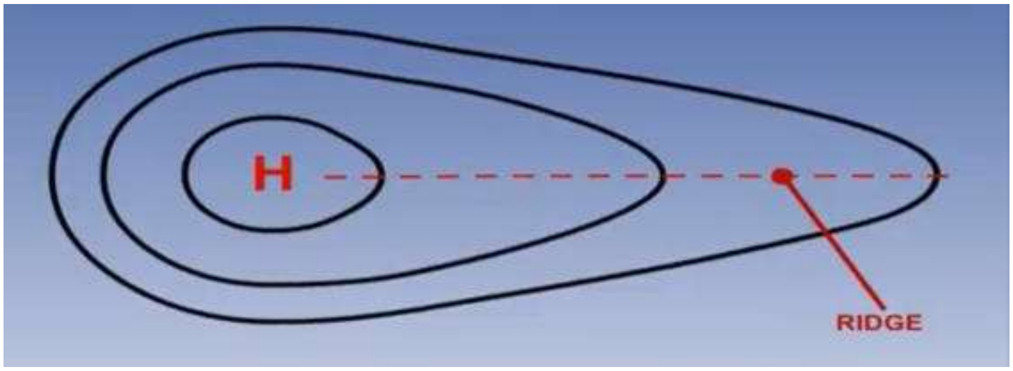
if the isobars move outwards from the center then the depression is growing outwards and covering a wider area if we see low-pressure isobars protruding outwards from the low-pressure into an area between two loaves we call this an isobaric ***trough*** as you can see isobars are a very useful way of visualizing pressure patterns and hence the weather.



next we will take a look at high pressures and how they are depicted. quickly a high-value isobar indicates a higher pressure an enclosed high-value isobar shows the highest pressure within an area and reveals its center as mentioned previously note that the isobars facing in high pressures tends to be further apart than the low pressure systems we will return to this point again. shortly I survive we can see over time how high pressures can change new concentric higher-value isobars developing in the center as the high indicate.

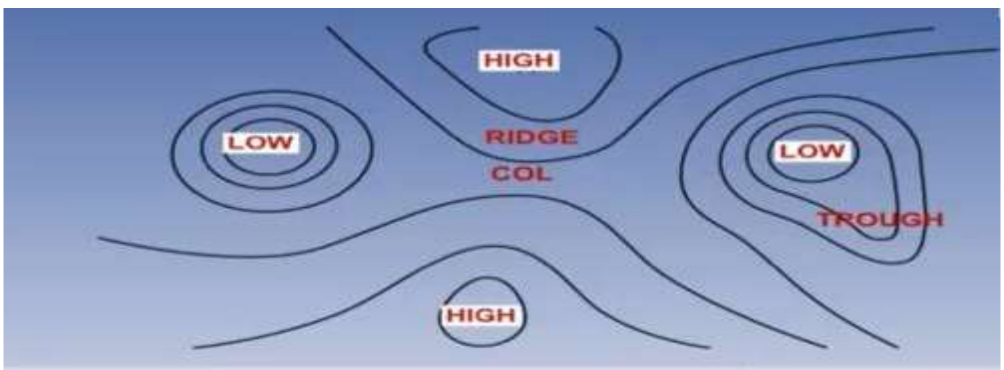


- the high pressure is intensifying if the isobars around the hybl moving outwards ,we could see the high pressure is growing if we see the isobars protruding outwards from the high-pressure into an area between two loaves we call this a ***ridge*** it signifies an extension of the high pressure into another area spreading its influence



it is possible to identify areas which are not high or low pressures these areas are generally found between highs and lows and are called **col** they are synonymous with calm conditions.

high pressures low pressures and col are dealt with in considerable detail later on

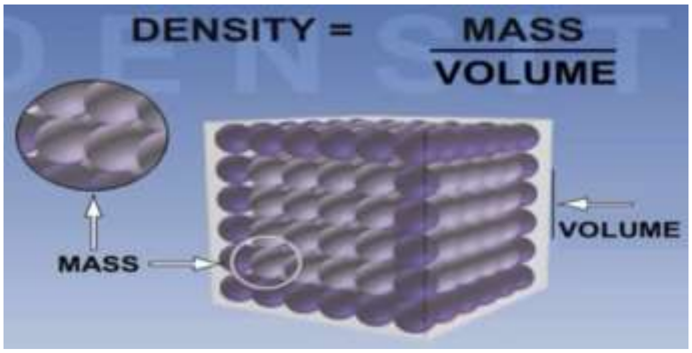


Meteorology Lesson 3 | Density

Density is defined as mass per unit volume

$$Density = \frac{mass}{volume} \quad kg \cdot m^{-3}$$

in other words how much material is inside a given space. Density can be expressed in many ways the first way you've already seen this is gr/m^3 or in standard international units kg/m^3



If you remember from the lesson on the atmosphere we talked about the standard atmosphere or ISA at sea level is a stated that

$$ISA\ sea\ level\ Density = \frac{1225g}{m^3}$$

so we have a mass which is 1225 gm in a volume which is one m^3, however there are other ways in which density can be expressed. If we know the standards level density in ISA then we can use this as a benchmark to compare densities from other areas, so we take the ISA density as 100%

$$\frac{1225g}{m^3} = 100\%$$

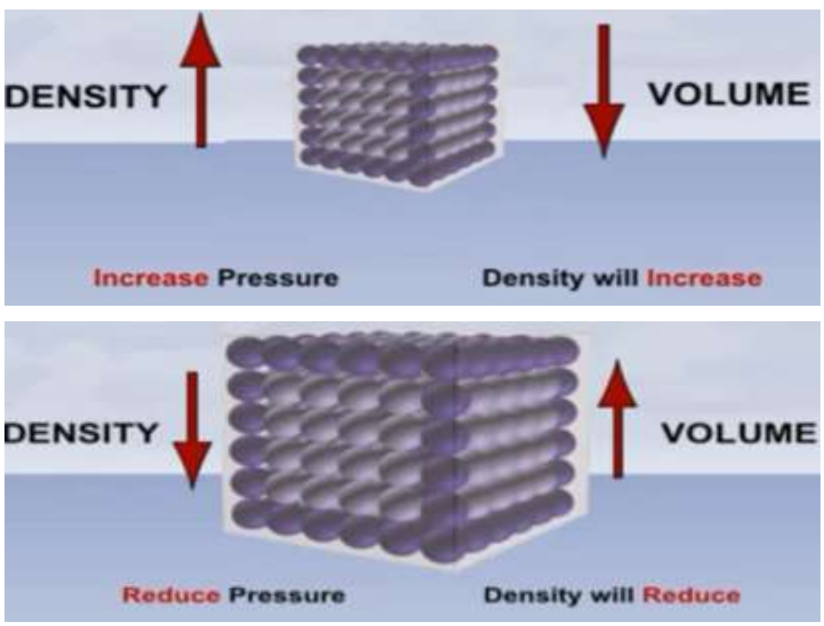
if another area has a density of only 1000 gm/m^3 then this density is approximately 82 % of the is a surface density

$$\frac{1000g}{m^3} = 82\%$$

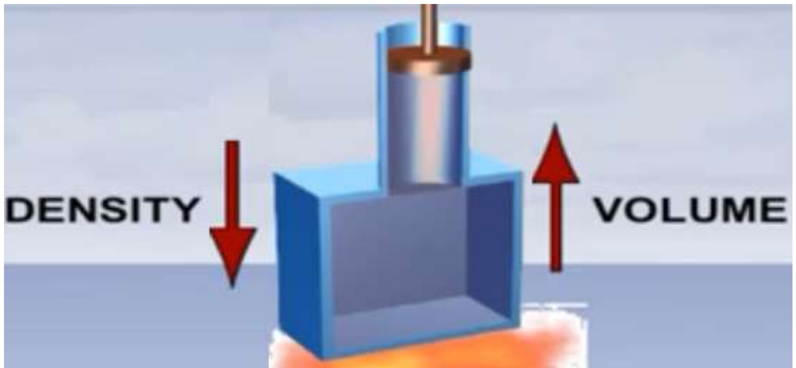
we call this expression of density **relative density** we're comparing the density in one area relative to the density in ISA at sea level

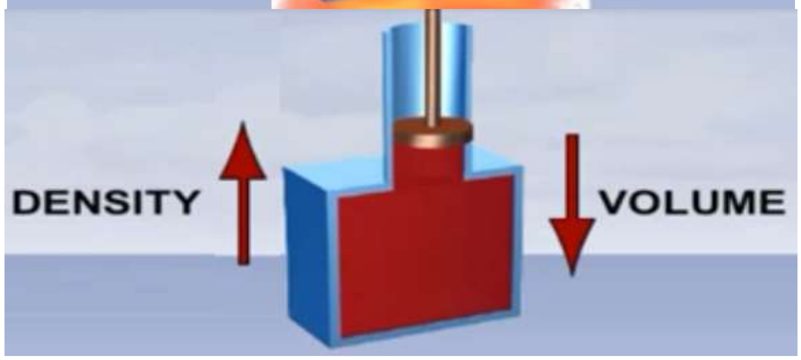
Another way density expressed is by using the term **density altitude**, trainee pilots seldom understand this term but it is essential especially when using it to discuss aircraft performance however before we analyze this term let's first look at the two main variable factors that can influence density these are temperature and pressure.

let's first look at pressure can change density, if we look at the diagram, we can see a mass within a volume as we increase the pressure surrounding the parcel of air you can see that it gets compressed this causes the density to increase we're keeping the mass the same but reducing the volume conversely if we reduce the surrounding pressure the parcel will expand and the density will reduce again the mass is the same but this time the volume has been increased, physical experiments confirm that **density is proportional to pressure**.

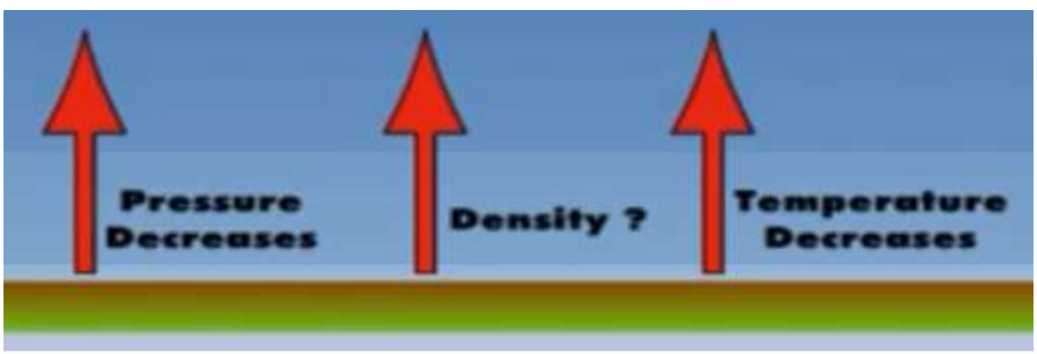


The other main variable we mentioned that controls density is temperature looking at the diagram. we can see that as we heat a parcel of air the particles get excited and cause the partial to expand this reduces the density the mass is staying the same but the volume of air is increasing conversely if we cool a parcel down it will shrink and the density would increase again the mass is remaining the same but we are reducing the volume we can therefore say that, **density is inversely proportional to temperature**



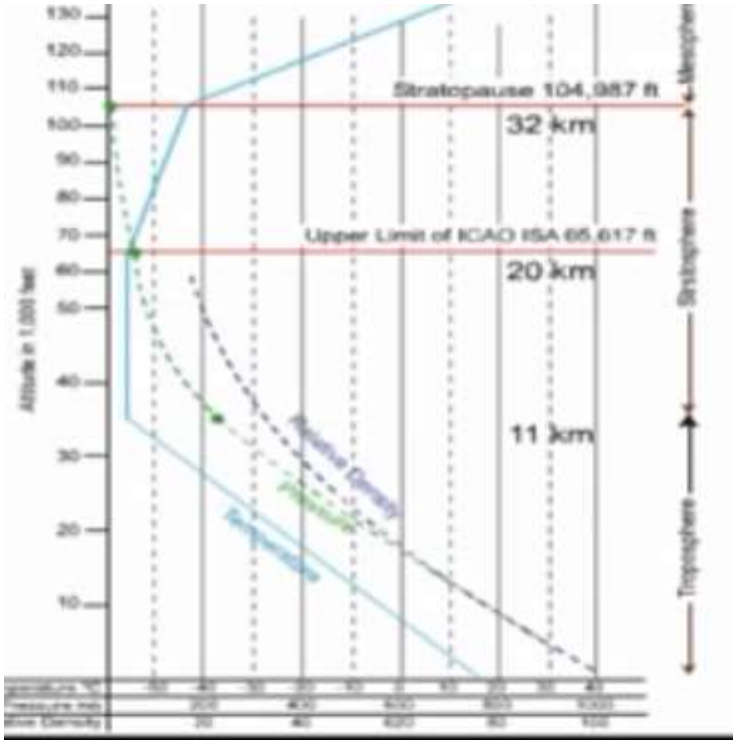


Having seen the effect of very and pressure on density, let's now consider the effect of altitude on density. Here we have a conundrum as altitude increases temperature falls therefore density should increase but as altitude increases pressure also falls these causes the density to decrease so **what does happen to density with altitude**?



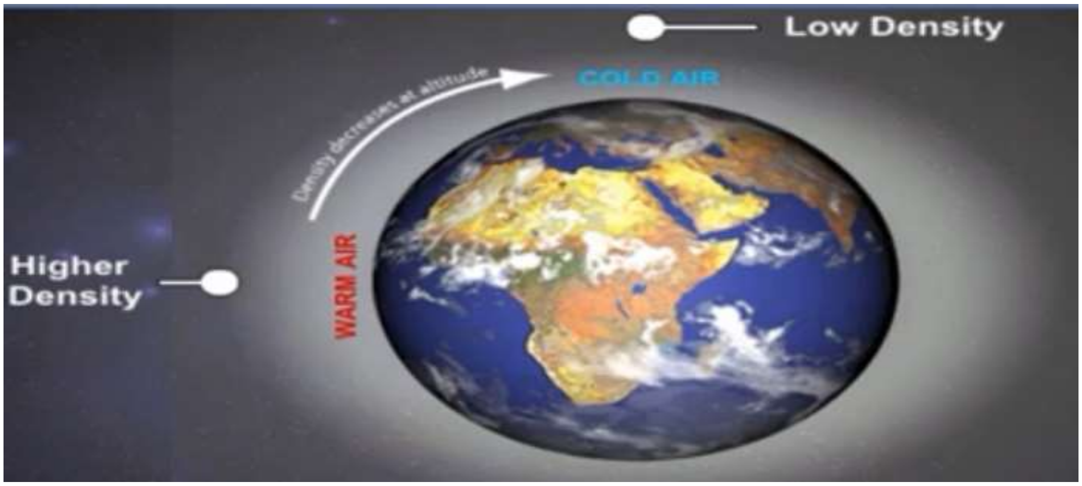
the overriding effect is the change of pressure the reduction of pressure reduces the density more than the reducing temperature causes density to increase, since pressure is the dominant effect it follows that because pressure decreases at a decreasing rate with altitude , so will density

Looking at the diagram of ISA we can see that relative density decreases with altitude at a decreasing rate having seen the effect of density with altitude.

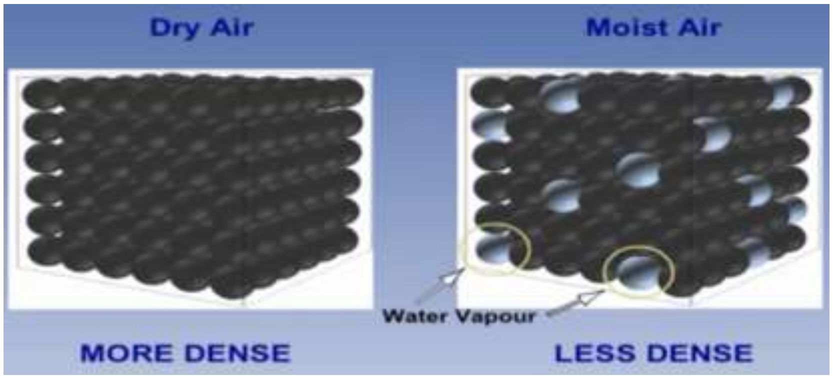


Let's now consider **how density changes with latitude**? Looking at just the surface conditions we can compare the poles to the equator from the diagram we can see that at the poles that temperature is generally colder and the pressure generally higher than at the equator the combined effect is that at the surface the density of the poles is greater than at the equator.

However at altitude the effect is different, if we remember from the pressure lesson, we stated that cold air increases the pressure lapse rate with altitude. in other words, pressure falls more rapidly with heightened cold air than in warm air because density is strongly linked with pressure it therefore follows that in cold air density would decrease more rapidly with altitude than in warm air as a result of this over the poles where we have cold air the density at a high flight level would be much lower than at the same flight level over the equator at high altitudes we can say that, density decreases with latitude.

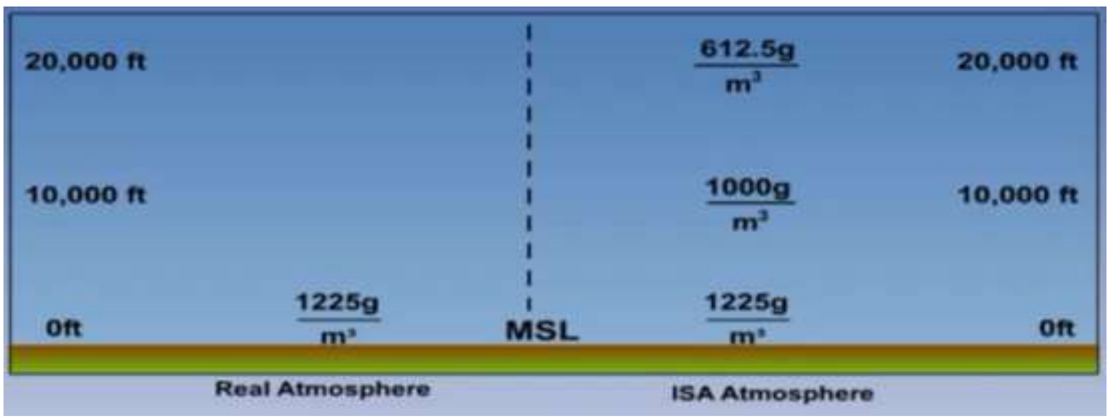


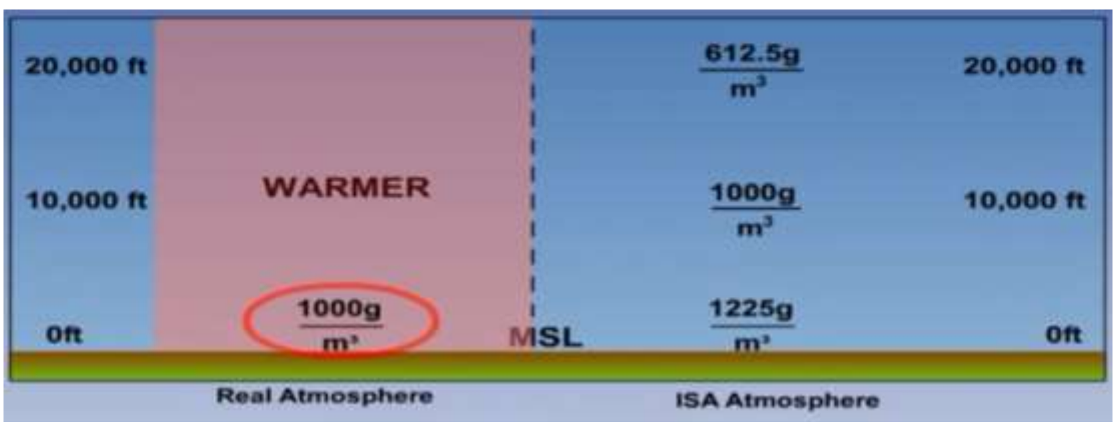
there is one more variable that can alter the density of air this variable is water vapor the effect is complicated and beyond the scope of the expected level of knowledge needed it's sufficient just to know that the density of water vapor is less than dry air such that if a parcel of air was to contain water vapor the density would be less than that of a parcel of dry air.



if you remember from the lesson, we mentioned density altitude having seen the effect of all of the variables on density the expression of density altitude can now be better explained density altitude is simply be find as being the altitude in ISA that the prevailing density would occur this is best explained by using an example let's say we're at sea level and the atmosphere happens to be exactly the same as standard the density at sea level in the real atmosphere will therefore correspond exactly to that found at 0 feet in ISA.

however now let's increase the temperature of our location at sea level we now know that the density will be less this new lower density at our location corresponds to a density found at a higher altitude in is a in our example we can see that the density at sea level in the real atmosphere equates to a density found at 10000 feet in ISA we therefore say that the density altitude of our location is 10,000 feet.





The knowledge of density altitude is important in assessing the effect of the changing density on aircraft performance we'll cover this later but for now let's see how we can calculate our density altitude. There are two simple ways of calculating the density altitude

- ✓ one method, is by using a flight navigational computer
- ✓ the other, is by using a simple numerical formula

$$Density\ Altitude = Pressure\ Altitude + (ISA\ Deviation\ \times 118.8\ ft)$$

this formula states that for every one degree Celsius away from is a depending on whether the deviation from is a is positive or negative you add or subtract 118.8 feet to your pressure altitude to find your density altitude. Now let's look at **an example** let's say the pressure altitude is 2,000 feet and the temperature is 25℃ this means the atmosphere is 13.96 ℃ warmer than ISA therefore the ISA deviation is +13.96 ℃

$$Density\ Altitude = 2000ft + (+13.96℃\ \times 118.8\ ft)$$

we can now see that the density altitude is 3658 feet

$$Density\ Altitude = 3658ft$$

Most density changes are accounted for in performance graphs by the use of altitude and temperature nets the example shown is the landing distance graph for a small single-engine aircraft will now look at the importance of density changes on aircraft operations.

One of the most fundamental effects of density is on the lift that an aircraft can generate looking at the lift formula we can identify density by the Greek symbol ρ

$$L = CL\, {}^{1}/_{2}\, \rho V^2 S$$

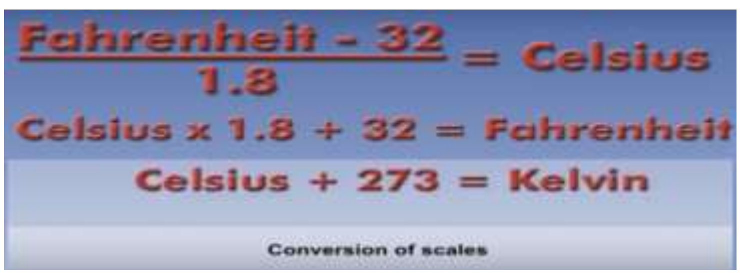
with all other variables remaining the same in the formula you can plainly see that a reduced density would decrease lift so for a given speed the lift generated would be less this has many implications on aircraft performance and can cause increased takeoff distances reduce payloads reduced engine power and so on it's therefore essential to take into account the prevailing density so that any changes in aircraft performance can be identified and calculated.

We generally must remember that in high hot and humid areas we'll have a reduced density and therefore poor aircraft performance be very careful not to exceed the limitations of the aircraft and accurately account for altitude and temperature effects using the aircraft manual

Meteorology Lesson 4 | Temperature Part 1

Throughout this lesson we are going to investigate temperature and demonstrate its importance to meteorology. Temperature is defined as a measure of how hot or cold a substance is. Temperature can be measured on a variety of scales using many different instruments. The two most common scales were used to measure the temperature of a substance our Celsius and Fahrenheit. The Kelvin scale is rarely used in general aviation meteorology, but you may see it in scientific formula. However Celsius is the scale we use throughout the cd-room where appropriate. You may be required to convert from one temperature scale to another: to convert

- Fahrenheit into Celsius simply the Fahrenheit value -32 and divide it by 1.8
- Celsius to Fahrenheit simply multiplied the Celsius value by 1.8 and add 32 alternatively there is a conversion scale for Fahrenheit and Celsius on your flight navigation computer
- Celsius into Kelvin simply add 273

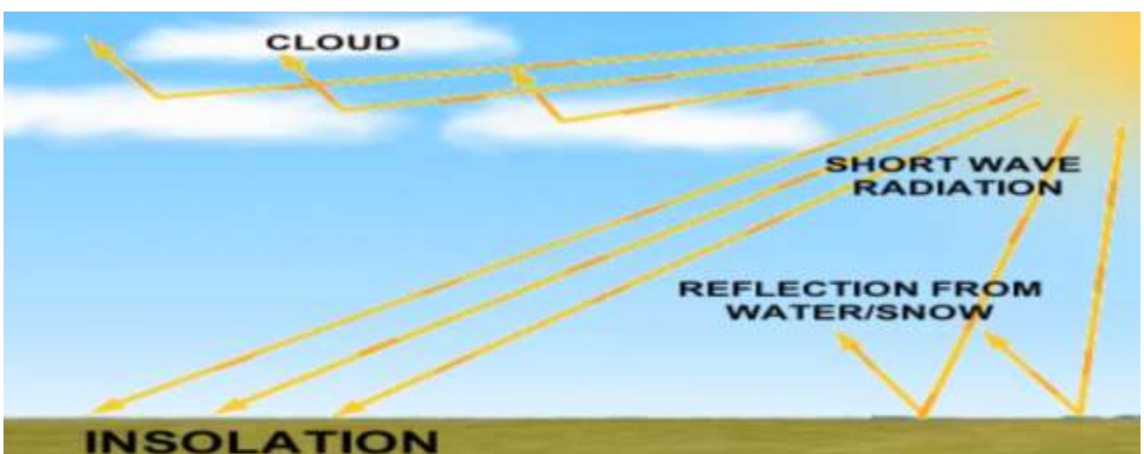


Conversion of scales

Temperature is measured using a thermometer, in meteorology thermometers are usually housed in a Stevenson screen giving a standard exposure to the atmosphere. However there are many different types of thermometer the one shown here is a thermograph similar to the barograph it records temperature over time using a rotating drum. For measuring the variation of temperature through the atmosphere meteorologists use satellite imaging radiosonde balloon ascents and aircraft reports all of these have their advantages and disadvantages.

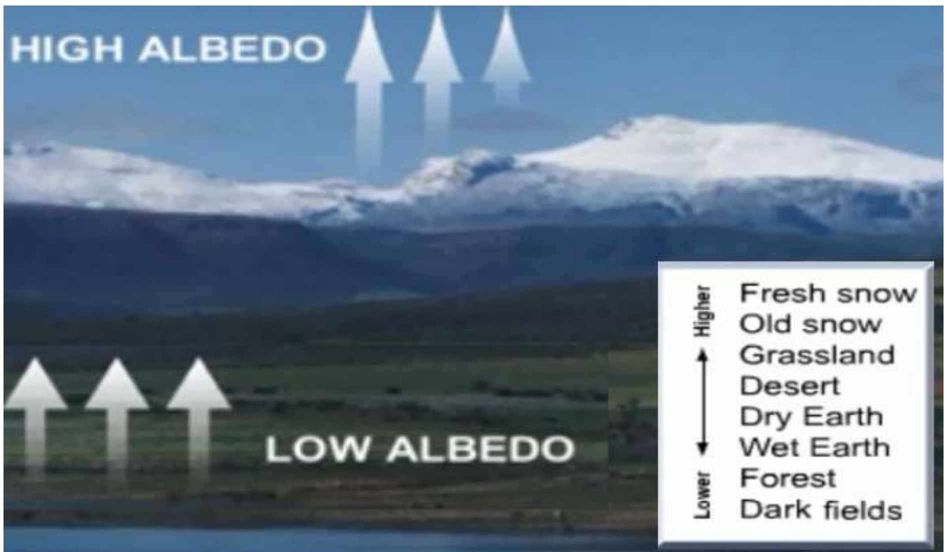
Measuring temperature

Let's now consider the practical implications of temperature in the atmosphere. Energy from the Sun or solar radiation as it is called for the short wavelength around 0.15 to 4 microns to be precise. The Earth's atmosphere is almost totally transparent to this incoming shortwave radiation. The incoming energy passes through the atmosphere with little effect only when solar radiation encounters, clouds or reaches the Earth's surface does it have an impact. Clouds will reflect part of the incoming energy backwards possibly out to space again, the rest will continue to the Earth's surface. In clear weather around 85% of the sun's original energy will reach the Earth's surface.



Incoming solar radiation

Looking at the right-hand side of the diagram we can see that some of the radiation is reflected and not absorbed by the earth, if the surface has a high reflective factor or **Albedo** such as snow or ice. A large part of the energy is reflected back up through the atmosphere the darker the surface the more of the sun's energy the surface absorbs and is said to have a low albedo. Here we see different surfaces in order of reflectivity highest at the top lowest at the bottom.



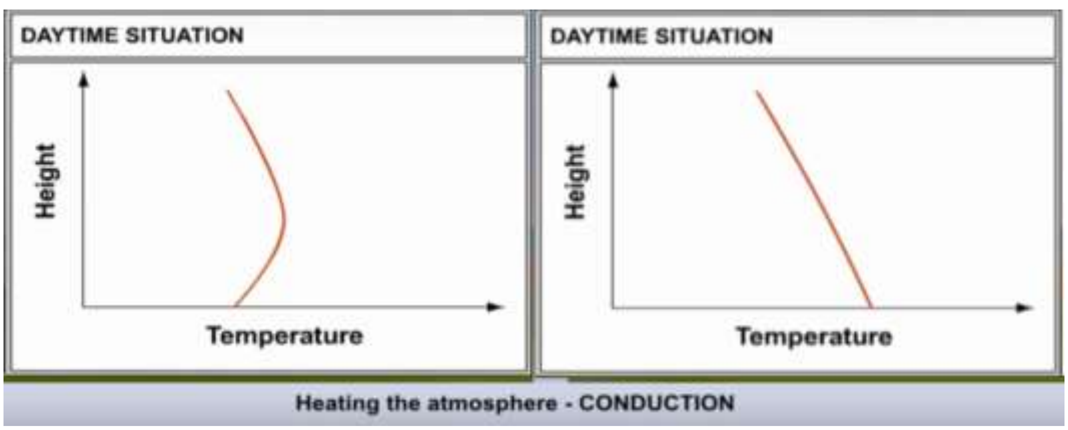
Reflection of incoming solar radiation - Albedo

At the surface of the earth the sun's energy has its greatest effect here we see a simple close-up view of the process incoming shortwave solar radiation or **insulation**, as it is also known, leads to some in separated processes of water and ice but most energy is used in heating the surface on which it falls. The energy that is absorbed is then available to heat the Earth's atmosphere by other processes.

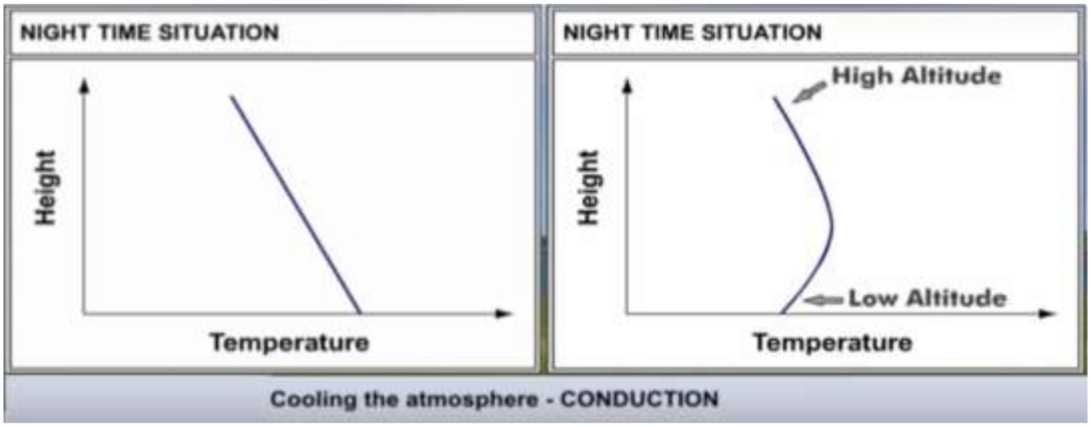
The earth continually radiates energy that it has previously absorbed. It is a relatively long wave radiation between 4 and 80 microns. The radiation that is emitted wants the air above the Earth's surface. A part from the ozone layer high in the atmosphere, which we shall look at later, this is the only source of heat energy for the atmosphere and explains why temperature falls with height. Hence the atmosphere is primarily heated from below not from above. The earth is the atmospheres main energy source not the Sun.

So, what happens to this energy as it is emitted from the Earth's surface? How does it heat the atmosphere? The most important process is where two of the constituents of the atmosphere water vapor and carbon dioxide absorb this long wave radiation from the earth. This then acts as a heat reservoir for the atmosphere warming it up this is the process called the **Greenhouse effect** and without it the earth would cool dramatically.

There are other means by which heat is redistributed through the atmosphere these are conduction, convection, advection and latent heat relief. Let's take a look at these in turn; **Conduction** is the simple process whereby heat is transferred from one body to another with which it is in contact. This diagram is a simple representation of the temperature change was tight through the atmosphere. Notice the lowest layers which are in direct contact with the earth are the warmest.



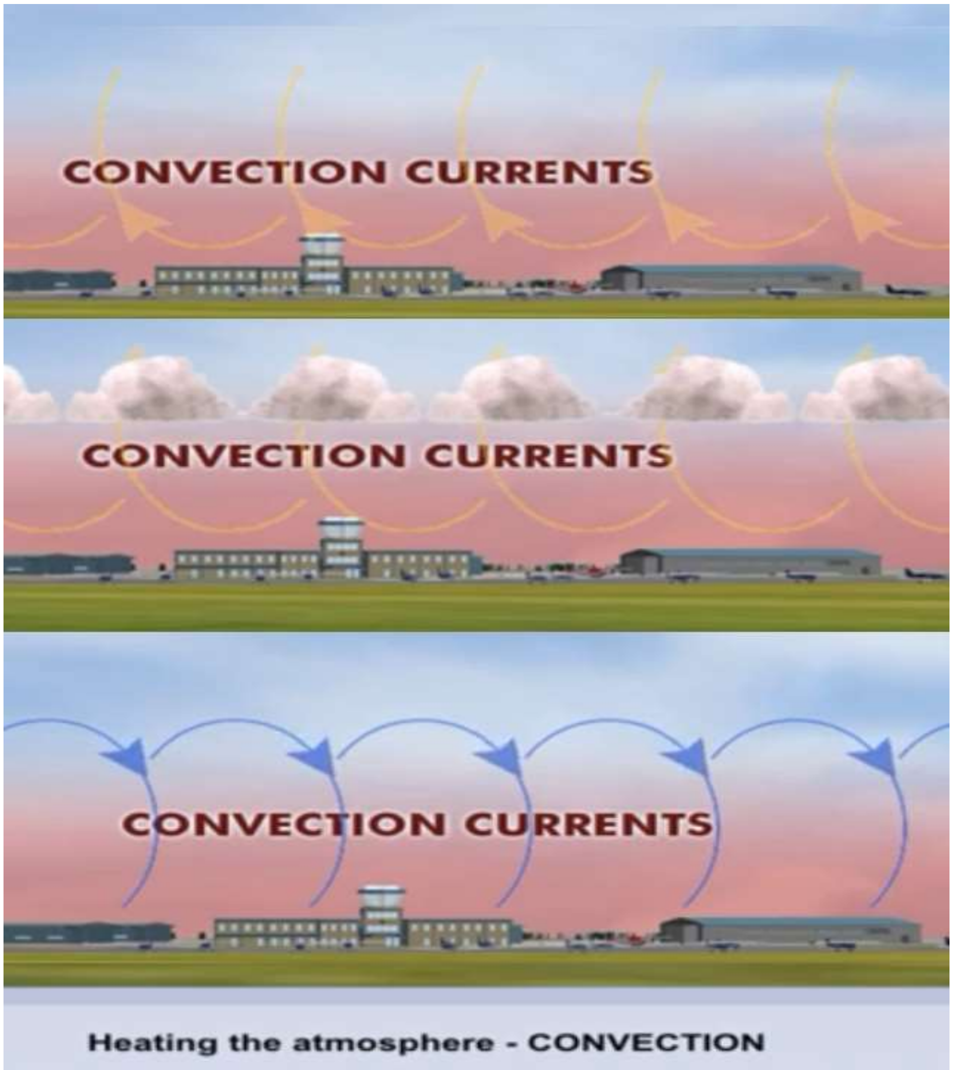
If we look at a typical situation just after sunrise this is how the temperature profile may look throughout the day as the earth's surface heats up it warms the air in contact with it. only the lowest layers of the atmosphere responds this heating by conduction. At night the Earth's surface temperature Falls since there is no incoming solar radiation via conduction the earth calls the air just above it. Here we see the cooling process and how the lowest layers of the atmosphere respond this is why a surface temperature inversion can form because air is a poor conductor of heat energy the air at higher levels retains its heat the air cools at the surface and this cooling spreads slowly upwards by conduction.



The next process we are going to consider is **Convection** infection is simply the way in which warmer less dense air raises cooler more dense air will tend to sink replacing the rising pockets of warmer air. We see this effect on many days when cumulus cloud forms. this process transfers heat energy up into the atmosphere that is most effective the more active the convection in fact with deep cumulonimbus clouds some heat energy is taken right up to the tropopause. We saw this effect demonstrator very well in the pressure systems lesson when we discussed small scale depressions.

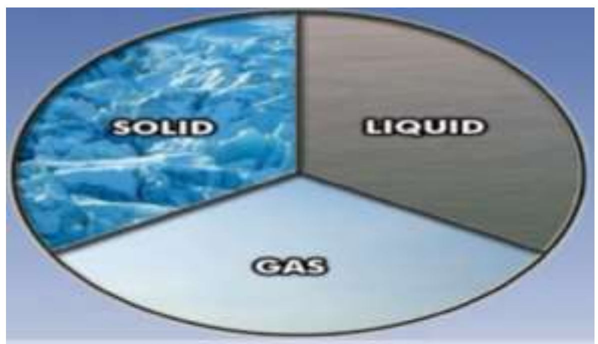
Advection is the horizontal movement of air into another region, the nature of affection may be warm or cold and can occur at any height within the atmosphere nevertheless it has an impact on the heat distribution of the atmosphere. Here we see examples of warm and cold advection. finally let's take a look at latent heat processes **latent heat** has a major impact on the heat distribution of the atmosphere here we see water vapor having been evaporated from a moist or wet ground surface as they rises perhaps due to convection the air cools it may eventually form clouds as the water vapor condenses this change of state from gas to liquid releases latent heat which warms the atmosphere around it note however that dandruff associated with heavy rain will drag high-altitude cooler air towards the surface cooling the surface layers.

So we have established that the Sun primarily heats the Earth's surface which then by various processes heats the atmosphere from below we stated that this is the reason the temperature generally falls with increasing height.

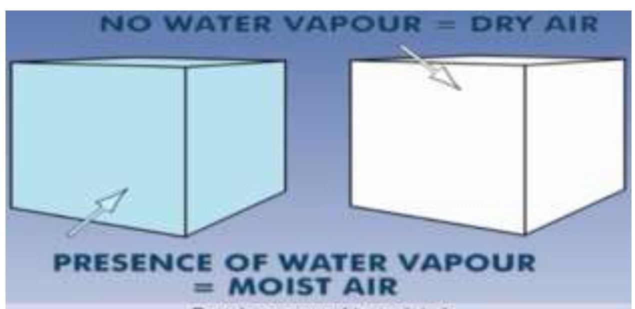

CONVECTION CURRENTS
CONVECTION CURRENTS
CONVECTION CURRENTS
Heating the atmosphere - CONVECTION

Meteorology Lesson 5 | Humidity *Part 1*

Through this lesson we are going to look at humidity and in particular issues surrounding water vapor the substance of water has three well-known states or phases the solid state called ice the liquid phase simply called water and finally the gaseous state called water vapor, which of course we usually cannot see. Dry air is defined as a body of air with no moisture content at all in reality this does not occur in the atmosphere when any amount of water in vapor form is present in a body of air the air is defined as being moist. Looking at the diagram, we can see a parcel of dry air with no water vapor and a moist parcel of air with water vapor.



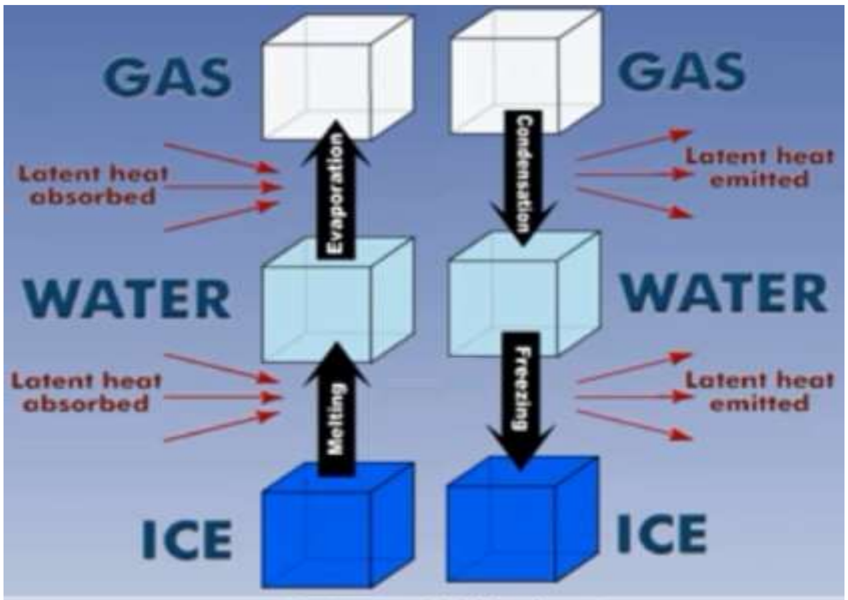
Three states of water



Dry air compared to moist air

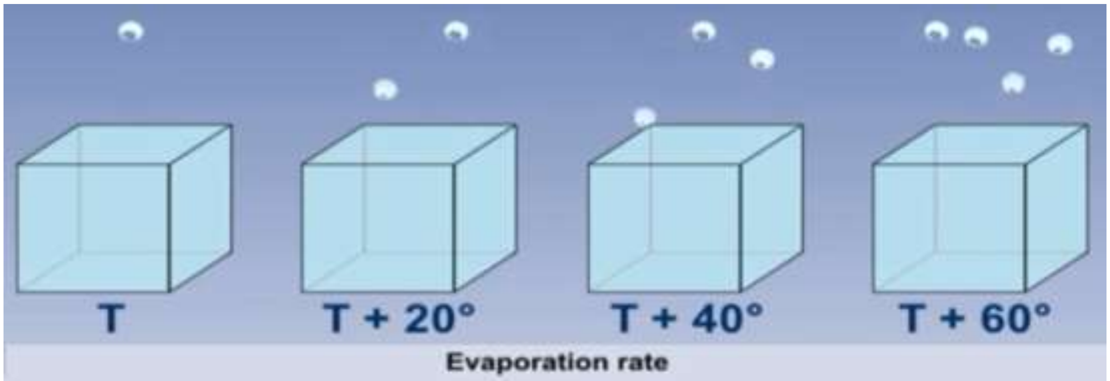
The presence of water vapor in the atmosphere has a major impact on the behavior of air. However the concentration of water vapor varies greatly both in space and times it is generally found in such small quantities that it is not even listed as a trace gas but yet its presence impacts on us greatly without it there would be no weather. Uniquely water can be found in the atmosphere in all of its three states. One of the major impacts water has on our atmosphere is when it changes from one phase to another during these changes energy is transferred in different ways this energy is known as latent heat.

Latent heat or hidden heat, as it is sometimes called, is the quantity of heat released or absorbed when a substance changes from one phase to another. On the way up from the solid state through liquid to gas latent heat is absorbed whilst on the way down from gas to solid through liquid latent heat is released.

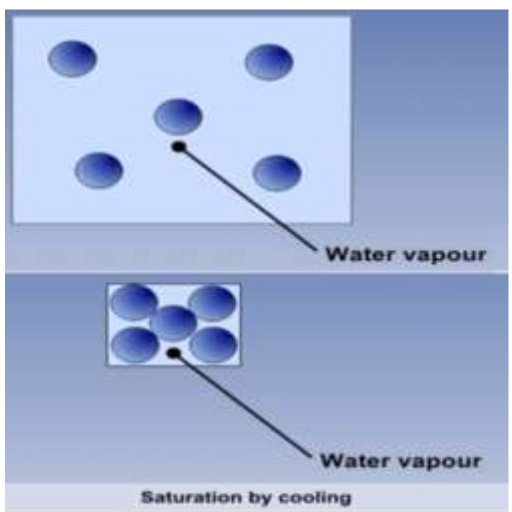


Latent or hidden heat

let us see what happens when we change state from solid to liquid in other words during **melting** as we heat the solid it will start to melt energy in the form of latent heat is then absorbed from the surface and then stored in the liquid. just as we for latent heat being absorbed into the water when it changed state from solid to liquid we shall now see the same occurring when we change state from liquid to gas this is known as **evaporation** during evaporation latent heat energy is absorbed from the surface and stored in the water vapor. If operation from a water surface will occur at any temperature above absolute zero -273 °C but the rate of evaporation increases as the temperature increases this is because as temperature increases the water molecules have more energy and are more likely to change state.

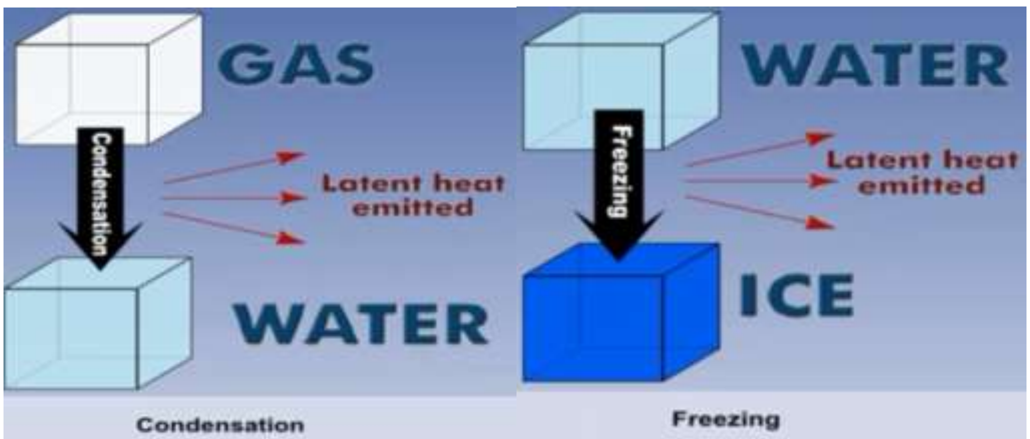


Looking at the diagram, in video, we can see that evaporation from the water surface is adding water vapor to the air however for a particular temperature there is a maximum amount of water vapor a body aver of unit volume can hold. So as evaporation continues the air above the surface will contain more and more water vapor and may eventually reach its maximum holding capacity, when this is reached evaporation will cease. the air above the water surface is said to be saturated it can hold no more water vapor to recap then if we continually add water vapor to a parcel of air it would eventually become full or **saturated**.



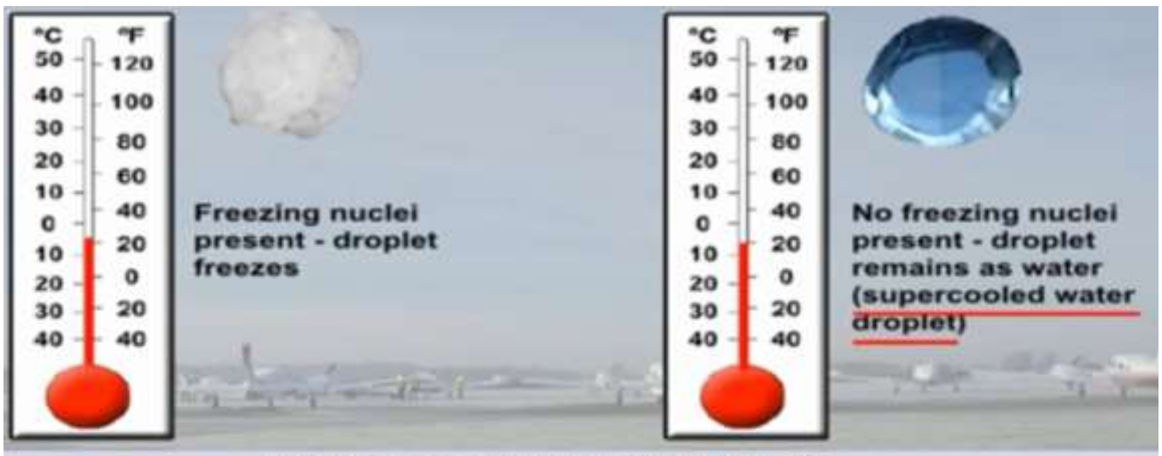
We have established that one way we can make our saturated is by evaporating water into it until it is full of water vapor. However there is another method of achieving this if we cool air down the space between air molecules decreases and therefore there is less space for water vapor to fit the opposite is true when warm air up warm air has more spaces between the molecules and can hold more water. So if we have a parcel of air that is partially filled with water vapor and then cool it down the air will eventually reach a point where it is holding as much more to vapor as it can now the air has become saturated.

Condensation is the reverse of evaporation it is the phase change from vapor back to liquid. If you remember the water vapor had a lot of stored latent heat so when it then condenses and changes into water again it releases this heat back to the surroundings again. we can appreciate this when we have been burned from steam the steam is hot anyway but when steam condenses onto our skin even more heat is given to us and we feel even more pain.



As we have seen condensation is said to occur when water vapor changes state into visible water like Dew clouds and fog but this process is actually quite complex for condensation to occur we need my new particles in the atmosphere for the water to form around these are called **condensation nuclei** and mainly consist of salt particles put into the atmosphere over the sea there are other condensation nuclei such as pollutants from industrial sources forest fires or volcanic eruptions if no condensation nuclei are present air will tend to become supersaturated and hence have a humidity of greater than 100%.

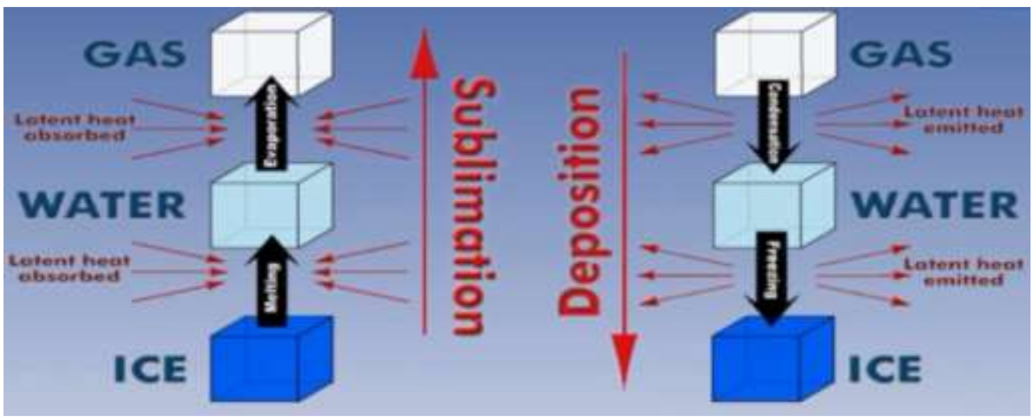
When the temperature of water drops below zero Celsius it generally begins to freeze i.e change from liquid to solid remember from earlier in the lesson that this involves the release of latent heat. Here we can see the heat being given up to the surroundings in a similar manner to condensation freezing usually requires the presence of particles in this case they are known as freezing nuclei so as the temperature of the drop that falls if there are particles in the water the droplet will freeze. however if they are not present then when the temperature falls below zero it will not freeze these are known as super cooled water droplets and are very important in aircraft icing.



Freezing - supercooled water droplets

Meteorology Lesson 6 | Humidity *Part 2*

There are two other phase changes that we need to mention these are less common in the atmosphere than condensation or evaporation but nevertheless are important when water goes straight from the solid to vapor state we call it **Sublimation**. Strictly speaking when water goes from vapor to the solid state directly it is called **deposition** but in meteorology this change is also called sublimation. Note that both of these phase changes miss out the liquid phase sublimation from ice to water vapor absorbs latent heat and sublimation or deposition from water vapor to ice releases latent heat.



In meteorology it is vital to know how much moisture the air contains at any one point, we can do this using a hydrometer also known as a psychrometer. Here we see a diagram of one type which uses a wet bulb and a dry bulb arrangement. If air is unsaturated water will evaporate into it from the muslin and latent heat will lower the temperature of the wet bulb. If the air is saturated no water will evaporate and the two thermometers will read the same. The wet bulb temperature is defined as the lowest temperature air will fall to by evaporating water into it at constant pressure.

The difference between the dry bulb and the wet bulb decides how moist oxygen with the air is the closer they are the more humid the air is and vice versa. From these two readings many values can be calculated including the dew point, vapor pressure, relative humidity and humidity mixing ratio, we shall now look at this in a bit more detail.

Instrumentation for humidity

the **dew point** of the air is the temperature to which air must be cooled at a constant pressure to reach saturation do not confuse this with the wet bulb temperature they are different things the dew point of the air will only change if the amount of water vapor in the air changes remember when we talked about the difference between dry and wet bulb temperature readings well in a similar manner the difference between the dry bulb temperature and the dew point signifies the humidity of the air. when the dry bulb temperature equals the dew point there is 100% humidity or saturation hence cloud or fog will form if the dry bulb temperature and the dew point are many degrees apart the air is relatively dry in fact its saturation the dry bulb wet bulb and dew point temperatures are all exactly the same.

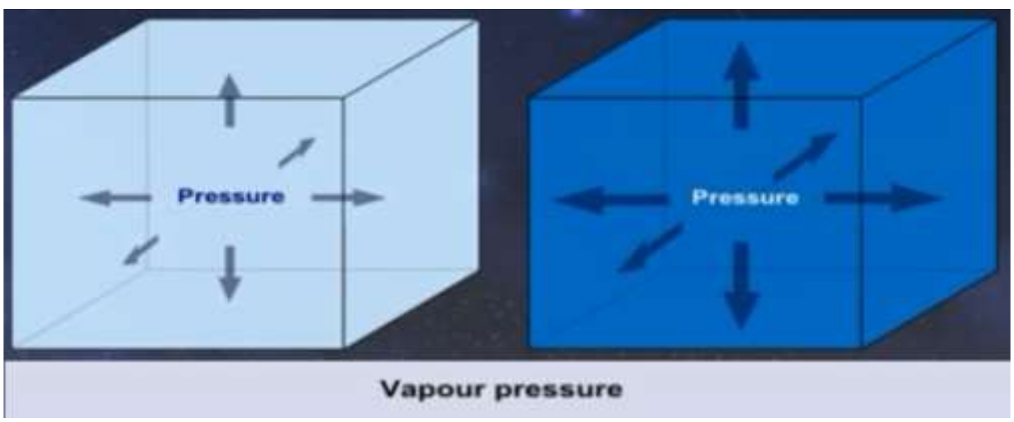
Dewpoint

The dew point lapse rate varies enormously on any one day with large changes in both spatial and temporal contexts but on average the humidity mixing ratio lapse rate is half a degree per 1,000 feet.

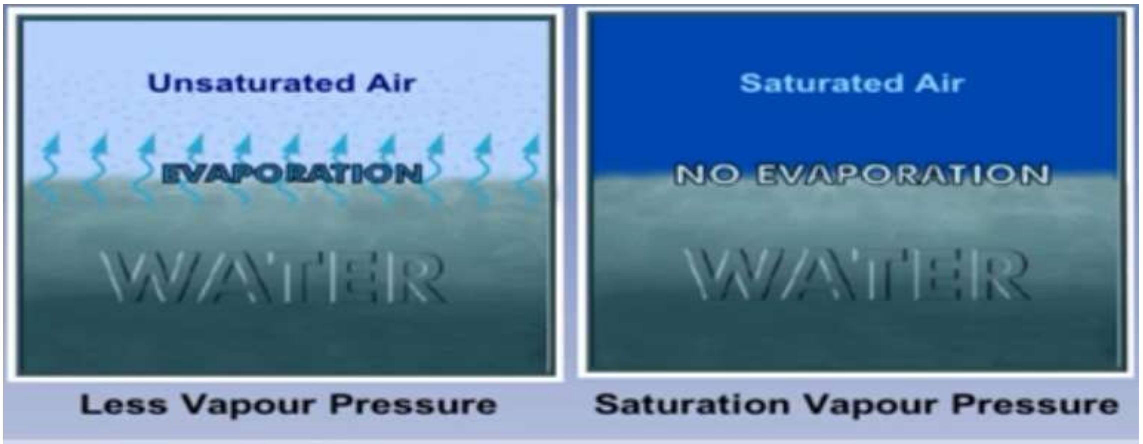
The simple rule of thumb is that:

$$\text{The difference between the dry bulb temperature and the dew point} = \frac{100 - \text{Humidity}}{5}$$

Here we see two boxes containing moist air however one is more moist than the other in the atmosphere each constituent gas that makes up the air exerts its own pressure it is the sum of these pressures that actually makes up the total atmospheric pressure that we often use in aviation water vapor is the same it is a gas therefore it exerts its own pressure and this we refer to as the vapor pressure. in our diagram the Box on the Left has a lower vapor pressure than the one on the right therefore the pressure being exerted on the walls of the container by the water vapor is less.



let us consider an enclosed box half filled with water with air filling the rest of the box initially the air above the water is unsaturated there will be a value for the vapor pressure however is a duration will immediately start to take . if we left this box alone for long enough in now water will have evaporated from the water surface for the air to become saturated at this point if saturation will stop and the vapor pressure will also cease to rise this maximum value of the vapor pressure occurs at saturation and is called unsurprisingly the saturation vapor pressure.



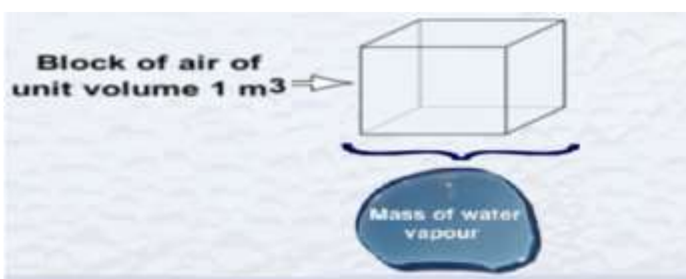
Saturation vapour pressure

We are now going to talk about humidity and its measurement we can reference humidity with two specific terms relative humidity and absolute humidity.

Relative humidity

Relative humidity is the percentage degree of saturation or put another way it is the amount of water vapor a body of air actually contains relative to the maximum amount it could hold expressed as a percentage a relative humidity of 100% is saturation.

Absolute humidity is the mass of water vapor contained in a unit volume of air it is expressed in terms of grams per meter cubed.



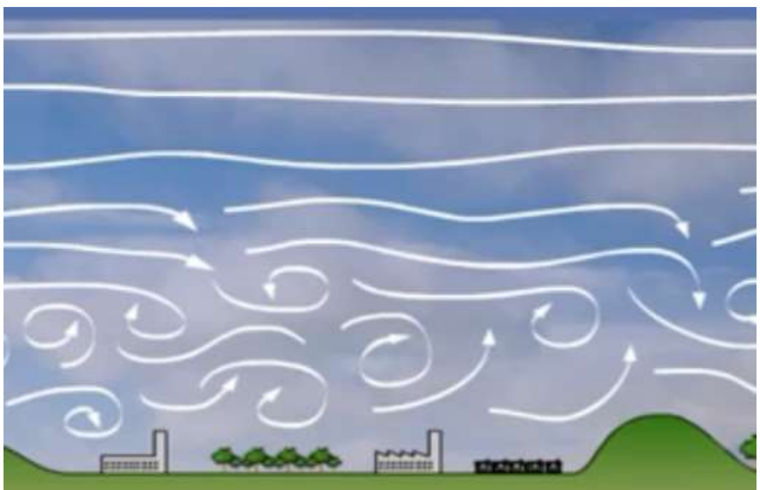
Absolute humidity
(grams of water vapour per 1 cubic metre of air)

Humidity mixing ratio or HMR is a similar property to absolute humidity in that it is a measure of the amount of water vapor contained in a sample of air but whereas absolute humidity is the mass of water vapor in a unit volume of dry air the humidity mixing ratio is the ratio of the mass of the water vapor to the mass of the dry air it is expressed in grams per kilogram. In calibrate latitudes the HMR value lies somewhere between five and fifty grams per kilogram in unsaturated air the HMR remains constant with increasing height whereas pressure and temperature decrease.

Saturation mixing ratio or FMR is simply the HMR when the air is saturated as a goal for the humidity lesson. We have looked in detail at water and its phases or States and also the practical implications of changes between these phases. as we have seen through this lesson water played a major part in the atmosphere and the weather despite the relatively small quantities in which it exists.

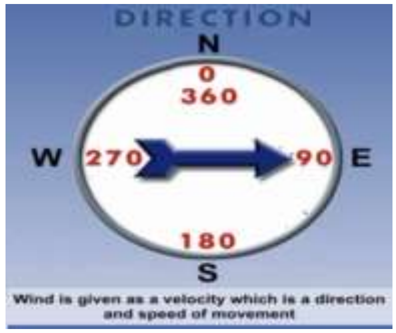
Meteorology Lesson 7 | Low Level Winds

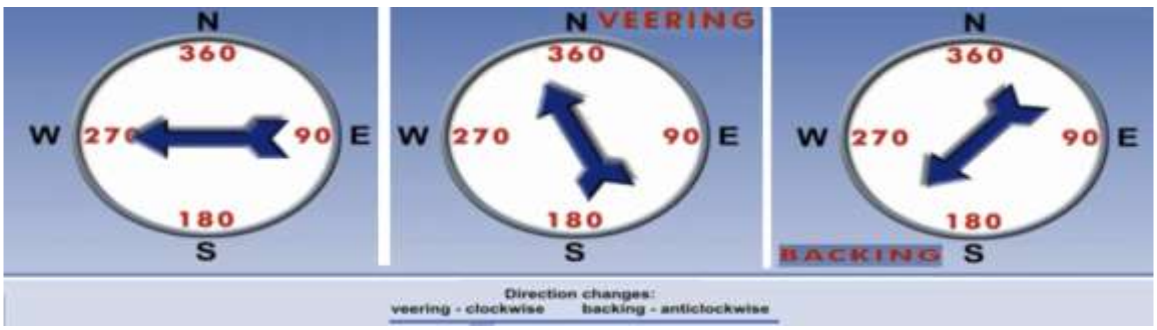
Through this lesson we are going to look at wind, primarily within the first few thousand feet of the surface. We will examine what creates wind what the forces involved are and how this change as the wind interacts with its environment particularly the surface over which it flows. what is window put simply it is the motion of air over the surface of the earth more particularly though it is the sustained horizontal flow of air over the earth on a large scale this flow is very closely related to the varying horizontal distribution of pressure namely high and low pressure zones. The essence of this lesson will look at this relationship in considerable detail. Firstly though let's examine the measurement of wind and its units.



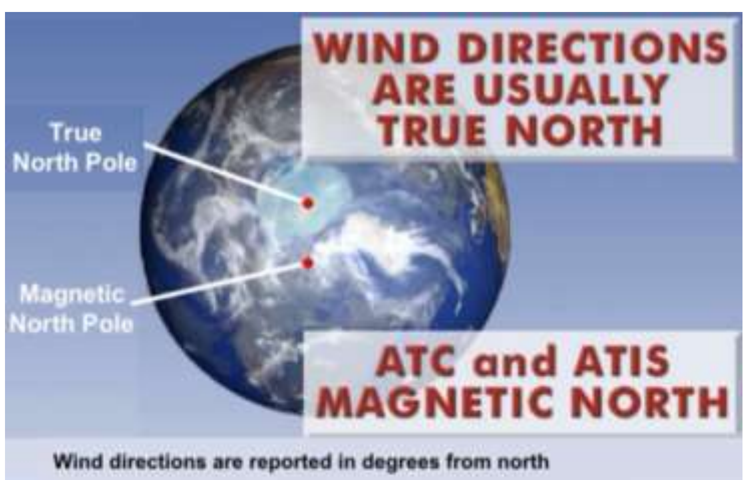
Wind is the sustained horizontal flow of air over the earth

Wind is usually represented as a velocity; velocity is a vector factor incorporating both direction and magnitude. So wind velocity gives both wind direction and wind speed. let's take a look at direction the direction of movement of any subject is usually given in degrees from north this scale starts from zero which is north all the way through to 360 degrees which is another way of expressing north. direction is referred to not as the heading of the wind but rather where the wind is coming from; for example a wind blowing towards the east is given a direction from the west and would therefore be shown as having a direction of 270 degrees a wind blowing towards the north in other words coming from the south would be shown as having a direction of 180 degrees.





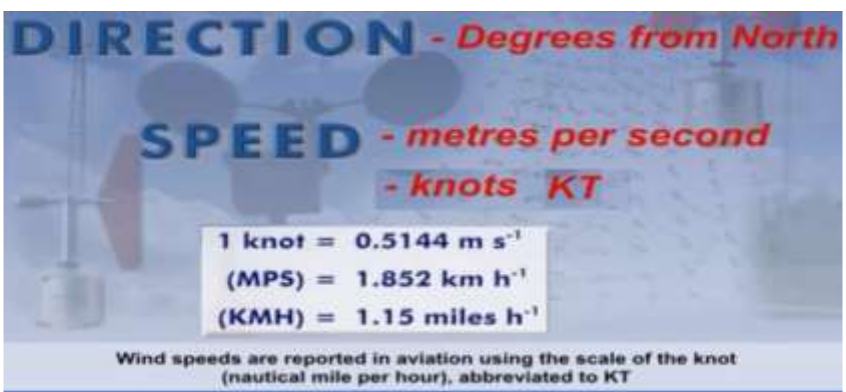
Changes in the direction of the wind are expressed using the terms **backing** and **veering**. A wind that is veering is changing direction in a clockwise manner. For example a wind that was 270 degrees and is now 360 degrees would be described as veering. A wind is said to be backing if the direction change of the wind is anti-clockwise for example a wind that was 360 degrees and is now a 180 degrees would be described as Backing.



However we have a true North Pole and a magnetic north pole, the problem is that these are not in the same geographical location. Traditional meteorology has little concern for magnetic north and therefore wind direction is referred to true north. However in flight headings are referenced to the compass which uses magnetic north; most wind direction given by meteorologists will be referenced to true north.

when using such wind directions be careful to adjust them using the relevant variation which allows the calculation of magnetic north. There are rare occasions when the reported winds are given as magnetic wind directions and not true range directions. These are typically whenever wind is reported by an air traffic controller from a tower and in the recorded aerodrome terminal information service.

If you remember wind is reported as a velocity; giving both direction and speed. The standard unit of speed is the meter per second. However this is mainly confined to scientific and theoretical use. More generally the unit adopted for operational purposes in aviation if they're not one not is one nautical mile per hour. The official our carrier abbreviation for youth in aviation is KT. Shown here are the conversion factors between the various units of wind speed namely knots, meters per second and kilometers per hour.



A Windscale to describe speed was introduced and devised by admiral **Beaufort** for use at sea. an adapted version for use over land is shown here and is often used by meteorological broadcasters today.

Measuring wind velocity is quite simple the most widely used instrument is the **cupped generator** and **wind vane** which is shown here. The three cups capture the wind and as a result they will rotate about a spindle. The rotation of the cups drives a sensitive electrical generator;

the greater the wind speed the greater the voltage generated. The generator moves a pointer around a dial graduated in knots.

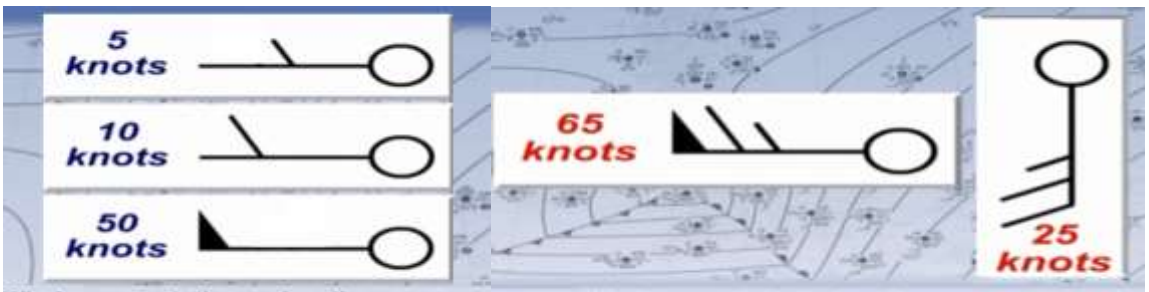
Wind instruments:
The cup anemometer and wind vane

The direction of the wind is measured by a remote transmitting wind vane this simply wants to turn into the wind and offer the least resistance to the airflow until recently these instruments only provided instantaneous readings but now it is more common for a computer processor to average out readings usually over a period of two to ten minutes. There is also a requirement to record details of any gusts or lulls in speed. These instruments are used around airfields to calculate the approximate surface wind velocity for aircraft either taking off or landing.

The definition of the surface wind is one that blows at approximately ten meters above ground level. The reason for this is that wind velocity changes dramatically with height and the very near surface velocity can be completely different from that a few meters above the surface consequently these instruments are placed ten meters above ground level and free of any nearby obstacles that may unduly disturb the flow of air and give misrepresentative readings.

On some weather charts you may see wind speed and direction being coded. shown here are a few examples of how these are presented, let's take a look at example number one the circle denotes the point of observation or the location of the reading the direction is shown by a straight line coming from the circle this line points towards the direction from which the wind is blowing shown here is a wind from 270 degrees in other words a westerly wind the wind speed coding is attached to the line emanating from the circle a thin straight line or feather represents 10 knots a short line or feather represents 5 knots the triangle shows a speed of 50 knots.

In this example we read the speed of 65 knots, example number 2 shows a southerly wind direction of 180 degrees and a speed of 25 knots now that we have learned some fundamentals about wind including speed direction units and coding let's examine some specific winds and the forces involved.



Wind representation and coding on some charts.

Wind representation and coding on some charts.

Meteorology Lesson 8 | Clouds & Precipitation

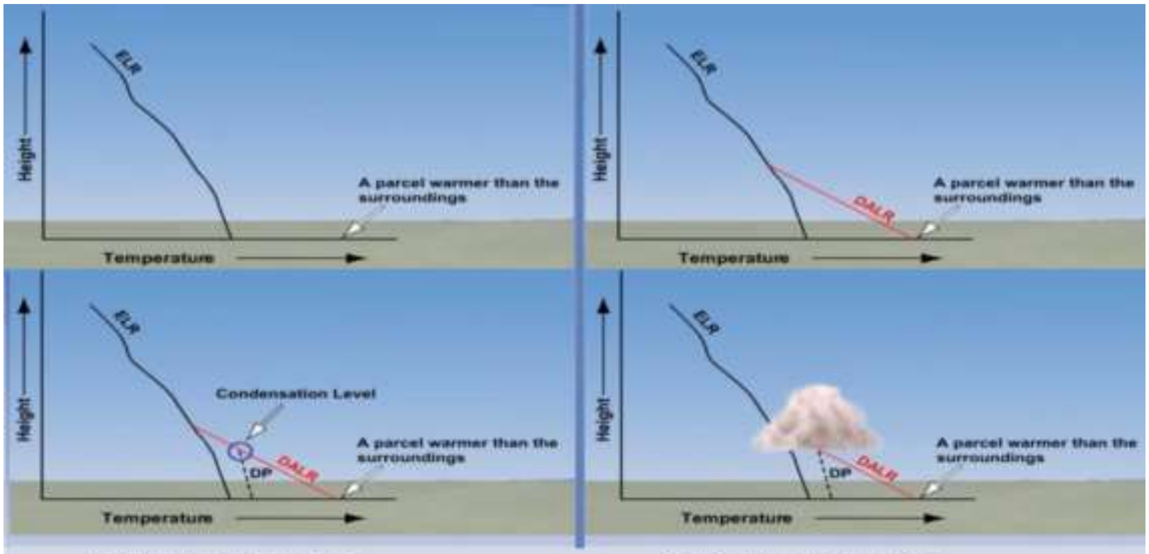
Throughout this lesson, we are going to look at clouds their formations and characteristics and how they relate to aviation. We shall also look at precipitation and how it is produced; this lesson links strongly with the principles of stability which we discussed earlier in this course.

Clouds form the basis of what we call weather and certainly for aviators they are significant indicators of what is happening within the atmosphere. so it is important to recognize the signs that are in the sky but how are they formed in the first place.

Cloud amount is measured in oktas or eighths of the sky. imagine the whole sky is divided into eight the number of eights of coverage is given for each cloud layer.

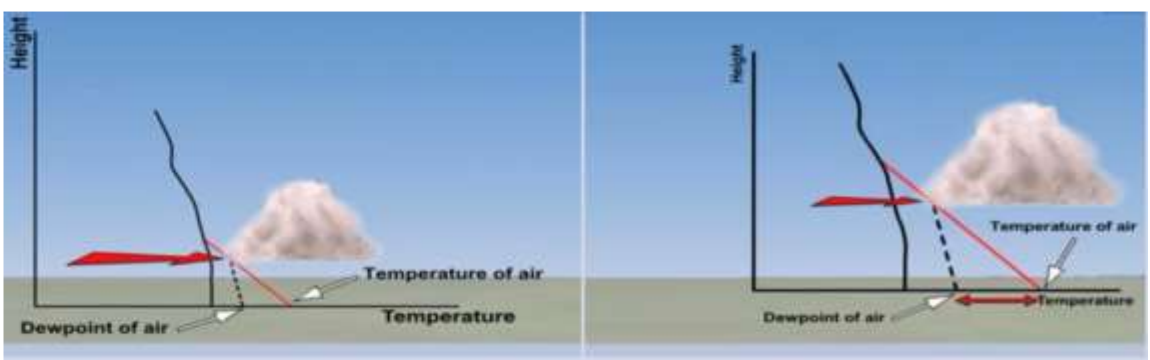
Cloud is formed by the vertical movement of air as it raises it cools adiabatically if the NASS cooling takes place saturation is reached and the water vapor condenses out into cloud droplets. the most simple form as we see here is a **cumulus cloud** appearing from a parcel of air which has been forced to rise this is called convection and is usually a result of surface heating there are however several reasons why air will rise which lead to varying types of cloud with different characteristics.

let us look at the convection process in a bit more detail; consider a plan of air forced to rise by surface heating the parcel will then be warmer than its surroundings the ELR and hence buoyant the parcel of air will therefore start to rise and since it is unsaturated the air will cool at the dry adiabatic lapse rate of 3 degrees per 1,000 feet of ascent or 1 degree per hundred meters at the same time the dew point of the parcel of air will cool at the steady rate wherever to meet saturation will occur this is called the **condensation level** and signifies the base of the convective cloud.



Cloud formation due to convection　　Cloud formation due to convection

let's consider how different dew points and temperatures at the surface change the **cloud base** this diagram shows how this temperature and this dew point of a parcel of air will give this cloud base. if during a summers day the temperature continues to rise to this point and the dew point falls to this point and then the cloud base will gradually rise to this point. Notice how the separation between the surface temperature and dew point has grown bigger we can see therefore that if the separation between surface temperature and dew point is greater than the convective cloud base will be higher.



Changing temperature and dewpoint　　The larger the difference between the temperature and dewpoint the higher the base of the cloud

an approximate way of calculating the cloud base in feet is to subtract the dew point temperature from the dry bulb temperature and multiply the answer by 400 this rule of thumb will give the cloud base in feet.so if the dew point is +5 degrees and the dry bulb temperature is plus 12 degrees then 12-5= 7 multiplying this by 400 is a convective cloud base of 2,800 feet above ground level.

Cloud base is defined as the lowest zone in which the type of obscuration perceptively changes from that corresponding to clear air haze to that corresponding to water droplets or ice crystals. The cloud base is the height of the cloud above ground level. how do we measure cloud base height; well there are several ways the most obvious one is from aircraft reports another way is by balloon a balloon is released which has a known rate of ascent. The time it takes to disappear into cloud is measured and the height of the cloud can be calculated. currently major cloud-based recorders are used at most military or largest civilian area drones to measure cloud base Heights accurately these fire a laser beam upwards which interacts with the cloud it encounters a proportion of the beam is then reflected back down to ground level where it is picked up by the receiver these are known more commonly as the low meters at night we can simply shine a powerful beam of light directly upwards this gives a spot on the underside of the cloud applying trigonometry and using an instrument called an alidade the angle of the spot is measured and the cloud base is calculated you may have heard the phrase cloud feeling as in calves okay ceiling and visibility okay cloud feeling is defined as the height above aerodrome level of the lowest layer of cloud of five octaves or more so we have looked at convective cloud bases and ceiling what about cloud tops the top of the cloud is a fairly simple concept in that it represents the transition into clear again noted by a sharp reduction in the relative humidity on a convective day when we have cumulus clouds as we see here the basis of the individual clouds are usually at a fairly constant level whereas the tops are at a multitude of heights above ground level aircraft observations radar and also satellite images can be used to measure the cloud tops but the more usual way is using a height temperature graph obtained from a radiosonde on our graph notice how the cloud stops at the point at which the fal are meets the ELR this part of the ELR is known as an inversion because the temperature starts to increase with height it is at this point that our parcel of air which was following the fal r is no longer warmer than its surroundings the ELR and therefore will no longer rise so far we have been considering convective cloud where a portion of air is either buoyant or stable in the atmosphere and so will either rise or remain stationary depending on its temperature and humidity but what about layered cloud like this let's consider our temperature height graph again if on our graph we introduce another line called the dew point curve to go with the ELR or environmental lapse rate it might look something like this these two curves together show us how moist the air is and our typical measurements that are taken by a weather balloon if they are close together the atmosphere is very humid when the temperature of the rising air is the same as the dew point we have saturation and cloud will form if cooling continues the graphs can tell us this and shows where layers of cloud could be found here and here we would expect to find layered cloud such as stratocumulus or altostratus whereas here the ELR and dew point curves are well separated so we expect clear and saturated air and hence cloudless conditions ploud can be produced by yet another mechanism turbulent mixing if for example we have very light winds overnight layers affair with very different humidity properties can develop but with no cloud after sunrise there may be an increase in wind causing these layers to become well mixed putting it simply when this happens the moisture contained within the whole layer can become concentrated at the top of the mixing layer trapped beneath an inversion the moisture content is enough to produce saturation and hence a layer of cloud beneath the inversion the cloud is not turbulent itself but created from turbulent mixing.