Lecture Notes on Physical Meteorology (E Learning Portions) For Forecaster Training Course

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Chapter 1
Upper Atmosphere

1.1. Composition of the Atmosphere

The atmosphere is the envelope of gases surrounding the earth and it is bound to earth by the force of gravitation. The atmosphere consists of a mixture of gases within which tiny liquid and solid particles called aerosols also exists. Among the various gases by which atmosphere is made up of, certain gases are permanent gases and certain gases are variable gases. Among the variable gases, the water vapour is the major one which occupies a maximum of about 4% of the volume of a sample of air. However, in spite of its very small concentration, this minor constituent of the atmosphere has a very important role in the atmospheric processes.

Let us discuss the composition of pure dry air first. The major constituents of pure dry air are Nitrogen and Oxygen which make up about 99% of the air but they do not play any active role in the meteorological processes. In addition to these, trace gases such as carbon monoxide, radon, nitrous oxide, methane etc. are also present in the atmosphere.

Carbon dioxide, the concentration of which is approximately 0.03 % by volume in the lower atmosphere, enters the atmosphere by processes like combustion, human and animal breathing, photosynthesis and volcanic activity. Its concentration varies little in general but in the local scale it shows variations. The concentration is higher in the cities as compared to country side and it is higher very near to the soil.

Ozone is another important constituent of the dry air. The total amount of ozone in a vertical column of the atmosphere is relatively small. If the total amount of ozone is brought down to mean sea level, it will form a layer of thickness of about 0.3 centimeters only. Measurements indicate that, the concentration of ozone increase with altitude and reaches a maximum at about 25 kilometers and then it starts decreasing falling to small amounts at about 50 kilometers. Above that, the concentration of ozone falls further and at about 70 kilometers altitude, the concentration is almost nil. Even though the concentration of ozone in the atmosphere is very little, this gas plays a significant role in the atmosphere. Solar radiation in the ultra violet (uv) region is strongly absorbed by ozone in the stratosphere hence the radiative balance and the thermal structure of the stratosphere is highly influenced by the distribution of ozone. In addition to that, absorption of solar radiation by ozone in the uv region effectively shields the earth's surface from that harmful radiation thus protecting the human and animal life on the earth's surface.

In addition to the gases which constitute the dry air, water vapour is also present in the atmosphere in varying proportions. Its distribution is highly variable in time and space and its concentration decreases normally with altitude. Water vapour enters the atmosphere by evaporation from water bodies and transpiration from plants. It exists in solid, liquid and vapour stages in the atmosphere and has the capacity to change from one phase to another. The change of phase of water vapour is involved with the absorption or release of latent heat hence it plays a major role in the atmospheric thermodynamic processes. In the processes associated with absorption of radiation also, water vapour has a major role to play.

The three minor constituents mentioned above are the most important gases with respect to meteorology. Earth atmosphere system looses energy by terrestrial radiation but carbon dioxide , water vapour and the ozone are very good absorbers of terrestrial radiation and because of this absorption and the resultant emission, a major portion of the energy lost by the earth atmosphere system is returned back to the earth. Thus these minor constituents play a major role in the radiation balance of the earth atmospheric system and they are generally termed as the greenhouse gases.

The composition of the dry air remains generally constant up to the height of about 80 kilometers which indicates the sufficient mixing which takes place in this region. The layer of the atmosphere up to the height of 80 kilometers is known as homosphere. Above 80 kilometers, oxygen begins to dissociate under the influence of ultraviolet radiation. At further higher levels, nitrogen also starts dissociating. However, the quantity of air above these levels is so less that these dissociations will not have much meteorological significances but this process have a significant influence on the propagation of radio waves.

The region above homosphere is known as hetrosphere. Here the gases separates out and exists in individual form with respect to their respective molecular weights. The heavier gases tend to concentrate in the lower levels with the lighter ones lying above. Thus this layer is characterised by decreasing molecular weight with height.

In addition to the gaseous constituents, aerosols; the solid particles and the liquid droplets suspended in the air are in enormous numbers and have their effective radius between 0.005 μ and 20 μ in the atmosphere. The aerosols can enter into the atmosphere by various processes like dispersion, combustion, photochemical reaction, evaporation of sea spray, industrial activities etc. Dust, smoke, salt particles and condensed water vapour are the major nongaseous materials present in the atmosphere. The concentration of aerosols varies with time and space.

Presence of aerosols in abundance will affect the visibility considerably. It also has some impact in the transmission of the radiation through the air. The aerosols, mainly from industrial origin, in abundance, pose severe health hazards. However, aerosols play a major role in cloud formation, as condensation nuclei or ice nuclei and are thus important meteorologically.

1.2. Vertical Structure of the Atmosphere

The atmosphere can be divided into different layers according to composition, ionization and the temperature distribution. However, the division with respect to the thermal stratification is the most commonly used one.

In 1950, Chapman divided the atmosphere into troposphere, stratosphere, mesosphere and thermosphere. The stratosphere and the mesosphere were bounded at the top by the stratopause and the mesopause. He also suggested a subdivision of the mesosphere into mesocline and mesodecline separated by the region of maximum temperature in the mesosphere at about 50 kilometers called mesopeak.
Goody in 1954, considered the entire region between the tropopause and the temperature minimum near 80 kilometers as stratosphere. He suggested the region from the tropopause to about 32 kilometers as the lower stratosphere and the rest of the stratosphere as the upper stratosphere. The region above stratopause at 80 kilometers is referred to as ionosphere by him.
The system which is most commonly used at present is associated with the name of Nicolet. It was recommended by International Union of Geology and Geophysics at its Helsinki meeting in 1960 and was approved by World Meteorological Organization's executive committee in 1962. In this system, the lower most layer is the troposphere in which temperature decreases with height and this layer is bounded at the top by an isothermal layer called the tropopause .The stratosphere extends from the tropopause to the temperature maximum near 50 kilometers

(stratopause) and the mesosphere lies between the stratopause and the temperature minimum near 80 kilometers(mesopause).The layer above mesopause is referred to as thermosphere in which temperature increases with height.

The vertical division of atmosphere according to thermal stratification is given in Figure 1.

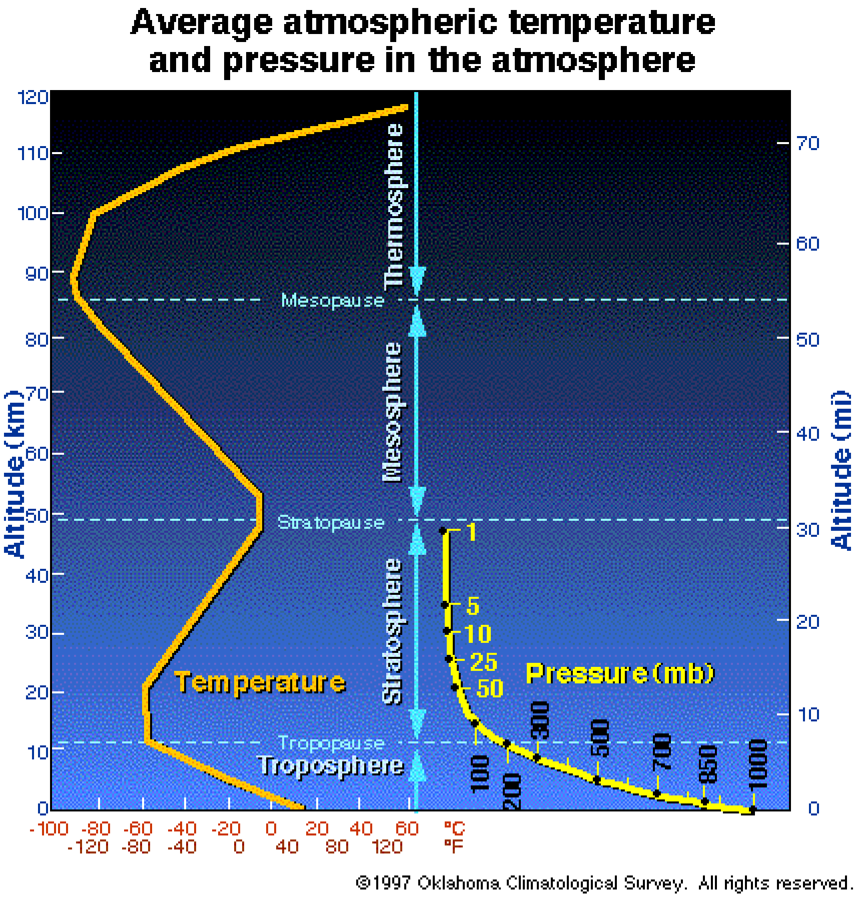


Figure 1: Vertical division of the atmosphere

The rate of fall of temperature with height is known as lapse rate. Hence when the temperature is decreasing with height, lapse rate is positive and when the temperature is increasing with height, lapse rate is negative. Accordingly, the troposphere and the mesosphere have positive lapse rates and stratosphere and the thermosphere have negative lapse rates.

The region above tropopause is generally considered as the upper atmosphere.

In Figure 1, the altitudes mentioned for termination of different layers is given on an average. But the tropospause in the equatorial region can be found at a height of about 16 to 18 kilometers where as in the polar region, it can be observed at a height of about 8 to 9 kilometers itself. Hence lower limits of the stratosphere and thus that of the upper atmosphere depends very much upon the thermal properties of the lower atmosphere at a given time and place and not by definite altitude limits.

The division of the atmosphere into homosphere and the hetrosphere according to composition is already discussed in the previous section. As suggested by Chapman(1950), the word homosphere can be used to refer to that part of the atmosphere upto about 80 kilometers with uniform composition and the word hetrosphere can be used to refer to further higher regions with varying compositions.

As suggested by Chapman, when the criteria of ionization is referred to, the word neutrosphere can be used to designate the lower part of the atmosphere upto about 60 kilometers where ionization is unimportant and the region above can be referred to as ionosphere where the ionization and thus the concentration of free electrons becomes significant.

In addition to these, the outermost region of the atmosphere, above a few hundred kilometres, where the mean free paths of the molecules are so long that they can escape from the atmosphere is often referred to as exosphere.

1.3. Tropopause

Tropopause is the boundary between the troposphere and the stratosphere. Troposphere is the region where the temperature is decreasing with height and stratosphere is the region where the temperature is increasing with height. Hence tropopause is the boundary between two layers where the temperature lapse rate reverses.

In the tropical region, the tropopause is coming at an altitude of about 16 to 18 kilometers where as in the polar region it is coming at about 8 to 9 kilometers.Hence tropopause is not a single continuous layer extending over the globe and its height is decreasing from equator to pole. The altitude of the tropopause can change with season. Fluctuation in its altitude can occur in association with the movement of the synoptic weather systems also.

The tropopause of the tropical region which is at a higher altitude is known as tropical tropopause and the tropopause of the polar region which is at a lower altitude is called polar tropopause.

Region between these two tropopause is known as tropopause break. On the average, there exist two breaks in the tropopause one occurring in the subtropical region at about 20 to 30 °N and the other occurring at middle latitude region at about 55 ° N. The tropopause break occurring in the sub tropical region is associated with subtropical jet stream. The tropopause break occurring in the middle latitude region is associated with polar front jet stream. Since the tropopause is not a continuous single layer all over the globe, in certain latitudes, there occur multiple tropopauses also.

The tropopause breaks are important in the process of vertical transport of radio active material from nuclear explosions. The tropopause breaks are also important in the dispersal of volcanic ash. Through the tropopause breaks, minute quantities of ozone are reaching the troposphere from stratosphere.

1.4. Stratospheric Warming

Stratosphere is the region situated between the tropopause and the stratopause. In stratosphere temperature generally increases with height. Within the stratosphere there exists a level of minimum horizontal temperature gradient (in the meridional direction) at about 25 kilometers. This region is called stratonull region. Taking into consideration of this stratonull region, the stratosphere can be divided into lower stratosphere and upper stratosphere. Lower stratosphere is the layer between the tropopause and the stratonull region and the upper stratosphere is the layer between the stratonull region and the stratopause. Hence the lower stratosphere is a thinner layer in the tropical region as compared to the polar region.

The tropopause in the tropical region is observed roughly around at a height of 16 to 18 kilometers and polar tropopause is observed at a height of around 8 to 9 kilometers. Hence if we move from tropical tropopause towards the poles, temperature is expected to increase. This normal feature is observed in the month of July for northern hemisphere (northern hemispheric summer) but during the winter season, this feature is not observed. During January, the representative month for winter for northern hemisphere, temperature increases pole ward from the tropical tropopause, reaching a zone of warmest temperature in the middle latitudes. Further pole wards, the temperature shows a decreasing trend, reaching a minimum value over the poles. The pole ward decrease of temperature beyond the middle latitudes is due to the absence of solar radiation to the north of about 66° N in January. Similar feature prevails in the southern hemisphere during July (southern hemispheric winter).

However the cold polar lower stratosphere occasionally gets interrupted by large scale warming during the winter season. This phenomenon is characterised by temperature increase in the polar region immediately above the stratonull by about 50 degrees within a period of 10 days or less accompanied by the disruption of the circumpolar westerlies of the winter.

The temperature increase can be in the range of 30 to 90 ° C over a period of one week and change in wind will be from 100 m/s westerlies to 50 m/s easterlies. The rise of temperature will be happening at the rate of 5 to 6 ° C per day but in extreme cases it can be as high as 20 ° C per day. The timing, intensity and characteristics of stratospheric warming change remarkably from year to year. This warming of the polar stratosphere occurs during the period between December to March in northern hemisphere. The region of high temperature is observed first close to the stratonull region, near the boundary of the polar regime, where the temperature gradient gets reversed in the winter season. From there it spreads to lower levels as well as pole wards in the horizontal direction, within a period of one week or two. This type of warming is found to be associated with the shifting of the cold polar low from its normal winter position or with the migration of two such lows.

Stratospheric warming is not a continuous phenomenon during the whole winter season. Occurrence of stratospheric warming will be followed by re establishment of normal winter pattern, with the re establishment of cold polar low and the strong circum polar westerly flow. However, within one winter season there can be two to three occasions of stratospheric warming and associated breakdown in the temperature and wind pattern followed by re establishment of normal winter features.

It has been observed that this type of sudden warming occur over the tropics also but the warming in tropics is found to occur in both summer and winter seasons.

1.5. Quasi Biennial Oscillation

Normally the winds in the lower stratosphere in the tropical region are easterlies. However, it was later found out that the lower stratospheric winds in the tropical area oscillate between easterlies and westerlies with a periodicity of 26 months. Hence depending upon the phase of this oscillation the lower stratospheric winds in the tropical area can be easterlies or westerlies between 100 hPa to 10 hPa levels. The oscillations

of the lower stratospheric winds in the tropical area between easterlies and westerlies are known as quasi biennial oscillation (QBO).
The important features of QBO are as given below:

1. The winds during easterly phase are stronger than the winds in the westerly phase.
2. The change over between easterlies and westerlies is observed in all the longitudes around the globe but it is not symmetrical .This type of oscillation is observed in both the hemispheres also.
3. The change over from easterlies to westerlies is rapid but the change over from westerlies to easterlies is gradual.
4. The amplitude of QBO increases from tropopause upto the level of 25 hPa . Above 25 hPa, the amplitude of the oscillation decreases and reaches a minimum near the stratopause.
5. The amplitude of QBO decreases with latitude also. It is more prominent in the lower latitudes, close to equator. However the oscillation with very small amplitude is found in higher latitudes also.
6. The westerly phase of the QBO is associated with higher temperature at the equatorial region.
7. The changeover from easterlies to westerlies and vice versa is usually observed first in the higher levels close to the stratonull region and the same will be descending downwards with a speed of one kilometre/month .Thus the transition from one phase to another phase at a lower level like 60 hPa may be occurring later than the changeover at 10 hPa level.

The reason for QBO is expected to be due to some mechanism occurring in the upper stratosphere or mesosphere since there is a downward propagation of the oscillation. QBO is observed to have some association with the sun spot activity also. Main reason projected for the QBO is the interaction of the stratospheric winds with the Kelvin waves or the Mixed Rossby Gravity waves. These waves are formed due to the release of latent heat from convective clouds in the tropical troposphere. These waves interact with the mean flow of the lower stratosphere and impart their momentum to the mean flow. Kelvin waves are westerly waves where as Mixed Rossby Gravity waves are easterly waves. Thus, westerly phase of QBO will be there when the Kelvin waves are prominent and easterly phase of QBO will be there when Mixed Rossby Gravity waves are prominent.

1.6. Water vapour and Particulate matter in the Lower Stratosphere

Even though the stratosphere is generally considered as a dry layer, the existence of the **mother of pearl clouds** in the upper stratosphere shows the evidence of condensation and thus the presence of water vapour in this layer. The stratospheric moisture has its origin in the vertical transport of moisture through convective systems reaching beyond tropopause or the diffusion of water molecules from oceans through which moisture slowly rises to the stratospheric levels.

The measurements indicates the existence of mixing ratios of the order of 10^{-5} to 10^{-4} g/Kg in the layer between 20 to 30 kilometers and that of the order of $2x\ 10^{-6}$ g/Kg in the layer between 10 to 15 kilometres .The lower values of the lower levels is explained mainly with respect to the reaction of water vapour with ozone.

For condensation of water vapour leading to formation of clouds, availability of particulate matter is also essential in the stratosphere. The particulates are found to be of internal as well as of external origin. Oxidation of hydrogen sulphide /sulphur dioxide present in the atmosphere contributes towards the internal origin of particulate matter. Volcanic eruptions and atomic explosions occurring in the troposphere as well as the dissipation of convective clouds reaching beyond tropopause levels also leave particulate matter in the stratosphere. Meteorite debris is another source of particulate matter for the stratosphere.

Particulate matter can be classified according to their size. Those with size less than 0.1 μ radius, with radius in the range of 0.1 μ to 1.0 μ and those with radius more than 1.0 μ. The particulate matter of tropospheric origin comes in the first category whereas the meteorite debris comes under the last category. The particulate matter of internal origin comes under the intermediate category.

Chapter 2
Air Pollution

Air pollution is the presence of foreign substances in the air. Generally, the air pollution is associated with human activities. However, the geophysical causes like volcanic eruption and electrical discharges also produce aerosols or ions in the atmosphere which can lead to atmospheric pollution.

Presence of any foreign substances in the air can be termed as pollution, only when it interferes with the well-being of the people.
Air pollution can be defined as the presence in the outdoor atmosphere of one or more contaminants such as dust, fumes, gas, mist, odour, smoke or vapour in terms of quantities, characteristics or of duration, so as to be injurious to human, plant or animal life or to property or which unreasonably interfere with the comfortable enjoyment of life and property.

2.1. Sources of Air Pollution

The main source of air pollution is combustion or burning of fuels. The sources include the exhaust emissions associated with vehicular traffic or the waste gases of industrial origin.
Fuels are mainly of fossilized plant material and consist of carbon and its compounds. On combustion, they produce heat, energy as well as gaseous and solid wastes. If the combustion is complete, carbon dioxide is the by product. But incomplete combustion produces carbon monoxide which is a toxic by product. Fossilized fuel contains 0.5 to 4.0 % sulphur also hence sulphur dioxide is another by product produced by combustion which is injurious to living things.
Vehicular traffic is the second major source of air pollution. During combustion of the fuel in the engine cylinder, Nitrogen monoxide is getting produced. When this goes out of the exhaust and cools down, it combines with more oxygen to produce N_2O_4 and NO_2 which are injurious. In petrol as well as in diesel oil, sulphur is present. Hence, sulphur dioxide will be produced by the oxidation of sulphur which is harmful. Unburned hydrocarbons emitted by diesel engine is another injurious by product. In addition to this, practice of using lead based compounds like tetraethyl lead also produces harmful by product on combustion of fuel. During combustion, the organic lead compounds decompose to produce inorganic lead which will be passing into the air through the exhaust. Lead is one of most toxic pollutant in the atmosphere.
Industry is the third main source of pollution. Combustion of coal, coke or petroleum for generation of power in industries produces smoke as well as sulphur dioxide. From cement, coal, iron and steel industries, dust pollution is also created. Paper mills, refineries produce toxic gases, heavy metals and organic compounds which are also harmful for the living things.
Natural radioactive elements and compounds present in the earth's crust produce radioactive gases in the process known as radioactive disintegration. In addition to that, there are manmade sources of radiation like nuclear weapons testing etc.

Human activities from mobile and stationary sources are responsible for the emission of common air pollutants like oxides of Sulphur and Nitrogen, particulate matter, hydrocarbons and carbon monoxide, volatile organic compounds and trace metals such as Lead, Cadmium, Copper, Mercury and Zinc.

2.2. Constituents of Air Pollution

The constituents of pollution are either gases or particulates. Particulates or aerosols are fine solid or liquid droplets suspended in the air. The constituents of air pollution can be classified in the following manner according to size.

Grit: solid particles with diameter more than 500 μ

Dust: solid particles with diameter between 0.25 μ and 0.5 μ

Smoke: gas borne solid particles with less than 1.0 μ in diameter

Fumes: suspended solids with diameter less than 1.0 μ from chemical and metallurgical process

Mist: Liquid droplets with diameter less than 200 μ

Aerosols: Solid or liquid particles with diameter less than 1.0 μ from other sources.

Atmosphere is highly polluted in the troposphere and in the lower stratosphere. According to concentration of pollution, the atmosphere can be divided into four layers.

1. 1 to 100m layer near the ground: Very polluted specially from local urban sources.
2. 100m to the cloud base (500-2000 m): This layer is also generally much polluted from local urban sources.
3. Cloud base to the tropopause: Here the pollutants are well mixed due to turbulence and contain drizzle, rain and fog droplets
4. Lower stratosphere: This layer is usually polluted with volcanic dust, meteoritic debris etc.

2.3. Scale of Air Pollution

The scale of air pollution problem can be described in the following way.

1. Local scale of air pollution problem is the case in which the source is located in the close proximity. For example, in case of pollution from automobiles, the recipients are the pedestrians on the road or the persons living in the buildings close by and in this case, the source and the recipients are in close proximity.
2. Urban scale involves the air pollution problem associated with a city and its suburbs in which the highest concentration of the pollution occurs at the centre of the city which goes on decreasing while moving towards the suburbs.

3. National scale of air pollution involves the case of pollution associated with biomass burning etc. in which very large area gets affected with the pollutants.

4. In case of global scale of air pollution, the pollution arising due to volcanic eruption, forest fire etc. are to be considered in which even adjacent continents can feel the impact of pollution.

2.4. Impacts of Air Pollution

Gaseous pollutants together with the rain and solar radiation can damage the surface of the buildings especially those which are made up of lime stone and sand stone. The impact of air pollution on metal surfaces leads to corrosion.

Plants and soil are also affected by gas pollutants as well as by the rain containing acid radicals. In the long run, it can cause lowering of the pH of the soil. Particulate matter which blocks the pores of the plants can reduce the absorption of carbon dioxide and reduce the photosynthesis and transpiration.

In case of human beings, ailments like bronchitis, pneumonia and breathing problems like asthma, chest related problems like tuberculosis, heart diseases etc. gets aggravated due to air pollution thus causing severe impact on health.

2.5. Dispersion of Air Pollution

The concentration of air pollution accumulating at a particular site depends largely up on the meteorological conditions. Hence for assessing the impact of air pollution, the source and sink of the air pollution as well as the state of the atmosphere needs to be considered. The meteorological parameter like wind, temperature, stability, mixing height, rain etc. influence the dispersion of air pollution.

The stability of the atmosphere is very much dependent upon the vertical distribution of temperature with height. The rate at which the ambient air temperature decreases with height is referred to as the environmental lapse rate (ELR). The rate of change of temperature that a parcel of air (which moves adiabatically in the atmosphere) will have with height depends upon the type of the air parcel. The fall of temperature for dry air parcel and for an unsaturated moist air parcel will be according to Dry Adiabatic Lapse Rate (DALR) and for saturated air parcel it will be according to Saturated Adiabatic Lapse Rate (SALR).If the ELR is greater than the lapse rate of the parcel, the parcel will be unstable. If the ELR is more than DALR, it means the ELR is more than SALR also and in this case, the atmosphere will be absolutely unstable ie. Atmosphere will be unstable for any type of parcel of air. In case of instability, dispersion of pollution will be more.

Mixing height or mixing depth is used by the Meteorologists to quantify the vertical mixing in the atmosphere. The concept of mixing height is based upon the principle that when the atmosphere is heated from below, it becomes unstable which will give rise to vertical motion and mixing. Mixing height thus can be defined as the top of the surface based layer in which vertical mixing is relatively vigorous and the lapse is approximately dry adiabatic(which is generally possible during day time under cloudless conditions).The mixing height is zero or absent in case of ground based inversion.

Mixing height can be found out using vertical temperature profile. The altitude at which the dry adiabatic line intersects the environmental curve on an aerological diagram can be taken as the maximum mixing depth (MMD).

The MMD is a function of stability. In unstable air, MMD is higher and in the stable air MMD will be lower. Mixing height change with season also. During summer daylight hours, mixing height can be a few thousand meters whereas in winter, it can be a few hundred meters only.

Mixing height shows variation during the course of a day also. It is lowest in the night and increases as the day progresses, with the increase of surface temperature. It will achieve a maximum around the time of occurrence of maximum surface temperature or slightly later depending upon the topography.

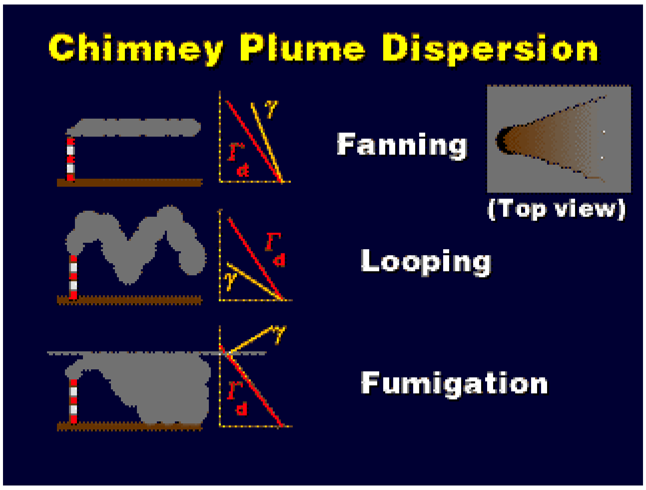
From the vertical temperature profile, the morning mixing height is calculated as the height above the surface at which the dry adiabatic extension of the morning minimum surface temperature plus 5 ° C intercepts the vertical temperature profile of 1200 UTC of the previous day. The afternoon mixing height is calculated as the height above the ground at which the dry adiabatic extension of the afternoon maximum temperature intercepts the vertical temperature profile of 0000 UTC of the same day.

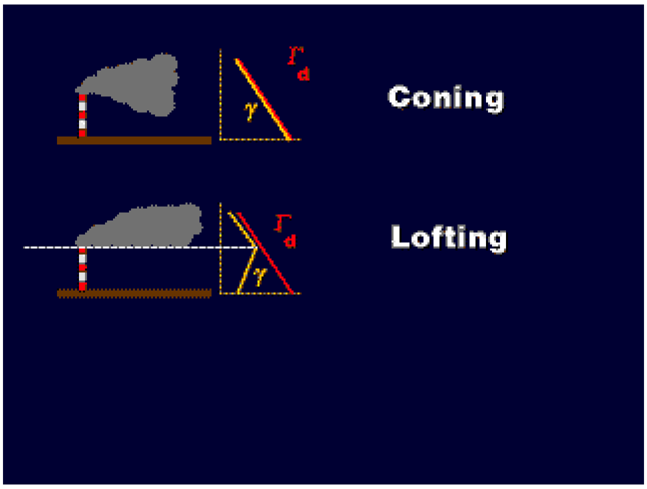
In the mixing layer of the atmosphere, the mixing height gives a measure of the vertical mixing in that layer whereas the mean layer wind gives a measure of horizontal transport of air in the layer. Product of mean layer wind with mixing height gives ventilation coefficient which is a measure of the total mixing or the volume rate of horizontal transport of air within that layer. Its unit is m^2/sec.

Thus the ventilation coefficient is a useful parameter to determine the pollution dispersing capacity of the air. Thus, high mixing height with light horizontal wind will have the same impact on pollution transport as low mixing heights associated with strong winds.

Also the high values of ventilation coefficient corresponds to high dispersion of pollution and thus it is associated with low pollution potential whereas low values of ventilation coefficient is associated with high pollution potential since it corresponds to lower levels of pollution dispersal.

2.6. Chimney Plume Dispersion & Atmospheric Stability





In the stable atmosphere case (producing a fanning plume), there is horizontal dispersion at right angle to the wind due to turbulence and diffusion. In the vertical, dispersion is suppressed by the stability of the atmosphere, so pollution does not spread towards the ground. This results in very low pollution concentrations at the ground.

In unstable air, the plume will whip up and down as the atmosphere mixes around (whenever an air parcel goes up, there must be air going down somewhere to maintain continuity, and the plume follows these air currents). This gives the plume the appearance that it is looping around.

An inversion aloft will trap pollutants underneath it, since the stable inversion prevents vertical dispersion. Pollution released underneath the inversion layer will fumigate in the mixed layer. On the contrary, if the smokestack is high enough to release the pollution within the inversion layer aloft, the plume would fan because the plume occurs within stable air. This causes the maximum concentration of pollution at the ground level.

In the neutral atmosphere case, the horizontal dispersion at right angle to the wind is due to turbulence and diffusion, which occurs at the same rate as the vertical dispersion, which is not being opposed nor encouraged by the stability (or lack of it) in the atmosphere. So, the plume spreads equally in the vertical and horizontal as it propagates downstream, forming a coning plume.

In the lofting case, pollution dilutes upward. In this case there will be an inversion and hence stable condition in the lower levels and the chimney height will be above the top of the inversion. This produces much lower pollution concentrations at the ground at a distance downstream than in the straight stable case (fanning plume). In case of stable atmosphere, because of molecular diffusion and slight turbulence, the smoke reaches the ground eventually at a distance downstream. Also the fanning plume does not have the upward dispersion as in case of the lofting plume.

2.7. Acid rain

Acid rain is a broad term referring to a mixture of dry and wet deposition or deposited material from the atmosphere containing higher than normal amounts of nitric and sulphuric acids. The precursors or chemical forerunners of acid rain formation result from natural sources like volcano and decay of vegetables and also from the man-made sources like emission of sulphur dioxide and nitrous oxides resulting from fuel combustion.

Wet deposition refers to acid rain, fog and snow. If the acid chemicals in the air are blown into areas where the weather is wet, the acids can fall to the ground in the form of rain, snow, fog or mist. As this acidic water flows over and through the ground, it affects a variety of plants and animals. The strength of the damage caused depends upon various factors like how much acidic the water is, the chemistry and the buffering capacity of the soil involved etc.

In areas where the weather is dry, the acid chemicals may get incorporated into the dust or smoke and fall to the ground through dry deposition or it can stick to the ground, buildings, homes, trees etc. Dry deposition can be washed down from these surfaces by rain storm, leading to increased run off. This run off water makes the resulting mixture more acidic. About half of the acidic substances in the atmosphere fall back to the earth by dry deposition.

Acid rain is measured using a scale called pH. The lower any substance's pH, the more acidic it will be.

2.8. pH Scale

Acidic and basic are two extreme terms that describe chemicals. Mixing of acidic and basic substances cancel out their extreme effects. Any substance which is not acidic or basic is neutral.

The pH scale determines how acidic or basic a substance is. It ranges from 0 to 14.A pH of 7 is neutral. A pH less than 7 is acidic and a pH greater than 7 is basic. Each whole value below 7 is ten times more acidic than the next higher value. For example, a pH of 4 is ten times more acidic than a pH of 5 whereas it 100 times more acidic than a pH of 6.The same hold true for the pH values above 7, each of which is ten times more alkaline or more basic than the previous lower whole value. Thus a pH of 10 is ten times more alkaline than a pH of 9 and hundred times more alkaline than a pH of 8.

Pure water is neutral with a pH of 7.0.When chemicals are mixed with water; the mixture can become either acidic or basic. Addition of vinegar or lime juice makes pure water acidic whereas addition of detergents or ammonia makes it basic.

Even though the pure water has a pH of 7.0, normal rain is slightly acidic because carbon dioxide dissolves into it forming weak carbonic acid, giving the resulting mixture a pH of approximately 5.6, at the general concentration level of carbon dioxide in the atmosphere.

2.9. Wind roses

The wind climatology of a location need to be considered while setting up industrial projects etc. in that location since wind is one of the main factors involved with the dispersion of air pollution.

Wind roses are the graphical representation of the wind climatology of a particular location for a specified period of time. It is a comprehensive diagram representing the frequencies of occurrence of wind from each direction with various ranges of speed.

In order to prepare the wind roses for a station, hourly data of the wind speed and the wind direction of that station are the basic information needed. This data can then be classified into wind speed ranges and directions in tabular form. Since the calm winds do not have any specified wind direction, it has to be considered separately. The total of all the columns and the rows corresponds to the total number of observations but it does not reflect the number of occasions if any in which the wind vane or the anemometer is not functioning. Considering the total number of observations, the individual number of occurrences in each box can be transformed into percentage frequencies. Using that, a second contingency table can be prepared in which column wise or row wise, the total percentage frequency is equal to 100%.

To draw the wind rose, first of all a circle is drawn and at the centre of the circle, the number of calms are mentioned in the denominator and the total number of observations are denoted in the numerator. Then for each direction, depending upon the frequency of occurrence of wind in a specified group, representation is made by projecting a line with a suitable symbol. After completing all the speed groups in one direction, next wind direction can be taken up and similar symbolization is performed and the same process can be repeated for all the wind directions of interest.

Similar type of wind roses can be drawn for monthly, seasonal and annual wind representation also.

When the number of calms is very large, it is desirable to distribute them in the lowest wind speed class among all the sixteen directions of the compass.

References:

1. Environmental Meteorology by B.Padmanabha Murty
2. Fundamentals of Air Pollution by Richard W.Boubel et al.
3. ‘Lecture notes on upper atmosphere’ by Dr.U.S.De
4. The Upper Atmosphere: Meteorology and Physics by Richard A.Craig