THUNDERSTORM

1. **Thunderstorm is** a violent short-lived weather phenomenon generated by Cumulonimbus (Cb) cloud and is associated with lightning, thunder, other dense clouds, precipitation, and strong winds. Thunderstorm build up takes place in highly unstable atmospheric condition. Up and down draft gets generated by the cloud and ultimately cause lightning and thunder. The precipitation caused by Cb cloud may be in form of hail as the grows beyond 0^{o}C isotherm, where water is in its solid form.

2. As far aviation is concerned, this cloud is considered the most hazardous one and all the aircraft, as far as possible, avoids this cloud. Due to prevailing up and down drafts, an aircraft experiences severe turbulence. Besides, due to presence of hail stone, the frame of the aircraft may get damaged. There are some other hazards associated with Cb clouds which will be discussed little later.

3. **Lightning.** Lightning is a naturally occurring electrostatic discharge during which two electrically charged regions, both in the atmosphere or with one on the ground, temporarily neutralize themselves, causing the instantaneous release of an average of one gigajoule of energy. This discharge may produce a wide range of electromagnetic radiation, from heat created by the rapid movement of electrons, to brilliant flashes of visible light. Lightning causes thunder, a sound from the shock wave which develops as gases in the vicinity of the discharge experience a sudden increase in pressure.

4. Lightning can be explained in terms of charges produced due to rubbing. During a thunderstorm, the air currents move upwards and the water droplets move downwards. And this is caused due to the separation of charge due to this vigorous motion. As a result of this process, the positive charges collect near the upper edge and the negative Charges accumulate near the lower edge of the cloud and also near the ground.

5. As the charge gets accumulated, its magnitude becomes very large. Water droplets in the air act as a conductor of this charge. These charges flow to meet, thus producing strikes of lightning and thunder. For this phenomenon to occur, a sufficiently high electric potential between two regions and a high resistance medium must be present.

The three main kinds of lightning are distinguished by where they occur: -

a) Inside a single thundercloud (intra-cloud)

b) Between two clouds (cloud-to-cloud)

c) Between a cloud and the ground (cloud-to-ground)

6. Many other observational variants are recognized, including heat lightning, which can be seen from a great distance but not heard, dry lightning, which can cause forest fires; and ball lightning, which is rarely observed scientifically.

7. The details of the charging process are still under study, but there is general agreement on some of the basic concepts of thunderstorm electrification. Electrification can be by the triboelectric effect as a result of ion transfer between colliding bodies. Uncharged, colliding water-drops can become charged because of charge transfer between them (as aqueous ions) in an electric field as would exist in a thunder cloud. The main charging area in a thunderstorm occurs in the central part of the storm where ait is moving upward rapidly (updraft) and temperatures range from -15 to -25 °C. In that area,

the combination of temperature and rapid upward air movement produces a mixture of super-cooled cloud droplets (small water droplets below freezing), small ice crystals, and graupel (soft hail). The updraft carries the super-cooled cloud droplets and very small ice crystals upward. At the same time, the graupel, which is considerably larger and denser, tends to fall or be suspended in the rising air.

8. **Effect of Lightning in an aircraft.** The modern aircrafts are designed to withstand any ill effect of lightning. Aircrafts are made of advanced composite materials, which by themselves are significantly less conductive than aluminium. The composites contain an embedded layer of conductive fibres or screens designed to carry lightning currents. The composite material not only safeguard the outer frame but also protects the sensitive instruments and communication equipment inside the aircraft. However, an aircraft which flew through lightning strike should undergo thorough inspection by engineers after landing.

9. **General Protective Measures against Lightning Strike.**

a) **Stay indoors.** The best protective measure during lightning period is to be inside a house. However, even though your home is a safe shelter during a lightning storm, you might still be at risk. About one-third of lightning-strike injuries occur indoors. Following Protective measures to be adopted as suggested by Centers for Disease Control and Prevention (CDC), USA: -

i. Avoid water (bathe, shower, wash dishes, or have any other contact with water).

ii. Don't touch electronic equipment.

iii. Stay away from outer doors and windows.

iv. Don't use corded phones.

b) **Outdoor Safety Tips.** In fact, no place outside is safe during a lightning. However, you can minimize your risk by assessing the lightning threat early and taking appropriate actions. The best defence is to avoid lightning. Here are some outdoor safety tips that can help you avoid being struck: -

i. Check the weather forecast before participating in outdoor activities. Either postpone your schedule or make sure suitable safe shelter is readily available.

ii. When thunder roars, go indoors. Hard-top vehicles (with the windows rolled up) can also be chosen.

If you are caught in an open area, act quickly to find shelter.

If you are caught outside with no safe shelter nearby, take following actions –

(aa) Immediately get off elevated areas such as hills, mountain ridges, or peaks.

(ab) Never lie flat on the ground. Crouch down in a ball-like position with your head tucked and hands over your cars so that you are down low with minimal contact with the ground.

(ac) Never shelter under an isolated tree. If you are in a forest, shelter near lower trees.

(ad) Never use a cliff or rocky overhang for shelter.

(ae) Immediately get out of and away from ponds, lakes, and other bodies of water.

(af) Stay away from objects that conduct electricity (such as barbed wire fences, power lines, or windmills).

10. **Installation of Earthing and Lightning Arrester Systems.** Earthing and Lightning protection is very important for everyone using electrical and electronics equipment. Nowadays there is no one in this world who is not using electrical equipment. We all have electrical and electronics equipment in one way or the other. Hence, Earthing and lightning arrester must be installed at all buildings. Installation of SPD (Surge Protection Device) is also important.

11. **Conditions Favourable for Formation of Cumulonimbus cloud**. In some of the chapters, namely Cloud, Atmospheric Instability, Vertical Motion of Air, etc, this topic has been discussed. A recap is as follows: -

The Cumulonimbus cloud (Cb) forms when three conditions are met: -

a) There must be a deep layer of unstable air.

b) The air must be warm and moist.

c) A trigger mechanism must cause the warm moist air to rise: -

i. Heating of the layer of air close to the surface.

ii. Rising ground forcing the air upward (Orographic Uplift).

iii. A front forcing the air upward (Frontal Lifting).

iv. Convergence.

v. Radiational or Katabatic cooling.

12. **Structure of Thunderstorm.** There has been massive advance in this subject in recent years. Credit goes to enormous efforts put in by the government agencies and individual scientists. Modern technologies like satellite reports, weather radar outputs, etc. have also great contribution.

13. There are three types of thunderstorms, single-cell, multi-cell, and supercell.

a) Single cell thunderstorm or the isolated thunderstorm generally forms due to local instability and availability of adequate moisture up to middle or higher levels. These are short lived storms and generally are not associated weather of violent nature.

b) Multi-cell thunder storms are associated with instability over a larger area like fronts. Such storms are often observed as the squall line. A squall line, or more accurately a quasi-linear convective system (QLCS), is a line of thunderstorms, often forming along or ahead of a cold front. Linear thunderstorm structures often contain heavy precipitation, hail, frequent lightning, strong straight-line winds, and occasional tornadoes or waterspouts.

e) Supercell thunderstorms are the strongest and most severe. Mesoscale convective systems formed by favourable vertical wind shear within the tropics and subtropics can be responsible for the development of such cells. These thunderstorms are characterized by the presence of a mesocyclone, that is, a deep, persistently rotating updraft. Supercells are the overall least common and have the potential to be the most severe. Supercells have the ability to deviate from the mean wind. Supercells can be any size-large or small, low or high topped. They usually produce copious amounts of hail, torrential rainfall, strong winds, and substantial downbursts. Supercells are one of the few types of clouds that typically spawn tornadoes within the mesocyclone.

14. **Life Cycle of a Cell.** As discussed earlier, warmer air rises upward. The rising moist air cools and condenses. When the moisture condenses, it releases energy known as latent heat of condensation,

which allows the rising packet of air to cool less than the cooler surrounding air continuing the clouds ascension. If enough instability is present in the atmosphere, this process will continue long enough for cumulonimbus (Cb) clouds to form and produce lightning and thunder. Meteorological indices such as convective available potential energy (CAPE) and the lifted index can be used to assist in determining potential upward vertical development of clouds. The three stages of development of Cb clouds are discussed below.

a) **Developing Stage.** The first stage of a thunderstorm is the cumulus stage or developing stage. During this stage, masses of moisture are lifted upward into the atmosphere. The moisture carried upward cools into liquid drops of water due to lower temperatures at high altitude, which appear as cumulus clouds. As the water vapor condenses into liquid, latent heat is released, which warms the air, causing it to become less dense and less cool than the surrounding drier air. The air tends to rise in an updraft through the process of convection. This process creates a low-pressure zone within and beneath the forming thunderstorm.

To illustrate in simple words, cumulus stage occurs when one or more cumulus clouds begins to grow into a large cumulus. A general updraft prevails throughout the cell at this stage. A general up draft prevails throughout the cell at this stage, in which extreme velocities of 100 ft. per second have been reported. At the same time, influx to the cell takes place through the sides at all levels as well as through the bottom of the cloud. The cloud might grow up to 20,000 ft above ground level.

b) **Mature Stage.** In this stage the storm has considerable depth, often reaching 40,000 feet or above. Strong updrafts and downdrafts coexist. This is the most dangerous stage when severe weather phenomena can be generated by the cloud. This stage begins with the fall of precipitation. The release of the precipitation starts a downdraft in a part of the cloud where there was previously an updraft. Due to evaporation of the falling drops, the descending air is kept saturated with the result that it warms at the SALR during descent. Since the ELR is greater than the SALR, the descending air is colder at every stage than the environment and hence continues the downward motion on its own. Down drafts up to 40 ft per second have been observed, the maximum being reached a little after rain starts falling. The speed of up draft is about the same as in the cumulus stage. Thus, at this stage both up draft and down draft co-exist in the cell.

c) **Downburst.** Sometimes thunderstorms will produce intense downdrafts that create damaging winds on the ground. These downdrafts are referred to as macrobursts or microbursts, depending on their size. A macroburst is more than 4 km in diameter and can produce winds as high as 200 km per hour. A microburst is smaller in dimension but produces winds as high as 250 km per hour on the ground. When the parent storm forms in a wet, humid environment, the microburst will be accompanied by intense rainfall at the ground. If the storm forms in a dry environment, the precipitation may evaporate before it reaches the ground (such precipitation is referred to as virga), and the microburst will be dry.

Downbursts are a serious hazard to aircraft, especially during take-offs and landings, because they produce large and abrupt changes in the wind speed and direction near the ground leading to deviate the aircraft from the track.

15. **Movement of Thunderstorm.** Maximum mass of a thunderstorm cloud is generally in the middle levels. Hener, in general, direction of the middle level winds determines the direction of movement of the cloud. The anvil, that is the top of the cloud tends to move with the higher-level winds and gradually dissociate from the mother cloud.

16. **Dissipating Stage.** In this stage the cooler air outside of the cloud environment increasingly infiltrates the growing storm cloud, the storm's downdraft eventually overtakes its updraft. With no supply of warm, moist air to maintain its structure, the storm begins to weaken. The cloud begins to lose its bright, crisp outlines and instead appears more ragged and smudged.

17. The entire lower portion of the cloud exhibits downdraft, while only slight upward movement exists in the upper portion of the cloud. The lack of vigour in the upward movement results in the top portion spreading out laterally. Since this part of the cloud contains ice crystals, the spread-out portion has an appearance of cirrus cloud. It is therefore referred to as false cirrus or anvil cirrus. The lower part of the cloud cannot continue for long, it may be the first stage of dissipation leaving the anvil cirrus and other stratified remnants at higher levels. Figure below illustrates the circulation in the dissipating stage.

18. **Regeneration of Thunderstorms.** Due to the cold downdraft from a mature or dissipating Cb cloud the other cumulus clouds in the vicinity may get triggered with instability and moisture and subsequently build up to Cb cloud. This process is known as regeneration. Process of regeneration may repeat, giving the impression of movement of the same thunderstorm cloud. In reality it is a chain reaction by means of which thunderstorms occur in quick succession. This may take place over a large belt covering hundreds of kilometres. The Kalbaisakhis (Norwesters) over eastern part of India during pre-monsoon season is an ideal example of regeneration. In radar or satellite image it can be seen existing as a line squall for hours and moving eastward.

19. **Squall**. Squall is defined as "Sudden increase of wind speed by at least three stages on Beaufort Scale, speed rising to Force 6 (24 Kt or more) and lasting for at least one minute". Since it is a strong wind accompanied by sudden gust, the damage caused by squall could be of large scale. Squalls are very dangerous for an aircraft taking off or landing as well as parked on the ground.

20. The initial downdraft from the Cb cloud spreads out horizontally on reaching the ground and appears as a squall at its leading edge. The average velocity is of the order of 40 Kt, however, the peak velocities can be as high as 100 kt. Maximum speed is experienced in the direction of movement of the thunderstorm. When the terrain affected by a surface squall is uneven or rough, violent eddies may be generated near ground level rendering landing and take-off extremely unsafe. Squall associated with thunderstorm occurs generally during pre-monsoon season in India.

21. **Hail.** Hail is one of the most dangerous types of weather which is caused by Cb cloud. Hailstorm can be defined as any thunderstorm which produces hail. An ice crystal with a diameter of 5 mm is considered a hailstone. Hailstones can grow to 15 cm and weigh more than 0.5 kg.

22. Besides causing damage in aviation, hail can also destroy crops and vehicles and structures to large extent. There has been report of injury to men and animals at time being fatal if not moved to safe place when hailstorm is on.

23. Hail forms from supercooled water. Supercooled water is something unique It is water that is below its normal freezing point of 0°C and yet remains a liquid. Supercooled water will freeze when it comes in contact with something like an ice crystal, dust particle, or raindrop. Hail is associated with high, vertical Cb clouds, the kind of clouds that produce severe thunderstorms.

24. Within a cumulonimbus cloud, ice particles develop from supercooled water. The particles fall toward the bottom of the cloud from the pull of gravity, but they are forced back up by powerful updrafts of air within the clouds. In the upper part of the cloud, they encounter more supercooled

water, which freezes on the ice particles, adding another layer of ice to them. This happens repeatedly. In this way, the small bits of ice grow larger and larger, becoming balls of ice or hailstones. The hailstones finally become too heavy to be lofted back up to the top of the cloud and they fall to the earth.

25. There are many reports of different intensities hailstorm and damages caused worldwide. Hailstorm at times may be so heavy that the area effected by hail give a look of snowfall. Below is a picture showing collection of hailstones on the ground over Moran, in the state of Assam, India on 22 Dec 22.

26. Hail is most common within continental interiors of the mid-latitudes, as hail formation is considerably more likely when the freezing level is below the altitude of 11,000 ft. Accordingly, hail is less common in the tropics despite a much higher frequency of thunderstorms than in the mid-latitudes because the atmosphere over the tropics tends to be warmer over a much greater altitude. Over India, hailstorm occurs over northern parts on approach of a cold front. Hailstorm also occur in India during pre-monsoon season when the freezing level is not yet so high and under the situation of high instability mainly over east India (associated with norwesters) and over close to the foothills over NE India (Associated with Katabatic cooling and cold front).

27. **Dust Storm.** A dust storm is a meteorological event that predominantly occurs in arid and semi-arid regions when large sections of fine loose dirt and sand are picked up by strong winds and blown into the atmosphere. It creates a dense wall of dust that can stretch for miles and be thousands of feet in height.

28. WMO defines dust storm as the result of surface winds raising large quantities of dust into the air and reducing visibility at eye level to less than 1000 m.

29. Dust storms can affect regions thousands of miles away. In fact, it can even cross oceans and affect countries on other continents. Dust from the Sahara Desert in Africa can reach as far as the Amazon in South America and even parts of the United Kingdom. In India migration of dust from the site of dust storm occurring over Rajasthan or other parts of NW India has been seen up to the Brahmaputra valley.

30. During dry and hot season (Pre-monsoon season in India) when Cb cloud forms over desert or semi-arid region (Rajasthan and adjoining parts of NW India) under atmospheric instability conditions, the cloud cannot grow to greater heights due to poor humidity conditions aloft. However, the clouds, if grow above the freezing level, they can cause thunderstorms. These storms often raise dust and other small and loose articles up to a height of about 10,000 Ft reducing visibility to less than 1000 M. Dust storm is locally known as Andhi in India.

31. A dust storm is nothing but a thunderstorm over arid or semi-arid regions under low humidity condition. Hence, the mechanism of dust storm is the same as that of thunderstorm. Low humidity condition does not allow the Cb cloud to grow up to a greater height. However, there is quick down draft due to fall of the cold water drops from above the freezing level. These water drops can hardly reach the ground in form of rain as high temperature and low humidity conditions prevail at lower tropospheric levels and at surface. Hence, the down drafts become weaker. On the other hand, the updraft becomes vigorous and raise the loose dust particles to a great height. The raised dusts are then carried by the prevailing winds.

32. If for some reason, there is suitable amount of moisture at higher levels, the Cb cloud would grow higher. In such case, it will appear as a dust storm in the initial condition due to initiation of raising of

dust due to prevailing up draft. However, the subsequent down draft causes rain and stops further raising of dust. Over NW India such weather events are seen when there is influx of moisture from the Arabian Sea due to the passage of extratropical system or before the onset of SW monsoon.

33. The vertical extent of the Cb cloud that causes dust storm is usually 25,000 to 30,000 Ft. It is seen that if the Cb cloud extends above 30,000 Ft, usually a thunderstorm occurs. The radar images give very good indication of the vertical extent of the clouds.

34. Prior advisory or forecast on occurrence of dust storm is very important for smooth and safe flying operation. Facing dust storm by the aircrafts suddenly can be highly dangerous as the visibility reduces abruptly at surface and at higher levels and it makes nearly impossible for the pilots to come into visual contact with the ground to make a landing or take off in poor horizontal visibility condition.

35. **Tornado.** Tornado is a small-diameter column of violently rotating air developed within a convective cloud and in contact with the ground. Tornadoes occur most often in association with thunderstorms over the region around the equator and mid-latitude regions, frequency being more around the equator. These whirling atmospheric vortices can generate the strongest winds known on Earth. Wind speed in tornado is very high. It is generally of the order of 200-300 Km per hour but highest speed of 500 Km per hour has been recorded. When winds of this magnitude strike a populated area, they can cause extremely heavy destruction and great loss of life mainly though injuries from flying debris and collapsing structures.

36. The rotating column of air that is in contact with both the surface of the Earth and a cumulonimbus cloud. It is often referred to as a twister. Tornadoes come in many shapes and sizes, and they are often visible in the form of a condensation funnel originating from the base of a cumulonimbus cloud, with a cloud of rotating debris and dust beneath it.

37. Technically, a type of thunderstorm known as supercells is what leads to the development of a tornado. Within the supercell, there is an air vortex known as a mesocyclone. As the mesocyclone moves down beneath the cloud, the air takes in cool and moist air from the lower sections of the storm. When the cool air comes together with warm air traveling upward, the result is the creation of a low-pressure point at the surface that begins to pull the whole system down towards the surface of the earth. This pulling action is what eventually leads to the visible funnel-shaped force that is known as a tornado. Supercells contain mesocyclones, an area of organized rotation a few kilo-metre up in the atmosphere, usually 1.6 to 9.7 km across.

38. The destructive nature of the tornado is primarily from something called the Rear Flank Downdraft (RFD). The RFD directs the base of the mesocyclone such that it assumes a funnel shape. When the funnel shape touches the earth, the RFD begins to move outwards leading to the creation of the powerful and destructive blasts of wind.

39. Occurrence of tornado is almost unknown in India. However, it doesn't mean that this phenomenon doesn't occur. Perhaps, the report with evidence has not been made. Life cycle of tornado being short spelled, and its effects over a small area, remains unobserved by the meteorological observers. However, nature of some of the destructions seen during pre-monsoon season in India, particularly in east India (associated with Norwesters) and reports obtained from the locals of the areas about uplifting of roof top and other heavy objects reveal that the damage caused could be due to a tornado. With the present generation of instant recording of events through smart phones, it can be expected that evidence of occurrence of tornado in India will be available, which, in turn will help the weather men to undertake studies and come out with clue full conclusions.

40. **Waterspout.** Waterspouts fall into two categories: Fair Weather Waterspouts and Tornadic Waterspouts.

41. Tornadic waterspouts are tornadoes that form over water, or move from land to water. They have the same characteristics as a land tornado. They are associated with severe thunderstorms, and are often accompanied by high winds and seas, large hail, and frequent dangerous lightning.

42. Fair weather waterspouts usually form along the dark flat base of a line of developing cumulus clouds. This type of waterspout is generally not associated with thunderstorms. While tornadic waterspouts develop downward in a thunderstorm, a fair weather waterspout develops on the surface of the water and works its way upward. By the time the funnel is visible, a fair weather waterspout is near maturity. Fair weather waterspouts form in light wind conditions so they normally move very little.