Course Name: Watershed Hydrology

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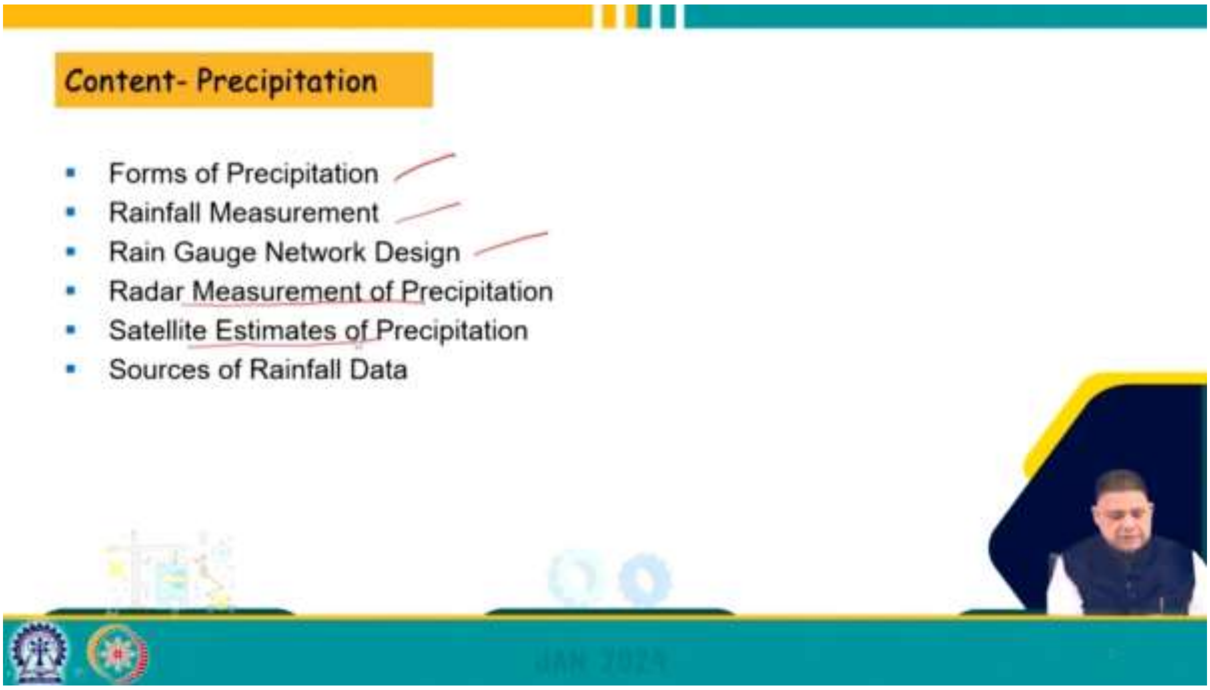
Institute Name: Indian Institute of Technology Kharagpur

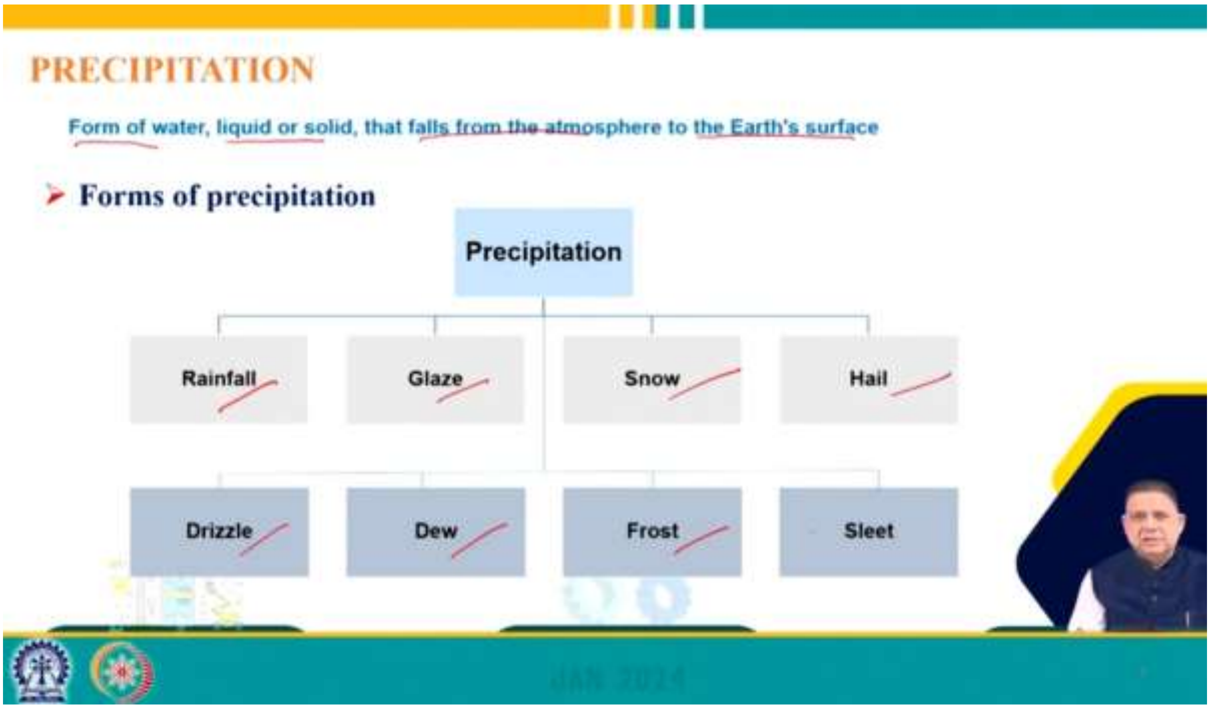
Week: 01

Lecture 02: Precipitation

Hello, friends, welcome back to this online certification course on watershed hydrology. I am Rajendra Singh, a professor in the Department of Agriculture and Food Engineering at IIT Kharagpur. We are in Module 1, Lecture Number 2, and the topic is Precipitation.

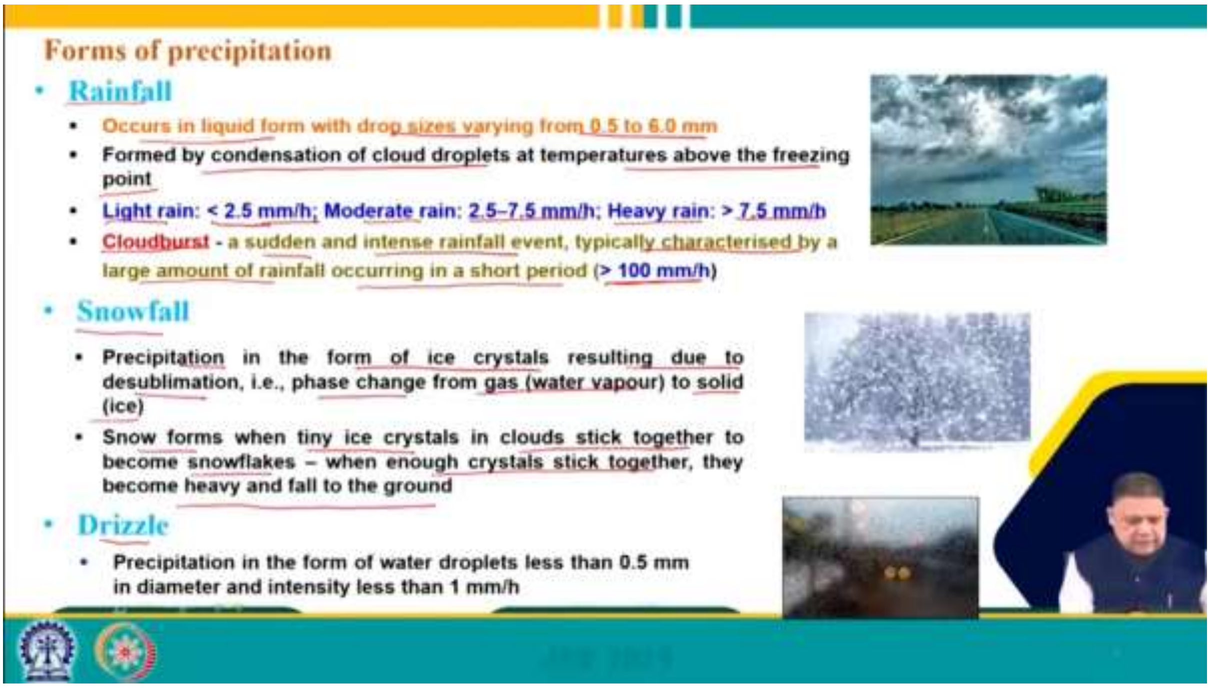


The course content of this particular lecture includes Forms of Precipitation, Rainfall Measurement, discussions on rain gauge network design, radar measurement of precipitation, satellite estimates of precipitation, and an overview of the sources of rainfall data.



Now, let's define precipitation. Precipitation is any form of water, which could be liquid or solid, that falls from the atmosphere to the Earth's surface. It encompasses any form in which water is delivered from the atmosphere to the land surface, as observed in the hydrological cycle.

There are various forms of precipitation, including rainfall, glaze, snow, hail, drizzle, dew, frost, and sleet. However, rainfall and snowfall are the dominant forms.



Let's delve into the description of different forms, starting with rainfall. Rainfall occurs in liquid form, with drop sizes varying from 0.5 to 6 millimeters. It is formed by the condensation of cloud droplets at temperatures above the freezing point.

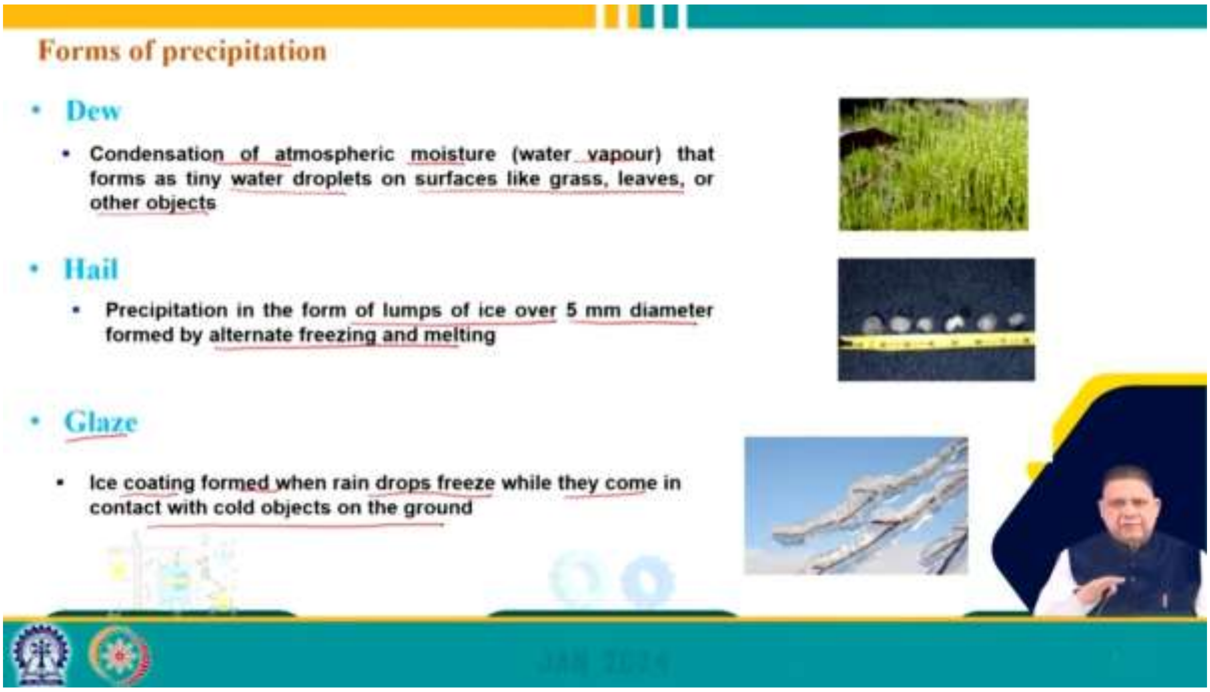
As we've seen in the hydrological cycle, evaporation and transpiration transport water from land to the atmosphere, where cloud formation takes place, followed by condensation. Rainfall then occurs in the form of liquid, with droplet sizes ranging from 0.5 to 6 millimeters in diameter. Rainfall is classified based on intensity. If the intensity is less than 2.5 millimeters per hour, it's called light rain. If it's between 2.5 to 7.5 millimeters per hour, it's considered moderate rain, and if it exceeds 7.5 millimeters per hour, it's classified as heavy rain.

Now, a term frequently encountered nowadays is "cloud burst." We often hear about cloud bursts in news reports, particularly in mountainous regions like Uttarkashi or Uttarakhand. A cloud burst is a sudden and intense rainfall event characterized by a large amount of rainfall occurring in a short period. Typically, the intensity of rainfall during a cloud burst exceeds 100 millimeters per hour. This sudden and intense burst of rainfall often leads to flash floods and various problems, as we often see in daily news reports whenever a cloud burst occurs in any region.

Another important form is snowfall, which is precipitation in the form of ice crystals resulting from desublimation—a process of phase change from water vapor to solid ice. When water vapor undergoes desublimation due to low temperatures, precipitation reaches the surface in the form of ice crystals, referred to as snowfall.

Snow forms when tiny icy crystals in clouds stick together to become snowflakes. When enough crystals aggregate, they become heavy and fall to the ground. So, snowfall is essentially in the form of snowflakes of varying weights, with weight being important because they need to be heavy enough to fall to the ground.

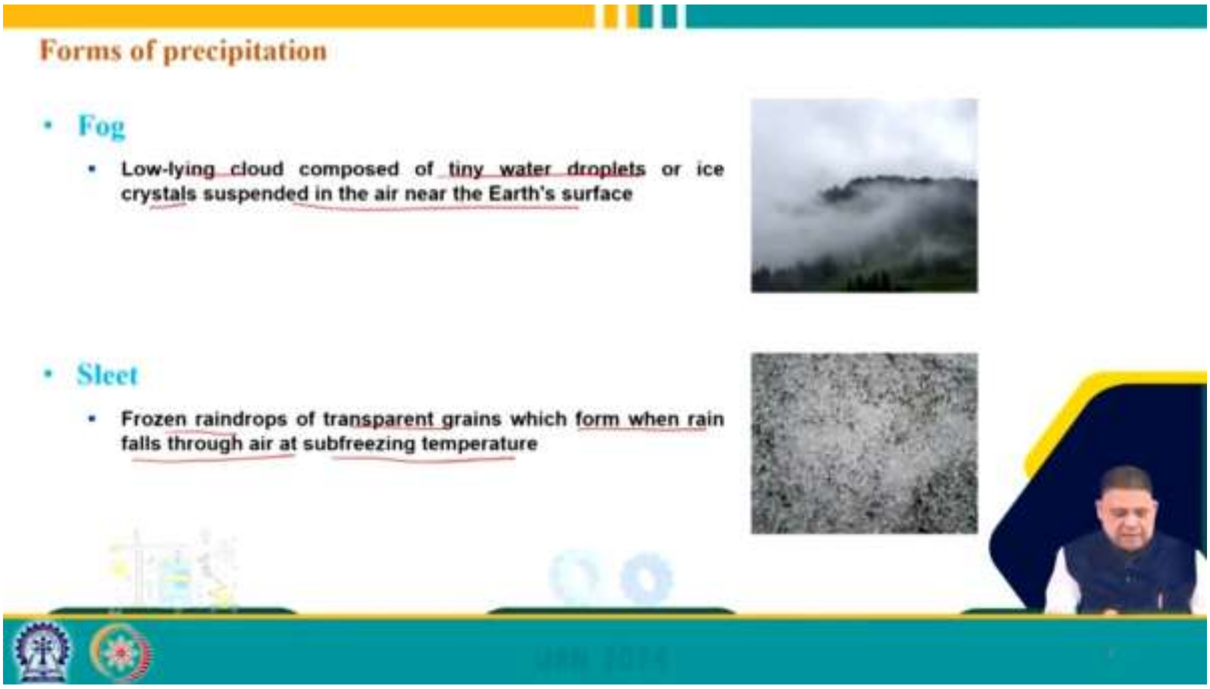
The third form is drizzle, which is essentially a light rainfall where precipitation occurs in the form of water droplets. These droplets are less than 0.5 millimeters in diameter, and the intensity is typically less than 1 millimetre per hour. Rain events often start with drizzle and then intensify into heavier rainfall.



Another form is dew, which occurs due to atmospheric moisture or water vapor condensing into tiny droplets on surfaces like grass leaves or other objects. We often observe this phenomenon on winter evenings or mornings, where water droplets accumulate on various surfaces like grass or leaves.

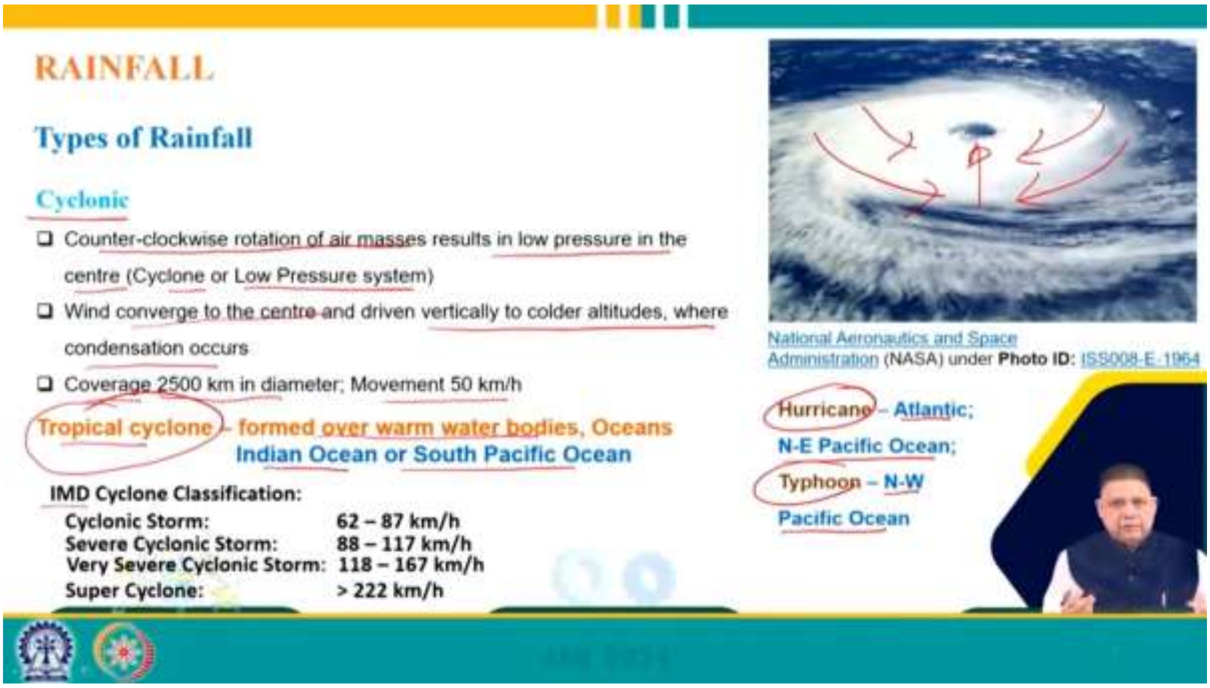
Hail is precipitation in the form of lumps of ice, with a diameter of more than 5 millimeters. It is primarily formed due to alternating freezing and melting processes. Hailstorms occur during specific seasons.

Glaze is common in colder regions, where ice coating forms when raindrops freeze upon contact with cold objects on the ground. If you're in a cold place during winter, you'll likely notice ice formations on metallic objects, which is glaze.



Another important form is fog, which is a low-lying cloud composed of tiny water droplets or ice crystals suspended near the Earth's surface. Fog is a common phenomenon during the winter season.

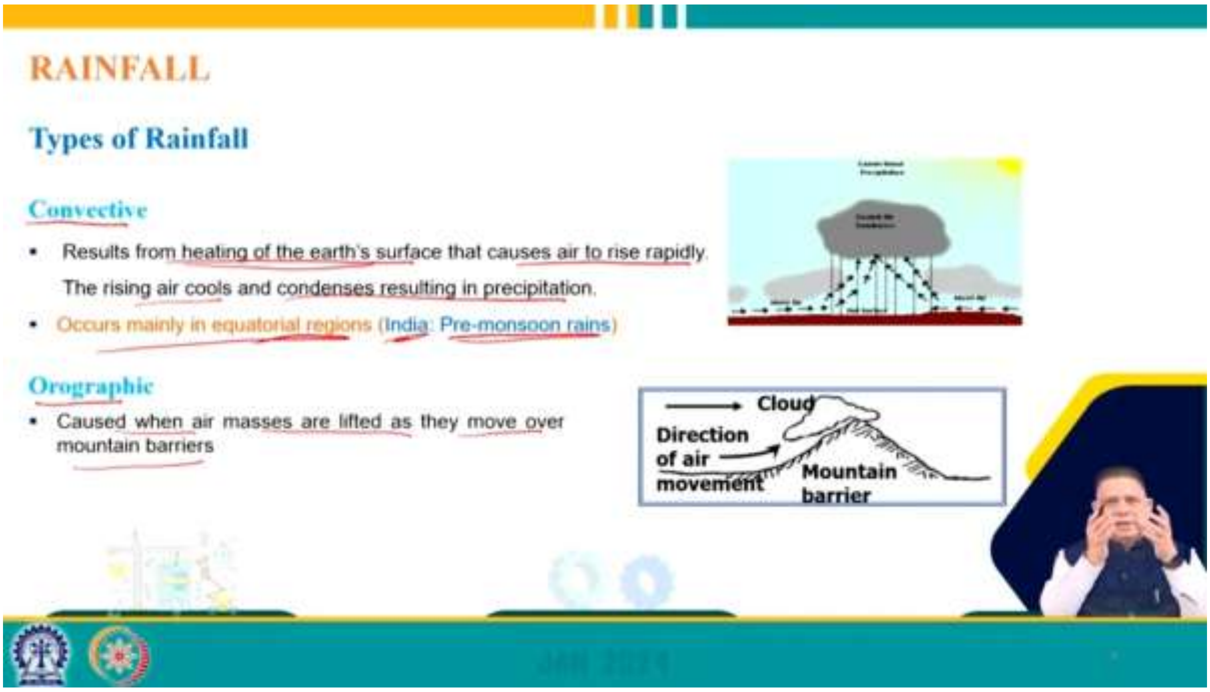
Sleet is frozen raindrops or transparent grains formed when rain falls through sub-freezing air temperatures. When rain falls and encounters sub-freezing temperatures, it freezes and falls in the form of sleet.



Now, let's discuss the types of rainfall. We have three major types, with the most common being cyclonic rainfall. This type occurs due to the counterclockwise rotation of air masses resulting in low pressure at the center, known as a cyclone or low-pressure system. The rotation of air masses toward the low-pressure center leads to the convergence of winds, which are then driven vertically to cooler altitudes where condensation occurs, leading to rainfall. Cyclones bring heavy rainfall to areas, with a coverage area of up to 2500 kilometers in diameter. They move quickly, typically at around 50 kilometers per hour.

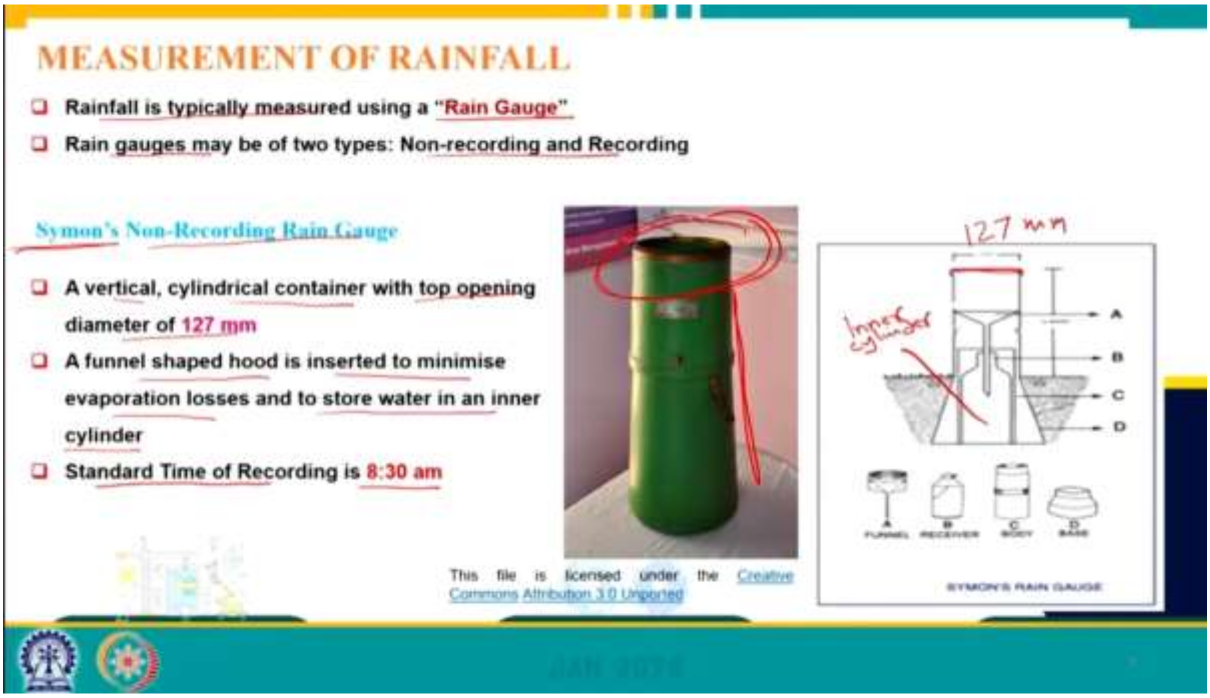
Tropical cyclones are common in tropics, often forming over ocean waters when the ocean temperature reaches a certain level. In the Indian Ocean and the South Pacific Ocean, they're termed tropical cyclones. In other regions, such as the Atlantic Ocean or the Northeast Pacific Ocean, they're called hurricanes, while in the Northwest Pacific Ocean, they're known as typhoons.

So, basically, hurricanes, typhoons, and tropical cyclones are all types of cyclonic rainfall. As you know, in coastal regions of our country, cyclones are a common phenomenon, and when they occur, they can wreak havoc if proper precautions are not taken. That's why the Indian Meteorological Department (IMD), which forecasts cyclones, has classified them into different classes based on their movement or wind velocity. If the wind speed ranges between 62 to 87 kilometers per hour, it's referred to as a cyclonic storm; 88 to 117 kilometers per hour is a severe cyclonic storm; 118 to 167 kilometers per hour is a very severe cyclonic storm, and if it exceeds 222 kilometers per hour, it's categorized as a super cyclone. Whenever a cyclone occurs, we hear about these terms to indicate its severity, all defined based on this classification provided by IMD.

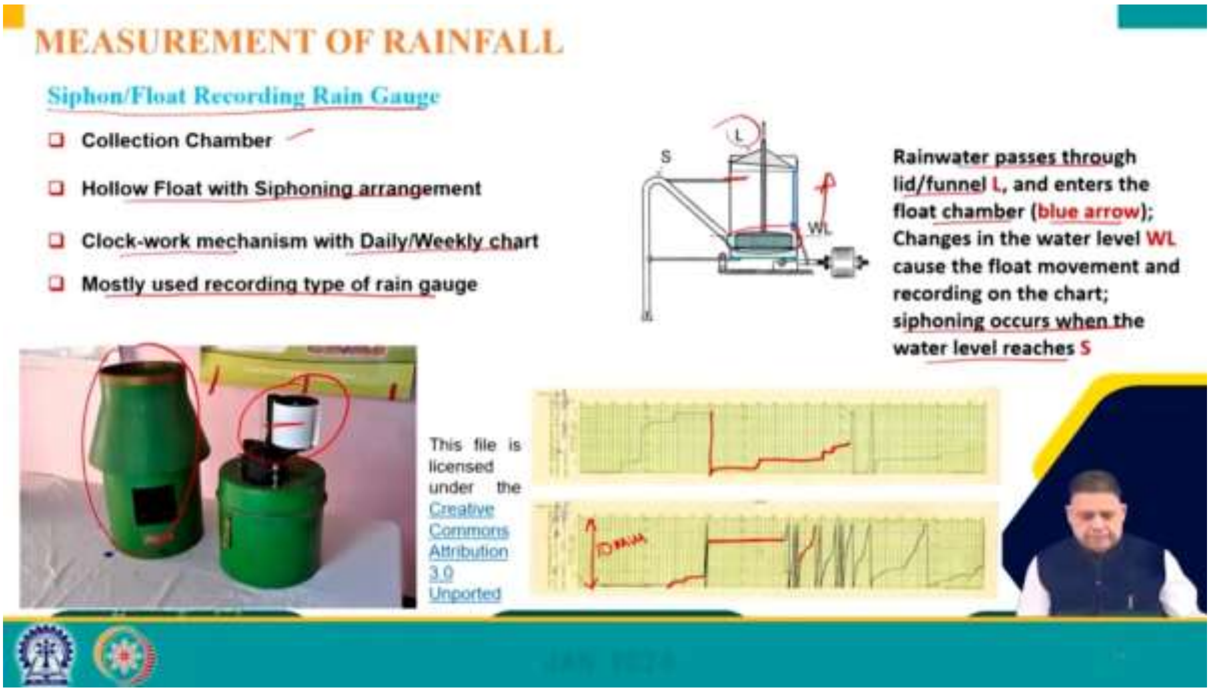


Another form of rainfall is convective, which occurs due to the heating of the Earth's surface, causing air to rise rapidly. The rising air cools and condenses, resulting in precipitation. It mainly occurs in equatorial regions, and in India, the pre-monsoon rains are mainly due to convective precipitation.

In the case of orographic rainfall, as the name suggests, it's linked to the terrain, occurring in mountainous areas. It's caused when air masses are lifted as they move over mountains. When the air encounters a barrier, it rises, cools, condenses, and rainfall occurs. In all three types of rainfall, the basic process involves the vertical movement of air to cooler temperatures, where it cools down, condenses, and rainfall occurs.



Now, let's discuss the measurement of rainfall. Typically, rainfall is measured using a rain gauge, which may be of two types: non-recording and recording. The most common non-recording type of rain gauge is the Simons rain gauge, which consists of a vertical cylindrical container with a top opening diameter of 127 millimeters. A funnel-shaped hood is inserted to minimize evaporation losses and store water in the inner cylinder. Water collects in the inner cylinder, and the standard recording time in India is typically recommended at 8:00 to 8:30 AM. Every day at 8:30 in the morning, the recorder empties the inner cylinder into a measuring cylinder and records the rainfall for the previous 24 hours. That's how a non-recording rain gauge function.

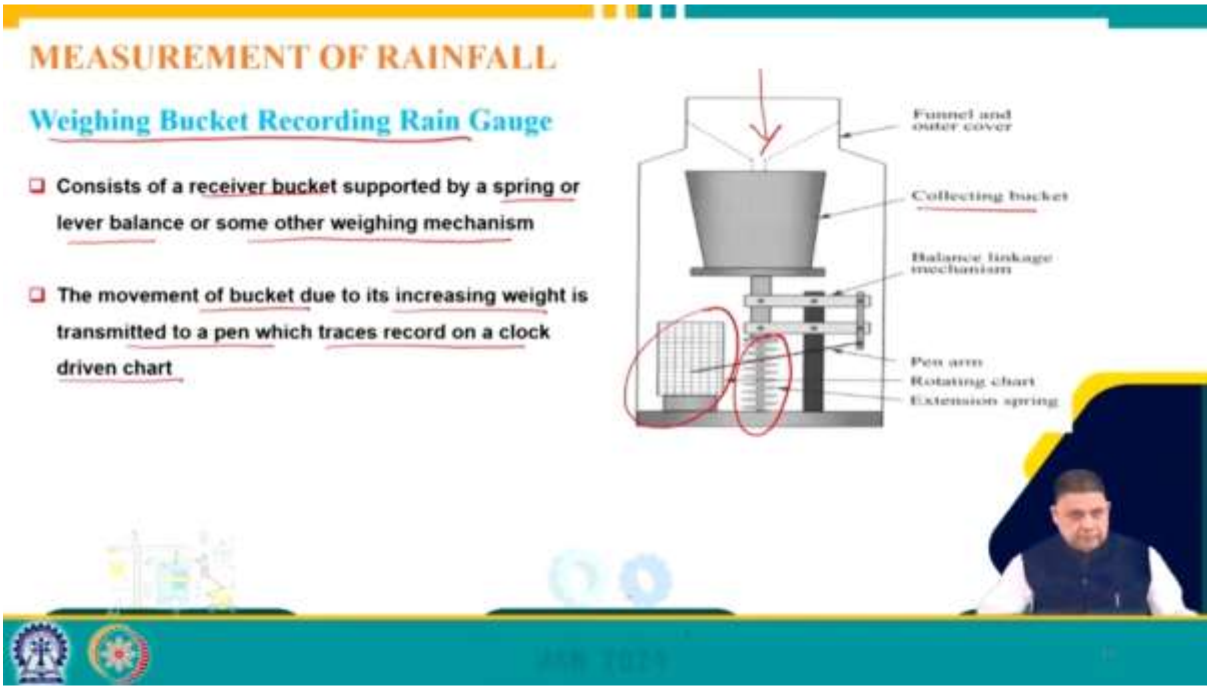


Moving on to the recording type of rain gauges, the most commonly used one is referred to as the siphon or float-type recording rain gauge. This gauge features a collection chamber with a hollow float and siphoning arrangement, along with a clockwork mechanism equipped with a daily or weekly chart. As depicted here, the chamber contains a float, and there's a drum with a chart driven by the clockwork mechanism. When rainwater enters through the funnel lid (marked as "L" here), it fills the cylinder or float chamber. As the water level changes, the float rises, activating the recording mechanism attached to it, which marks the rainfall on the chart. You can observe a horizontal line indicating no rainfall, and when there's rainfall, the float rises, causing the pen to record it on the chart. The siphoning arrangement triggers when the water level reaches a predetermined level, as shown in this calibrated chart. When 10 millimeters of rainfall occur, siphoning takes place, resetting the pen to the zero level to resume recording.

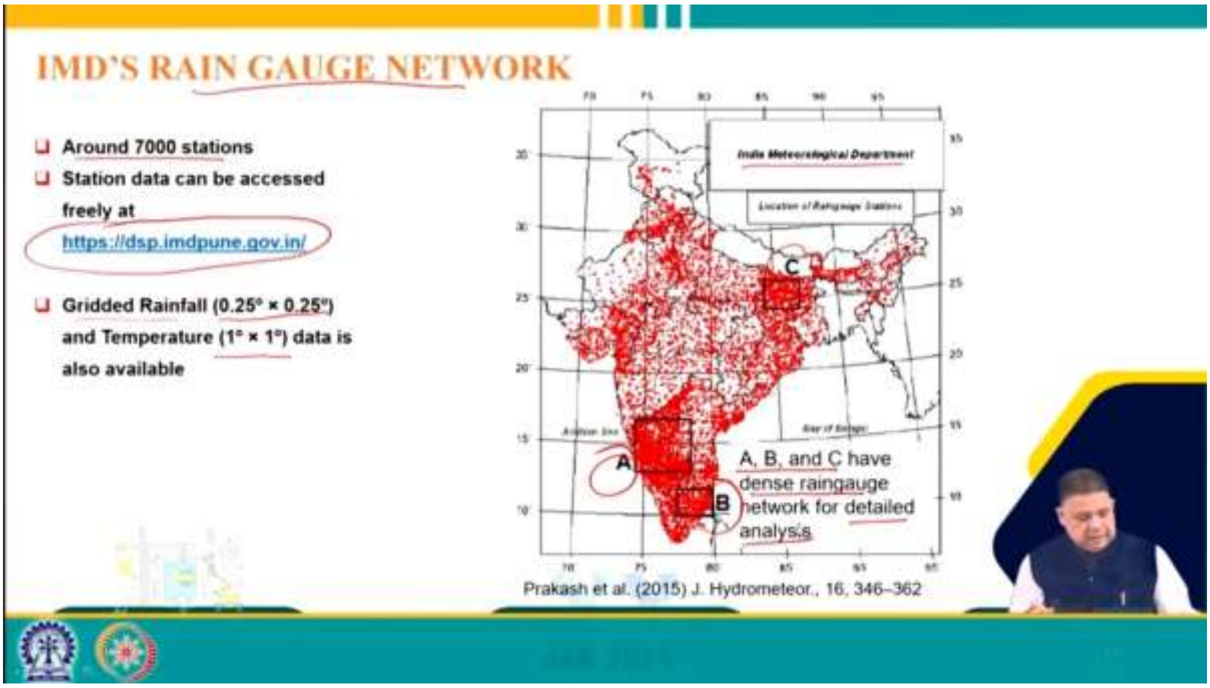
The advantage of this type of rain gauge is its ability to accurately record heavy rainfall events due to the siphoning mechanism. It's widely used for recording rainfall data.

Another type of recording rain gauge is the tipping bucket recording rain gauge. It consists of two containers on a balanced beam forming the tipping bucket system, as illustrated here. When rain fills one bucket below the entry point, it tips over, and the rain is collected in the other bucket. This process repeats, with each bucket tipping alternately as it fills. The capacity of each bucket is typically manufacturer-specific, often around 0.5 millimeters. When one bucket tips due to 0.5 millimeters of rainfall, the other begins collecting, and a digital recording mechanism records the data, as shown by the ticker here.

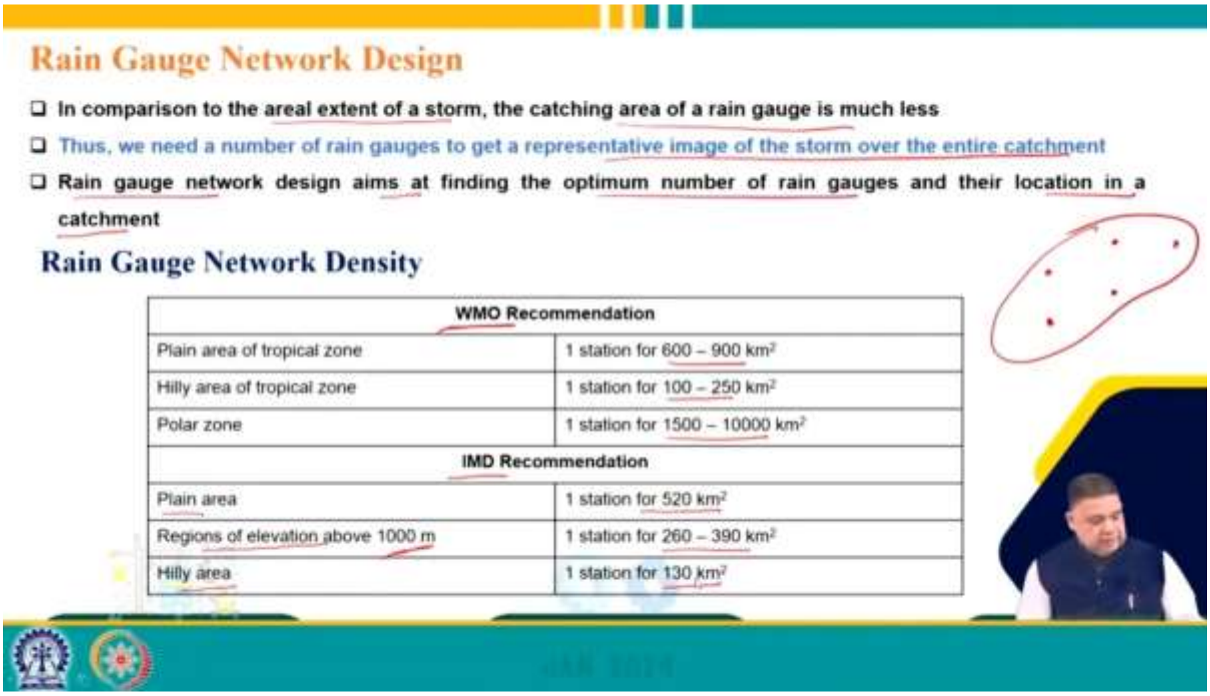
So, basically, it records the number of tips of these buckets, and from there, we can determine the magnitude of rainfall.



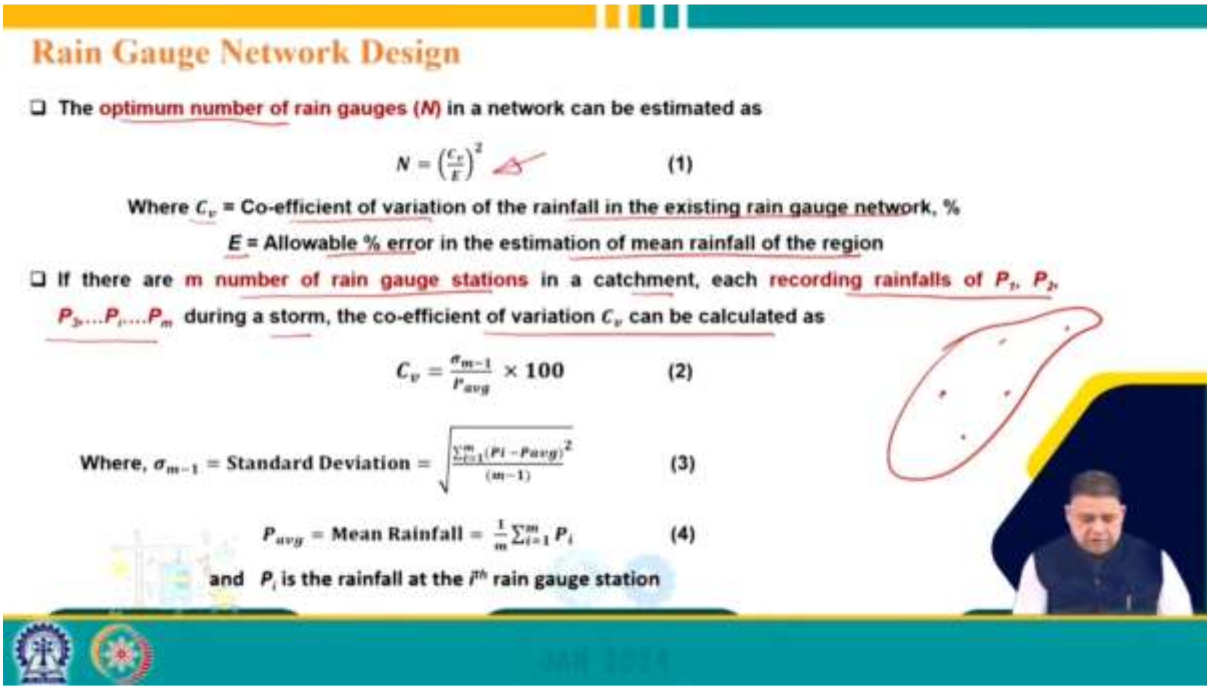
The third type of recording rain gauge is the weighing bucket recording type, which consists of a receiver bucket supported by a spring, lever balance, or some other weighing mechanism. As the name suggests, it functions based on some kind of main weighing mechanism, with a spring being the most commonly used. When rainfall occurs, the weight of the collecting bucket increases, pressing the spring. This movement of the bucket due to increasing weight is transmitted to a pen, which traces a chord on a clock-driven chart. The clock-driven chart mechanism is very similar to the siphon type, but in this case, there's no siphoning involved; it simply keeps on recording. Therefore, it has a limited capacity for measurement from that perspective.



Now, regarding IMD's rain gauge network, the India Meteorological Department (IMD) is the custodian of rain gauge records and other meteorological data in our country. They maintain a rain gauge network across the country with around 7000 stations, and the data from any of these stations can be freely collected from their website. Based on this data, IMD also produces gridded rainfall data at a resolution of 0.25 by 0.25 degrees and temperature data at a resolution of 1 degree by 1 degree. The network is divided into three major blocks of interest - A, B, and C - as shown here. In these areas, IMD maintains a dense rain gauge network for detailed analysis of rainfall characteristics.

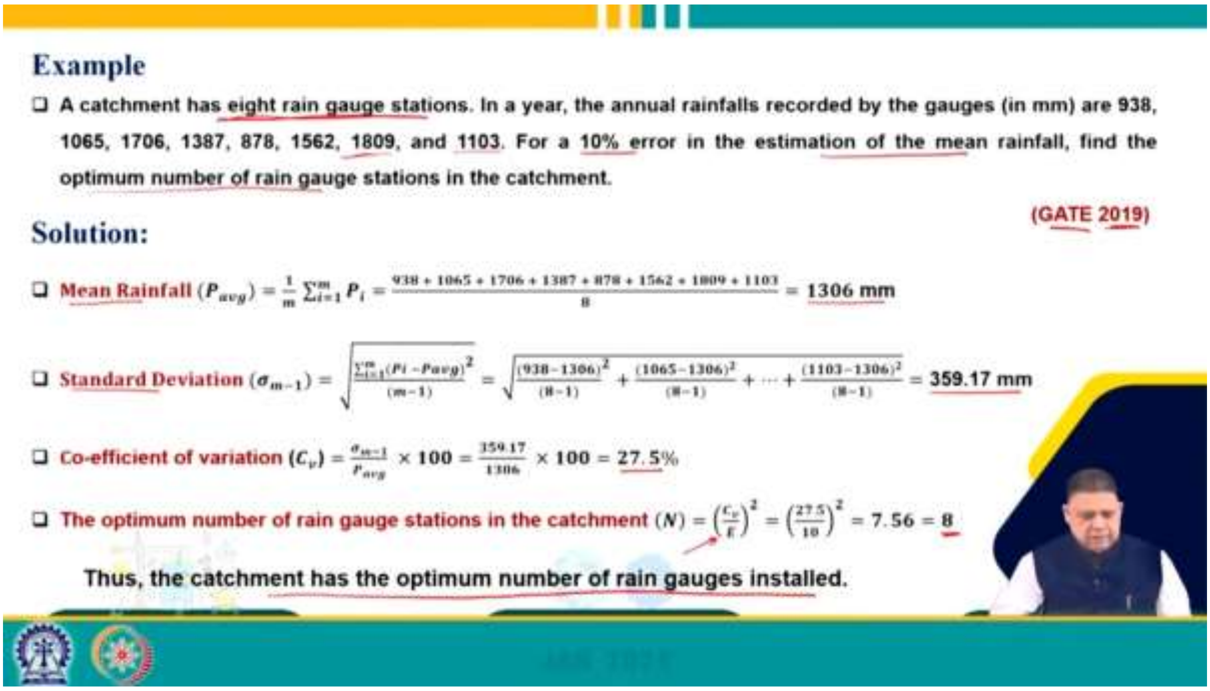


Typically, a single rain gauge may not represent the rainfall over the entire catchment due to its limited coverage compared to the aerial extent of the storm. Thus, rain gauge network design aims to determine the optimum number of rain gauges and their locations in a catchment to obtain representative rainfall data. The World Meteorological Organization (WMO) and IMD provide recommended network densities. WMO recommends one station for 600 to 900 square kilometers in plain areas of the tropical zone, one station for 100 to 250 square kilometers in hilly areas, and one station for 1500 to 10000 square kilometers in polar zones. IMD has modified recommendations based on elevation and terrain type.



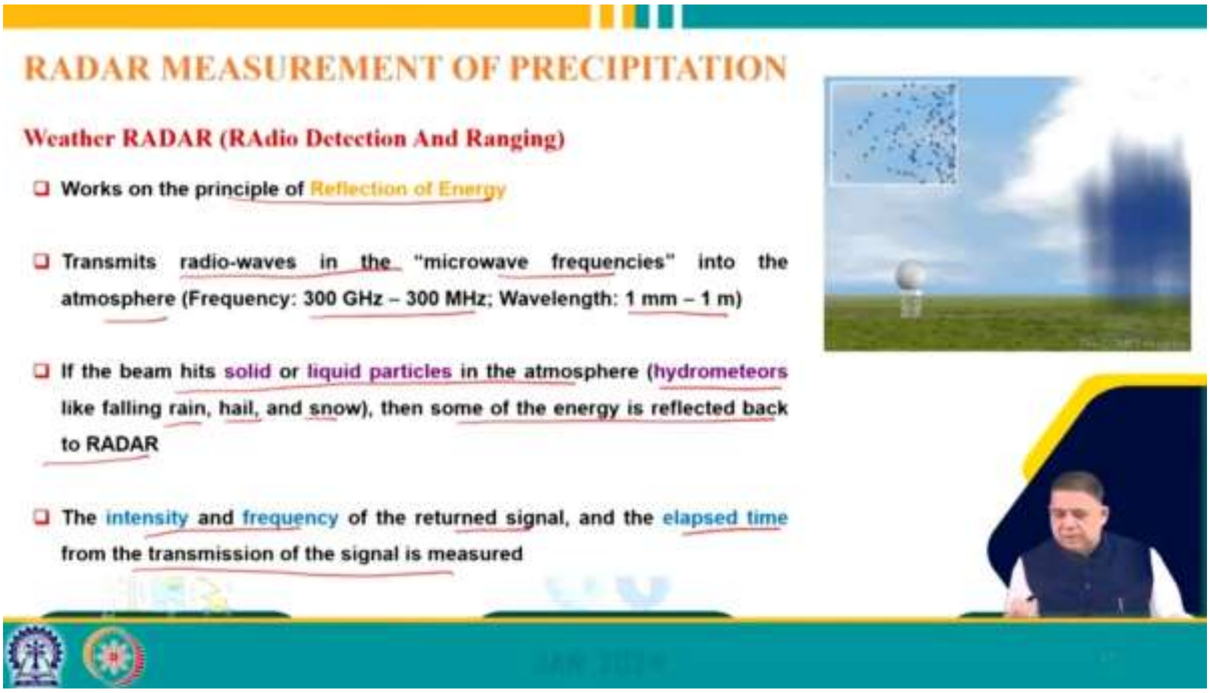
In rain gauge network design, we need to find the optimum number of rain gauges that should be installed in a catchment. This can be estimated using a simple relationship, where n=$(C_v/E)^2$, where C_v is the coefficient of variation of rainfall in the existing rain gauge network, and E is the allowable percent error in the estimation of mean rainfall. The coefficient of variation (C_v) can be calculated as the standard deviation divided by the mean of the recorded data from the installed rain gauges in the area. If there are mm number of rain gauge stations in a catchment, each recording rainfall of P_1, P_2 to P_m during a storm, the coefficient of C_v can be calculated using the standard deviation divided by the average, and standard deviation can be calculated using the formula provided, and the mean can be calculated conventionally.

So, where P_i is the rainfall at the i_{th} rain gauge station. Using this data, as I already mentioned, we need to calculate the mean of the rainfall and the standard deviation. Once the mean and standard deviation are calculated, we can determine the coefficient of variation (C_v).

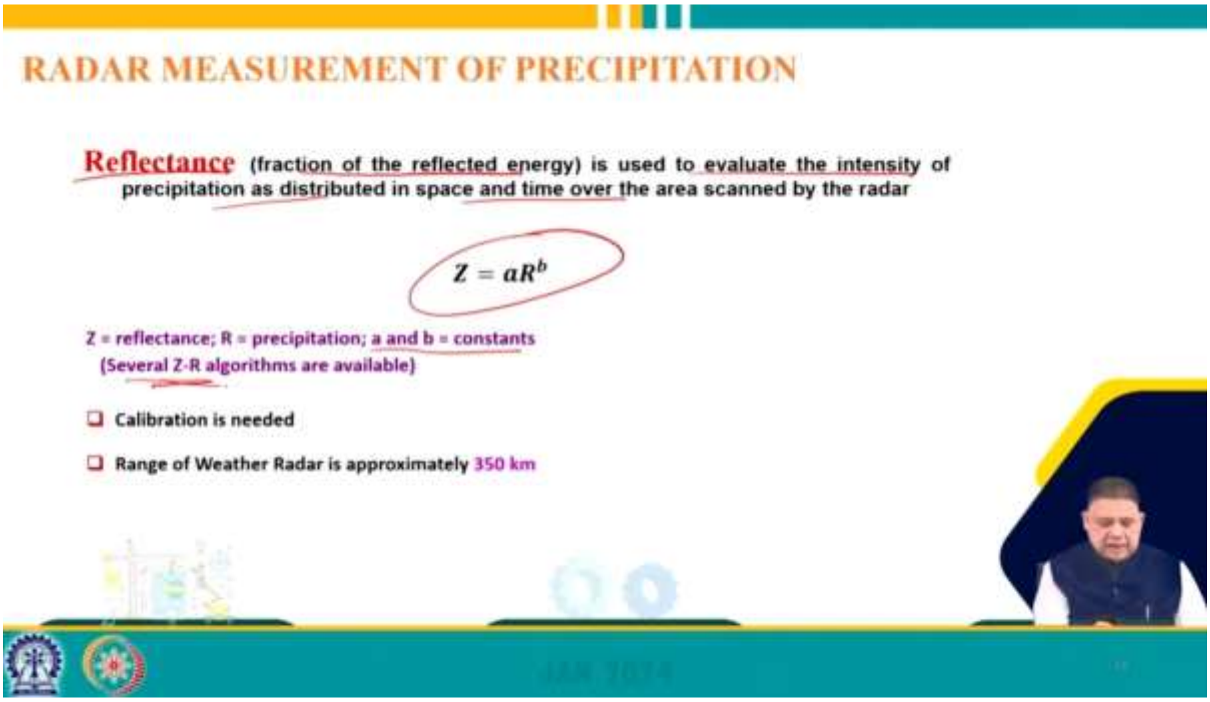


Let's consider a simple example: a catchment with 8 rain gauge stations. In a year, the rainfall recorded by the gauges in millimeters are 938, 1065, 1706, 1387, 878, 1562, 1809, and 1103. For a 10 percent error in the estimation of mean rainfall, we need to find the optimum number of rain gauges. This question is taken from the GATE question paper of 2019.

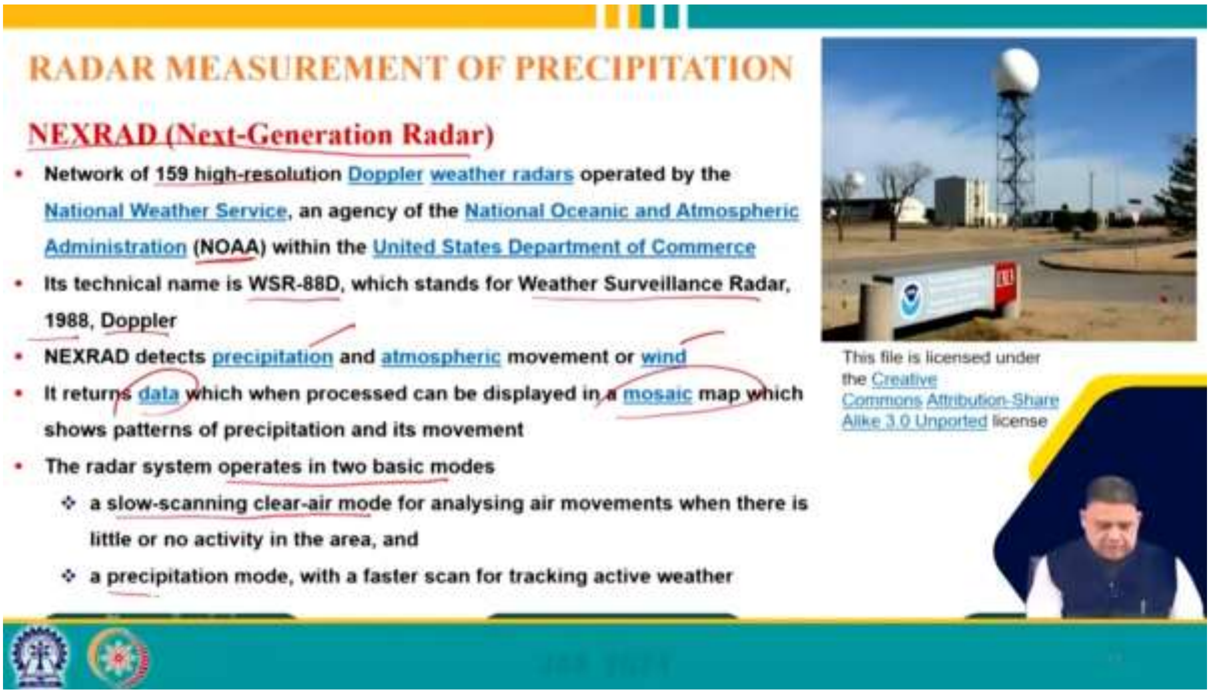
The solution involves calculating the mean rainfall, which comes out to be 1306 millimeters, and the standard deviation, which comes out to be 359.17 millimeters. Subsequently, we calculate the coefficient of variation, which comes out to be 27.5 percent. Using the given E value of 10 percent, and by plugging in C_v and E into the equation, the optimum number of rain gauge stations is determined to be 8. Fortunately, in this catchment, there are already 8 rain gauge stations installed, making it optimal. However, the location of rain gauges requires various kinds of statistical analysis, which we won't cover in this course.



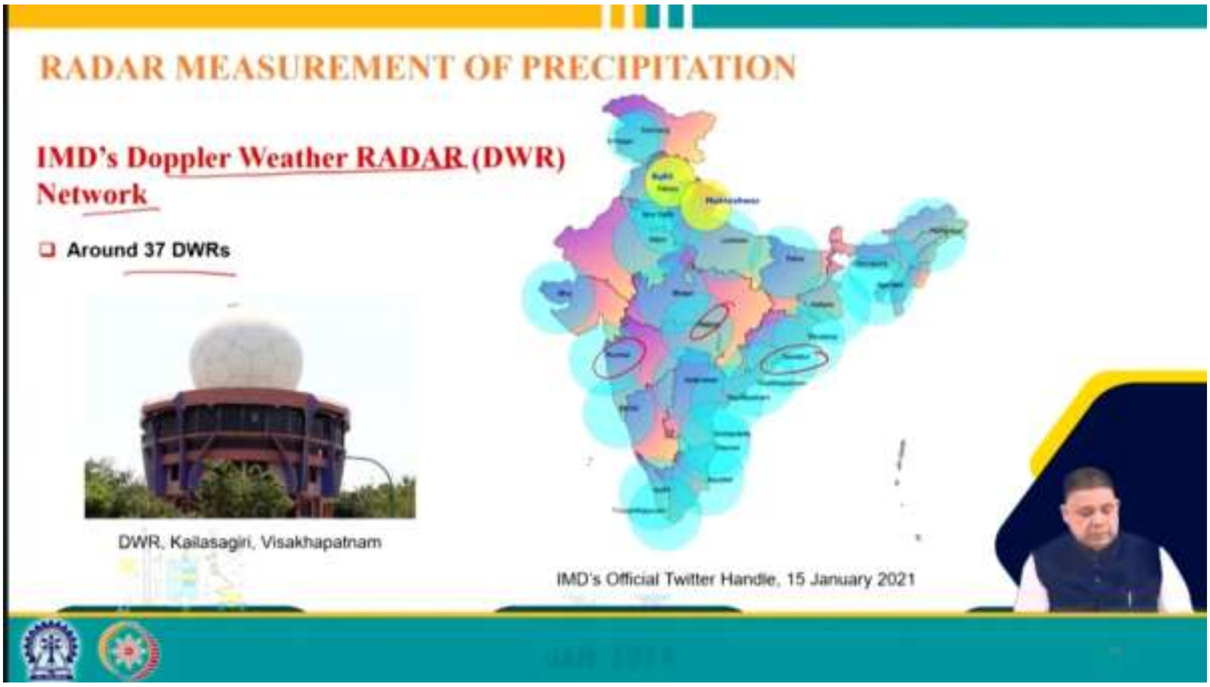
Besides rain gauges, nowadays, weather radars are very popularly used for measuring rainfall. These radars work on the principle of reflecting energy; they transmit radio waves in microwave frequencies into the atmosphere. The frequency range could be from 300 gigahertz to 300 megahertz, and the wavelength could vary from 1 millimetre to 1 meter. When these microwaves are transmitted, they interact with solid or liquid particles in the atmosphere, known as hydrometeors, which could be in the form of falling rain, hail, or snow. Some of the energy is reflected to the radar, and the intensity and frequency of the return signal, along with the elapsed time from the transmission of the signal, are measured to determine the location and amount of precipitation.



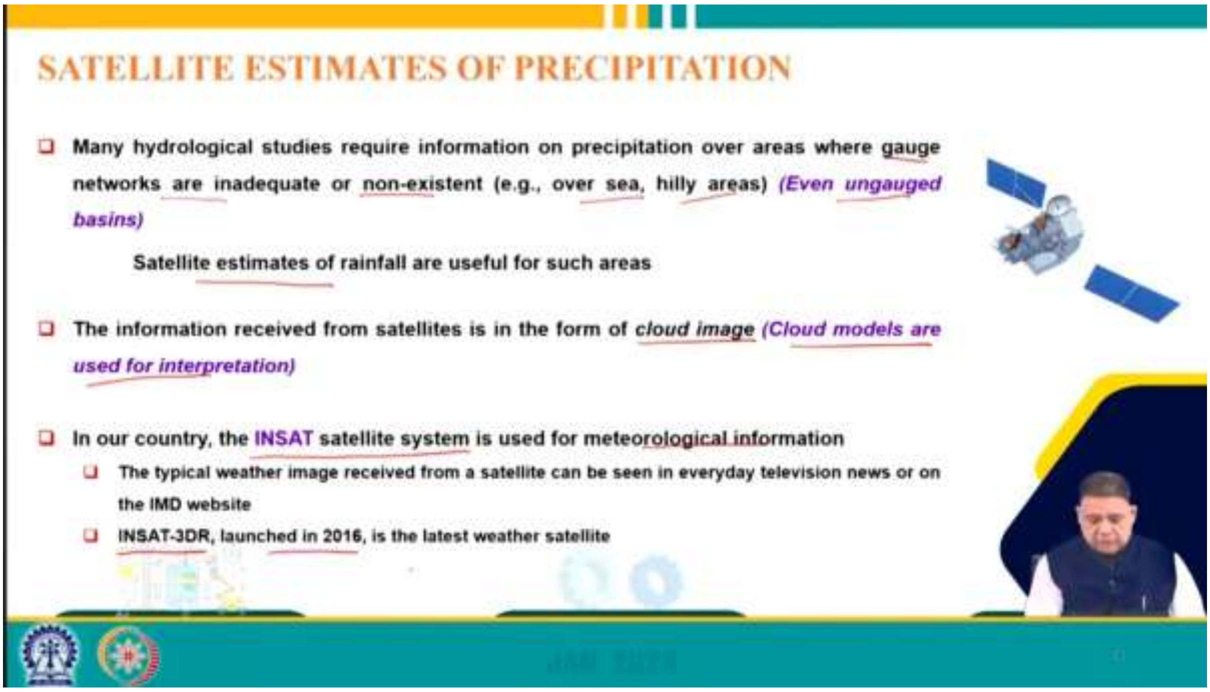
Reflectance, the fraction of reflected energy, is used to evaluate the intensity of precipitation distributed in space and time over the scanned area. For this purpose, Z-R algorithms are used, where Z represents reflectance, R represents precipitation, and A and B are constants. These algorithms are location-specific and instrument-specific, requiring calibration. The range of weather radar is approximately 350 kilometers.



In radar measurement of precipitation, a significant development is the Next Generation Radar, which is a network of 159 high-resolution Doppler weather radars operated by the National Weather Service, an agency of NOAA (National Oceanic and Atmospheric Administration) within the United States Department of Commerce. The technical name of the radar is WSR-88D (Weather Surveillance Radar - 1988 Doppler), and it detects both precipitation and wind movement. Data is available in the form of mosaic maps for the entire scanned area. It operates in two basic modes: a slow-scanning clear air mode when there is no rainfall and a precipitation mode with a faster scan for tracking active weather.

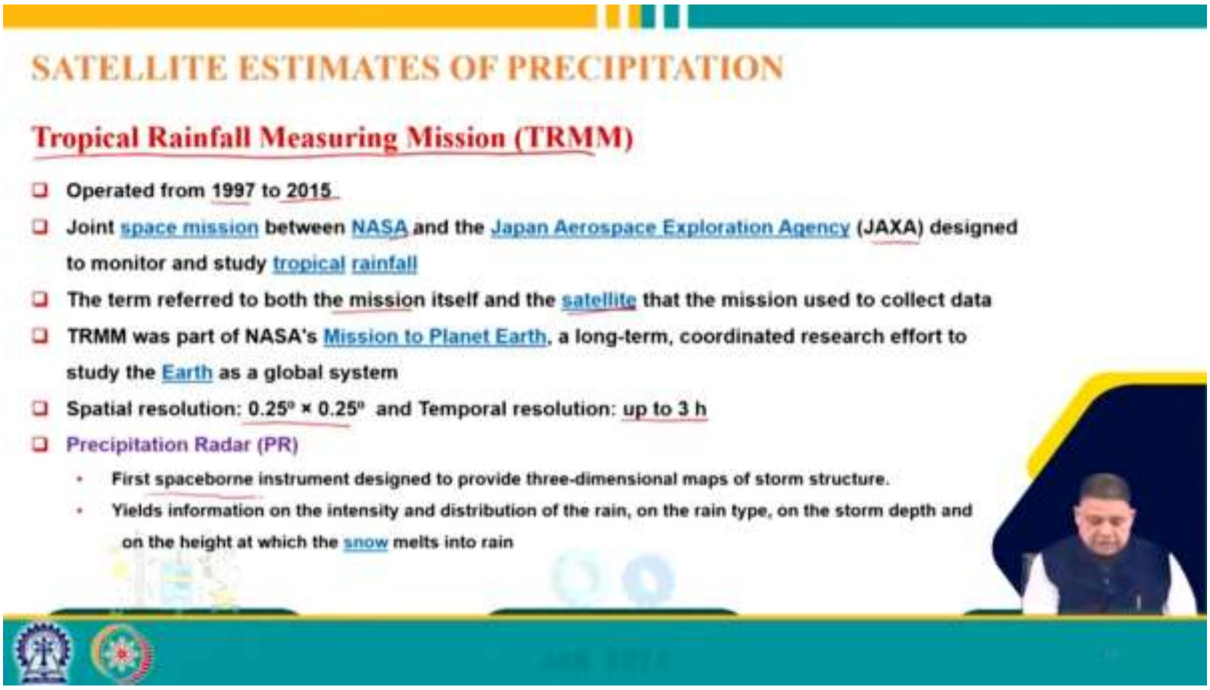


In India, IMD (India Meteorological Department) also has a Doppler weather radar network consisting of around 37 Doppler weather radars, mostly located in coastal areas such as Mumbai, Nagpur, and Gopalpur, as well as major airports. One such radar is installed in Kailasagiri, Visakhapatnam, as shown in the picture.

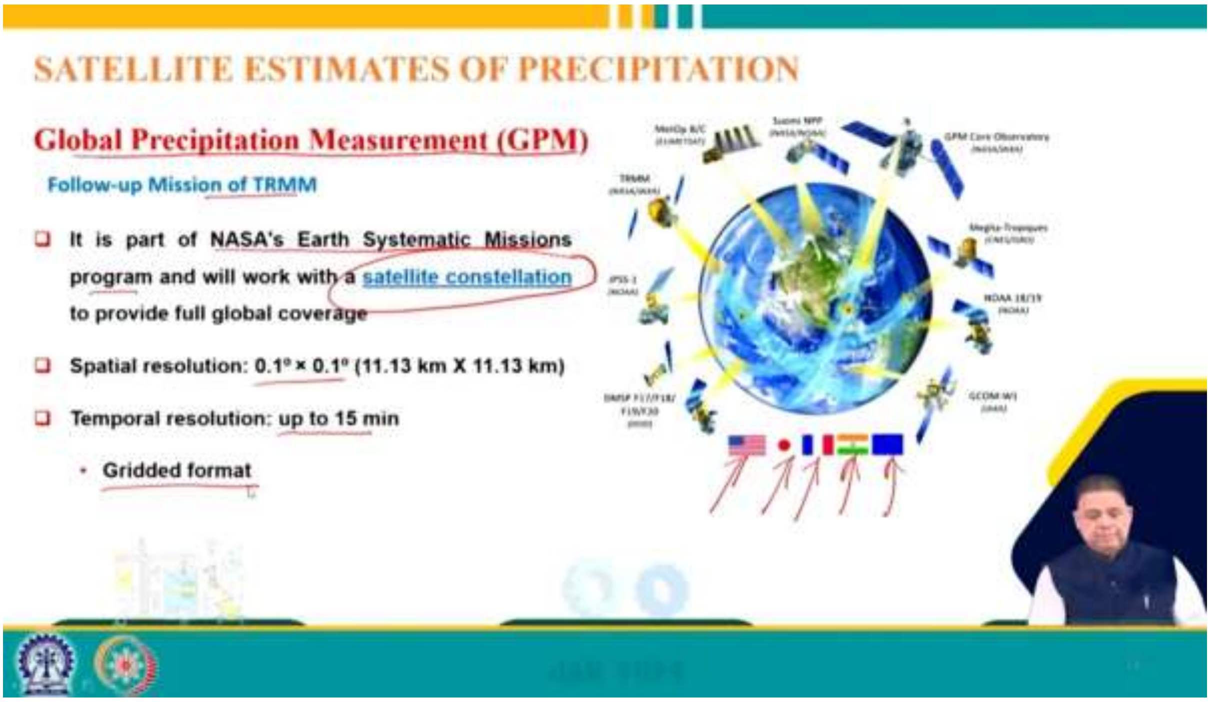


Besides rain gauges and radars, satellite estimates of rainfall are also utilized, especially in areas where gauge networks are inadequate or non-existent, such as overseas or hilly areas, and ungauged basins. Satellites provide information in the form of cloud images, and cloud models are then used for interpreting this data.

Now, in our country, the INSAT satellite system is used for meteorological information. Through newspapers, weather reports, television news, or the IMD website, you can always access satellite images that illustrate the movement of precipitation, among other things. Currently, INSAT-3D, which was launched in 2016, is the latest weather satellite used by India.

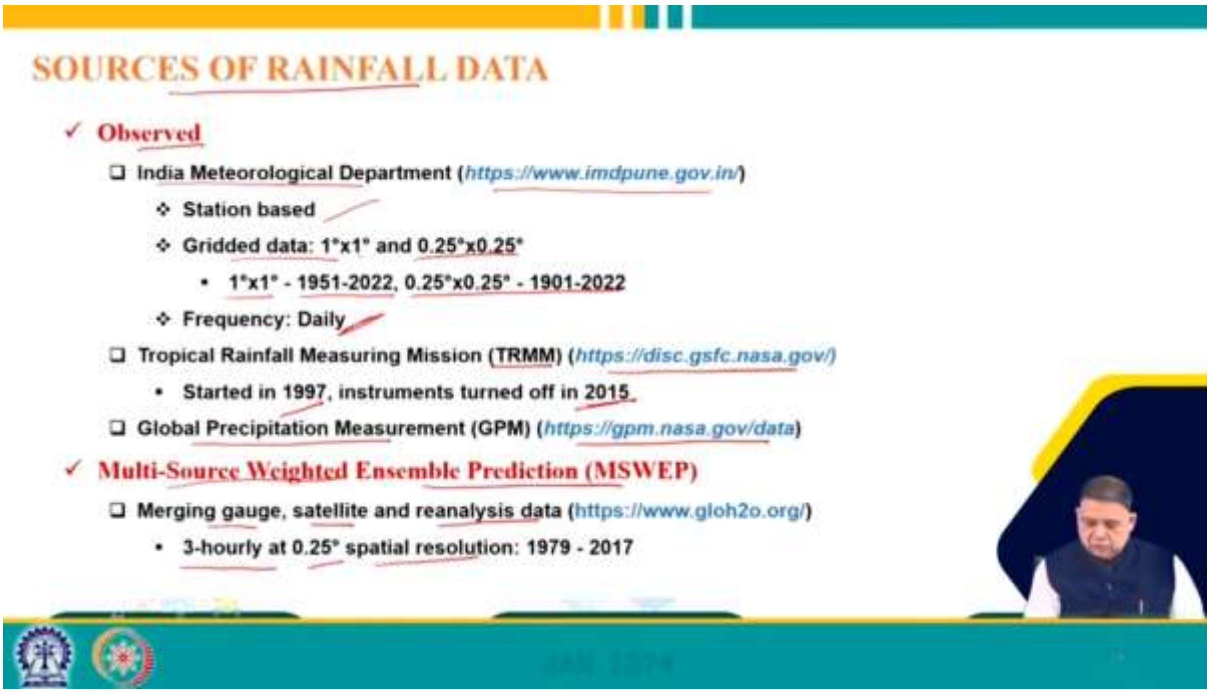


Within satellite estimates of precipitation, a major development has been the Tropical Rainfall Measuring Mission (TRMM), which operated between 1997 and 2015. TRMM was a joint space mission of NASA and the Japan Aerospace Exploration Agency (JAXA) aimed at monitoring tropical rainfall. It provided measurements at a spatial resolution of 0.25 degrees and a temporal resolution of up to 3 hours. The mission utilized the Precipitation Radar, the first spaceborne instrument designed to provide a three-dimensional map of storm structures.



Following the conclusion of TRMM's operation in 2015, there was a follow-up mission called the Global Precipitation Measurement (GPM), which is part of NASA's Earth Systematic

Mission program. GPM utilizes a satellite constellation involving several countries, including the USA, Japan, France, India, and the European Union. Data from GPM is available at a spatial resolution of 0.1 degrees and a temporal resolution of 15 minutes. It also provides data in grid format.



Before we close, I would like to mention the sources of rainfall data. In India, observed data can be obtained from the India Meteorological Department (IMD) website, providing station-based as well as gridded data at resolutions of 1 degree by 1 degree or 0.25 degrees by 0.25 degrees. TRMM data is available from 1997 to 2015, while GPM data can be downloaded from its respective site. Additionally, there's a multi-source weighted ensemble prediction value that merges gauge satellite and reanalysis data, provided at 3-hourly time steps and a spatial resolution of 0.25 degrees over the period from 1979 to 2017.

With this, we conclude. Thank you very much. Please feel free to give your feedback and ask any questions on the forum or in any way so that we can address them. Thank you very much.


THANK YOU