Advanced Hydrology
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Lecture – 12

Good morning and welcome to the next lecture of this video course on advanced hydrology. In the last class, we looked at how to calculate or estimate the precipitable water in a static atmospheric column. We derived the associated equations, we also look at how the pressure and temperature varies with respect to height as we go up in the atmosphere. Then we look at the mechanism of formation of precipitation and we said that there are 2 basic physical mechanisms that are required for a rainfall to form in a cloud; one of them we said is the lifting of an air mass of moist air, so that when an air mass lifts up its temperature goes down, it cools and due to that cooling of the temperature the moisture condenses right, and in the form of tiny droplets the water vapor becomes into rainfall.

The other mechanism we said is the nucleation which is the condensation of water vapor on the nucleii or aerosols or small particles, very tiny particles which are present in the air. With this what we would like to do today, we will get started and look into the dynamics of a cloud what actually happens inside a cloud, alright.

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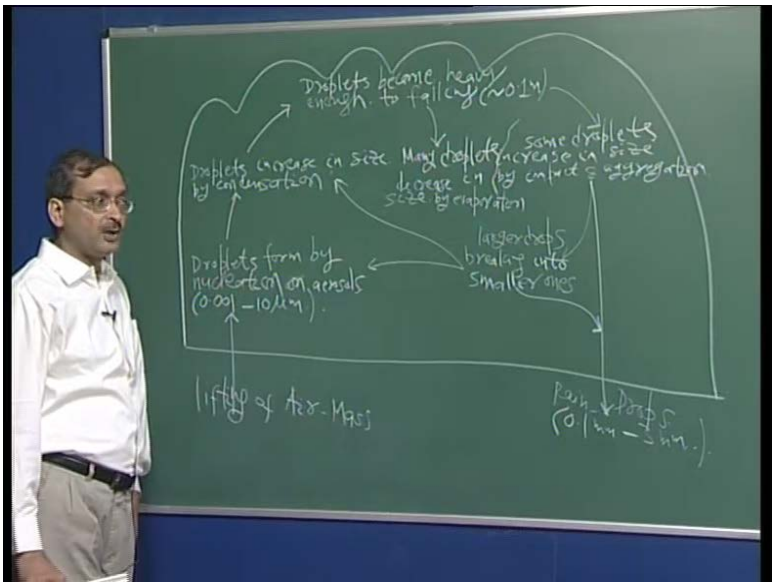

So what I would like to do is draw your attention on the board, we will come here and look inside a cloud, so what we have is, let us say this is a cloud and one of things we have said is that there is lifting of air mass is necessary right. So, air mass gets lifted into a cloud and then let us say that the nucleii are present or the aerosols are present in them and then what happens right. So, if you look at the mechanism how it get starts started is the droplets form by nucleation or aerosols or on aerosols or nucleii agents which are of the size or the order of 0.001 to 10 micro meters; we said that yesterday.

After that what happens is some of these droplets increase in size by condensation or by further condensation right, so we have these 2 basic mechanisms; lifting of the air mass, presence of nucleii or aerosols so small tiny droplets are formed and after that there's lot of activity that takes place in a cloud right. So these droplets will increase in size due to further condensation, then the droplets become heavy enough to fall or to start falling, this is of the order of 0.1 millimeters. So what happens is that the air mass is getting lifted, droplets are forming and then these droplets of water are increasing in size right; due to further condensation and what happens then is they are the floating in air right. Due to further condensation they become larger in size and they become heavy enough to start falling to the air. After that you may have some droplets increasing in size, increase in size further how; by impact and aggregation.

What do we mean by that? 2 or 3 more drops can combine and aggregate to form a bigger drop. It's not exactly condensation but due to impact and aggregation 2 or more drops can combine to form a bigger drop and then start falling more quickly. From here what may happen to some of them is many droplets may in fact decrease in size, this is the different; a decrease in size how, by evaporation. So within the cloud we see that is a lot of activity taking place, there is condensation and at the same time there may be some of the drops getting evaporated back into the water vapor form right; and these size of these drops will then become smaller. And then from here you see that when the droplets become heavy enough they start falling through the atmosphere on to the ground, and that is when you say that rain drops of size approximately 0.1 millimeters to 3 millimeters will be falling on the ground.

While it is happening you may have the larger drops breaking into smaller one, breaking into smaller ones and then some of them can combine again to become heavy enough to fall again and from here some can drop go to this size and some can go to slightly bigger

size and so on. So you see that see that is a lot of activity that is taking place inside a cloud. So just to refresh; you have 2 basic mechanisms, one is the lifting of the air mass other is the presents of nucleii that are those 2 are required. Once that happens there is lot of activity taking place and ultimately what we see coming out of the cloud is the rainfall of approximately this size, this will keep falling. Later on today we will see how the rainfall actually, these drops of rain will actually fall right. You will look at the forces that will be acting on a raindrop and how actually it will be falling through the air, through what is called terminal velocity.

So now will come back to the table and continue for the here. So what we will do next is we looked at the formation of the precipitation or formation of the rainfall in a cloud.

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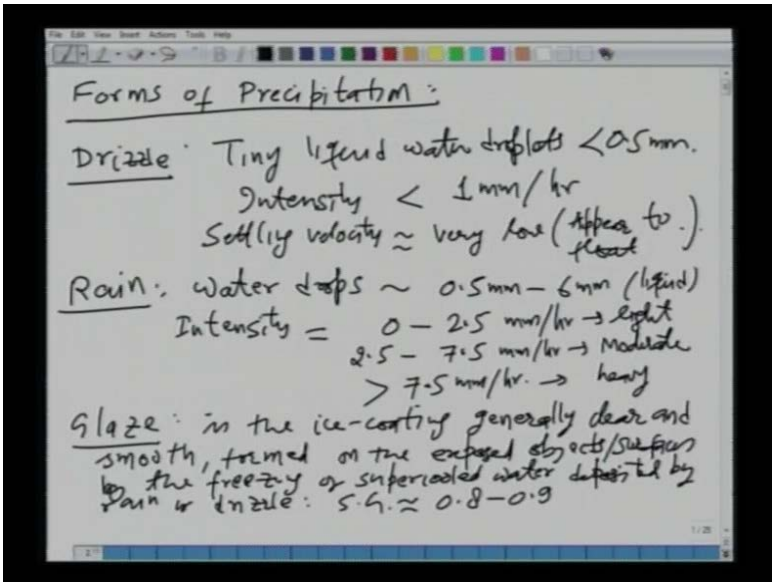

Now, what will do is we look at the forms of precipitation. What to do you mean by the forms of precipitation? Means the precipitation is a general term, it may include rainfall, it may include snow, and it may include hail and so on right. So there is general term call precipitation and the precipitation can be in many different forms. So what will do is we will look at various types of precipitation that can occur on the land, right. So will start with what is called drizzle which are nothing but the tiny liquid water droplets which are of the size about less than 0.5 millimeters. The intensity of the drizzle is less than 1 millimeter per hour, that's the rate at which the drizzle is falling.

The settling velocity or the terminal velocity or the fall velocity with which drizzle falls on the ground is very small, very low. It basically appears to float. So I am sure all of you have experienced drizzle, drizzles are you know it is a very small tiny droplets of water just falling through or just floating through the air right; and they cannot be matched and they will not you know, they will not able to accumulate in any rain gauge right. So it will be just very little traces right and when the size of the drops become higher that when we are there is called rainfall or rain. So that is the next form of precipitation is your rain which is classified as the water drops of size 0.5 millimeters up to 6 millimeters, and remember that when we are talking rain it is liquid form of water. The rain may be classified into 3 different kinds depending upon its intensity.

If the intensity of rainfall is between 0 and 2.5 or up to 2.5 millimeters per hour it is called or characterized this as light rain right, and if it is between 2.5 and 7.5 millimeters per hour we say that the rain is falling at a moderate intensity or it is a moderate rain. But, when the intensity of rainfall is more than 7.5 millimeters per hour then we say that it is heavy right rainfall. So this is the 2 different forms of you know rainfall, not rainfall I should a precipitation, drizzle and rain right. Continuing further next one we have what is called the glaze, some of these you may not have an experienced but may have heard about them, is let me first define is the ice-coating which is generally clear and smooth; which is formed on the exposed objects or surfaces by the freezing of super cooled water that is deposited by rain or drizzle which we have just seen, rain or drizzle.

So what is a glaze is a it's an ice coating which is formed on the exposed objects or surface is which are outside all right; it may be the top of the cars, it may be tree leaves, it may be any anything lying outside. So what happens basically is as the rain or drizzle is falling it falls as liquid water and then once it comes in contact with the very cold object which is outside then it freezes into ice coating or some kind of solid which is called glaze. So you see that glaze is a phenomenon which actually occurs on the ground not in the air, so it is important to understand that. The specific gravity of that ice that forms is of the order of 0.8 to 0.9.

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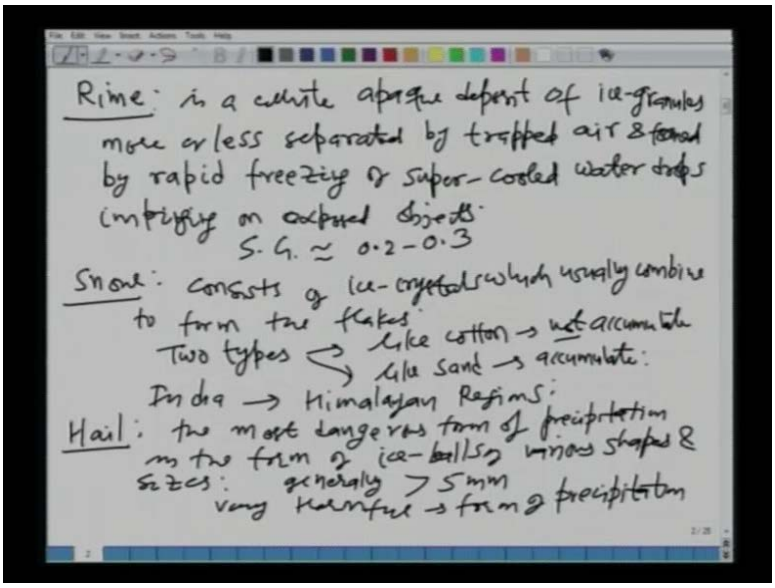

Moving on the next form of precipitation is what is called a rime. Rime is a white opaque deposit of ice granules which is more or less separated by the trapped air and formed by rapid freezing of super-cooled water drops depending on exposed object. So what is rime is, it is a again a phenomenon that occurs on the ground. In this case you have the liquid water falling and coming into contact with the exposed objects on the ground all right. However in this case what happens is there is lot of air that gets trapped while the water is getting frozen into solid, and because of that air that gets trapped the whole coating of rime is opaque you cannot see through and it is whitish color.

So the difference between the 2; the glaze and the rime is that glaze is more gradual process and rime is a little rapid process in which the air gets trapped. Now, if I ask you what will be the specific gravity of the rime, what would your answer be as compare to the specific gravity of the glaze? Well as you know as a because the air is getting trapped inside, the specific gravity has to be lower, so it is in the range of 0.2 to 0.3.

The next form of precipitation we are going to look at is what is called as snow. I am sure all of you are know or understand or may have seen, at least some of you what is snow. Snow basically consists of ice crystals, so it is a solid form of precipitation that is actually falling to the atmosphere. So it consists of ice crystals which usually combine to form the flakes or the snowflakes. So it is a solid form of precipitation in which the water is falling in the solid phase in the form of ice crystals or snowflakes right. Now snow

also, those of who may have seen snow occurring; it can be of 2 different kinds, what are those 2? Well in one of that kinds you will see that the snow is falling like you know some flakes of like cotton you know very light in just floating through the air all right, that will come close to the ground and it will not accumulate.

The other kind is like sand particles all right. The other snow is like sand particles which will tend to accumulate as its falls on the ground, right. So you can say that it is of 2 types all right; one of them is like cotton all right, it just appears to float and it will not accumulate it will just melt by coming with contact on the ground at any object, not accumulate. So you cannot measure it, when you say snow is 2 inches that is not the cotton type of snow all right. The other one is like sand particles or like sand which tends to accumulate, that is the real snow we refer to when we say the snow fall you know in the in the Himalayan region you know 2 inches, 4 inches or foot or whatever. And as you all know in India where do we get snow? Mainly in the Himalayan regions or hill areas right, so that is about the snow.

The next form of precipitation which we are going to look at is called hail. What is hail? Hail is very dangerous form of precipitation. It is like ice balls, in Hindi we call them Olay Ola Vishtri, ok. So it is the most dangerous form of precipitation in the form of ice balls of various shapes and sizes, right and this is size is generally is more than 5 millimeters. So this is the size of ice balls, ice crystals they can occur in many different forms. Normally it may be spherical or but they can be very irregular also when it is falling very quickly due to the dynamic climatic conditions. When I talk about this hail well it very harmful of course, I should say dangerous and harmful form of precipitation of course ok.

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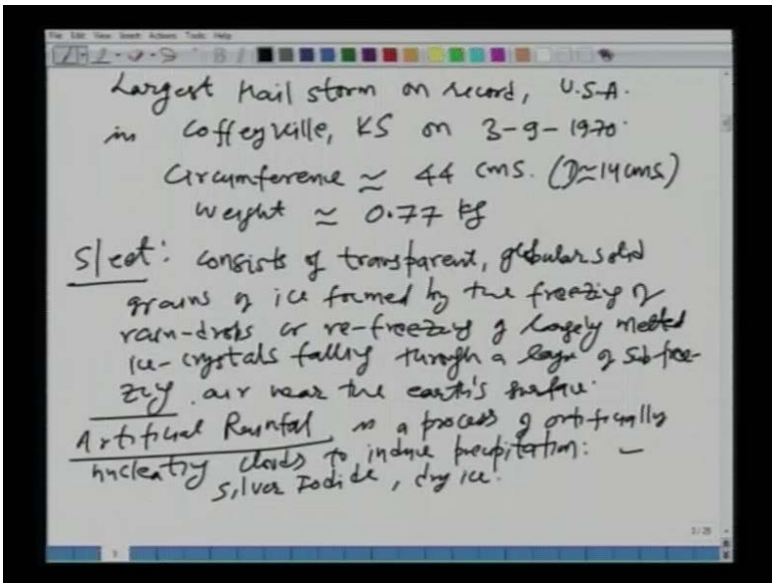

I like to give an example of the largest hail storm on record right, anywhere in the world. So just to give you an idea of how dangerous it can be right, so the largest in terms of size hail storm on record historical records is in the USA right and it was in Coffeeville; Coffeeville is the name of that town in Kansas state in US and this hail storm occurred on 3-9-1970, long time ago.

The ice balls or the hails that fell on that day had measured circumference of approximately 44 centimeters, the circumference of the ice ball right. Can you tell me what will be the diameter? Diameter is 2 pi d, so we can calculate the divided by 2 pi or sorry pi d; so we can divide by pi or 2 r. Let me see, it will be approximately 14 centimeters not exact but about 14 centimeter diameter ice balls, can you imagine how big it is ? Well it is size of a football right. So that is kind of hail storm that can actually occur and it can do lots of damage, not only to the fields and the agriculture sector but also to the life and property of the people. And on that day the weight of each ball was of the order of or approximately 0.77 kilograms almost 1 kilogram. Also, moving on I would like at the next and probable the last form of precipitation which is called sleet.

The sleet consists of transparent, globular solid grains of ice formed by the freezing of rain drops or re-freezing of largely melted ice-crystals falling through a layer of sub freezing air near the earth surface. So what is sleet is, sleet is a phenomenon again that occurs in the atmosphere not on the ground; it’s not like glaze or rime. So it is but it is

not more like snow or hail, snow or hail forms very high up in the atmosphere and then falls very quickly; but sleet is something that that is your liquid water is falling and the very close to the ground there is temperature is very low and due to that it freezes very quickly close to the ground right and then it will consist of a sheet, a sheet of ice coating on the roads or on the objects and in all the exposed object outside right. Sleet is again very harmful because you know all your traffic will be stand still.

You cannot drive, you cannot walk because of the sleet coating or ice coating on the roads and footpath and everything. So this is also quite dangerous form of precipitation. So in this we see that there many kinds of forms of precipitation which will occur in different climatic conditions in different places or in the same place in different types of conditions right. So moving further what will do next next is look at the precipitation characteristics in India. But before I go to that, I would like to look t what is called the artificial rainfall. Remember we looked at the 2 different mechanisms of formation of rainfall; one was the lifting of the air mass another one was the presence of the nucleii. But many times what happens is we have the air mass lifting all right; there is a moisture in the atmosphere, but it does not rain. It happens in some areas due to the non-existence of the nucling agent right.

So what many researchers have tried to do is they have artificially tried to inject to the nucling agents into the clouds right. Because there is no nucleii, so the condensation of the water vapor does not take place right. So artificial rainfall is nothing but is a process of artificially nucleating the clouds to induce precipitation by injecting these nucling agents into the clouds, and many kind of you know techniques or methodologies have been adopted you know mainly in the USA and other western countries to conduct these experiments in which the aircrafts are used, the hot air balloons have been used to inject these nucling agents into the cloud, and it has you know resulted into some success not very big success I would say, because this lot money that was spent in early seventies and eighties and the increase in rainfall in those areas was very minimal. You know it is less than 10 percent. And the cost associated with the artificial rainfall is humongous, it’s too much.

So the benefits were not you know seen to be very large right, that is why will have artificial rainfall being practiced you know very popularly anywhere. Anyways what are these nucling agents is the most popular which have been used is what is called the silver

iodide, and also the dry ice the carbon oxide, the dry ice has also be and there are many other types of nucling agents all right. So we will live it at that, those are interested in looking at the artificial you know the rainfall can go through some of the resources on the internet, it is a very interesting phenomenon of course no doubt, but it is very difficult to practice and perfect.

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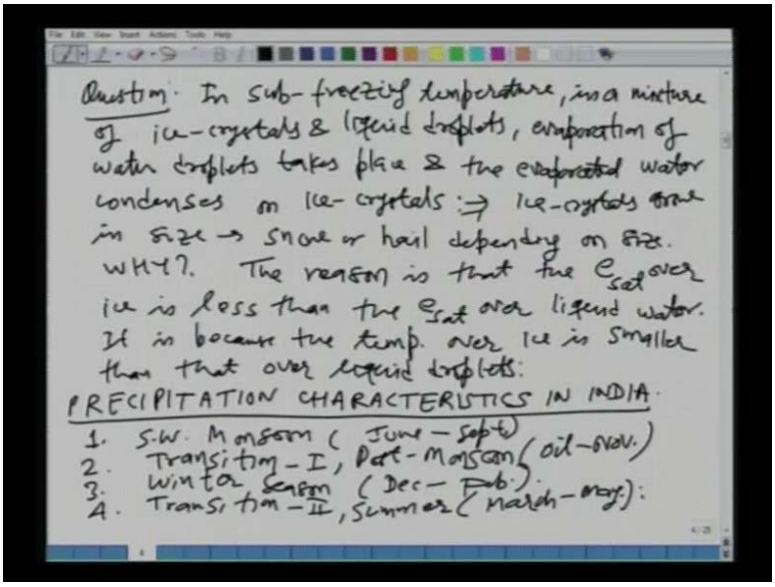

So moving further what I would like to look at is I will pose a question to you actually, which is very interesting; why does the solid form of precipitation form in the atmosphere? In the atmosphere you have water vapor which will condense right, then it will be either liquid or solid.

Ice crystals will be there, the liquid water will be there, water vapor will be there all right. Sometimes only the rain falls, the liquid water falls and sometimes you have the solid water or the ice crystals forming. Why do this snow or hail or ice crystals form? right and let me pose this question to you may be slightly in more technical manner. In the sub-freezing temperature, well we know that whenever we have solid form of precipitation forming the temperatures are very small. They are sub-freezing means are below 0 degree centigrade right. So in the sub-freezing temperatures, in mixture of ice crystals and liquid, liquid water we are talking droplets, evaporation of water droplets takes places and the evaporated water then condenses on ice crystals. That means the ice

crystals grow in size, grow in size to become snow or hail depending on the size in conditions known ok, why?

Why does it so happen that when you have mixture of ice crystals and liquid droplets in the in the air the mass transfer takes place from liquid to solid all right. That is when the hail is formed or the snow is formed or the size of the solid water increases and we have the hail falling. Why does that happen? Right so there is the liquid water gets evaporated and that evaporated water quickly condenses on to the ice crystals and they grow in size, why does this happen? Think about the answer lies in the saturation vapor pressure of solid and liquid water right. If you think about it the reason that the e sat or the saturation vapor pressure over ice is less or more then the e sat over the liquid, well the temperature over the solid will be lower and if the temperature is lower the saturation vapor pressure would be obviously lower right.

So the saturation vapor pressure over the ice crystals is less than the saturation vapor pressure e sat over the liquid water right, it is because the temperature over ice is smaller or less then that over liquid droplets. So it's basically it is a natural phenomenon or mechanism in which the mass transfer takes place some higher energy to lower energy right. The saturation vapor pressure over the liquid droplets is higher and saturation vapor pressure over the solid or ice crystals is lower, that's why the transfer of mass takes place from droplets water droplets towards the ice crystals during the formation of the a the hail storm and snow. However for all of this to happen the favorable conditions have to be there ok, so it's an interesting aspect I thought will take it up before the move on to the characteristics in India. I would like not to go too much into the detail of this but; the next thing we are going to look at then is what is called the precipitation characteristics in India all right.

So we have looked at so much, the different forms of precipitation but whenever we talk about the precipitation in India we just talk about rainfall. In most of the country all we have is the liquid precipitation in the form of rainfall all right, most of our country is dependent on this rainfall for various needs as I have earlier. However in very small regions in the Himalayan regions we do have you know solid form of precipitation but that does not contribute probably too much to our economy. So first I will define there are 4 different seasons which have been characterized by the India Meteorological department or IMD alright or from hydrological point of view we have 4 seasons; one is

called the south-west monsoon which runs from June as you know to September. June to September is called the south-west monsoon, second one is called transition one which will also known as the post monsoon which is from October to November.

The third one is called the winter season or winter which runs from the December to February and number 4 what is called a transition 2, which is also known as summer which is during March to May. So you see that the whole year is divided into the 4 different seasons, as far as the studying precipitation characteristic in India is concerned. Now this seasons all probably will not match with the season as you know but these are as per as the hydrology is concerned all right. So what we will do next is we would look at the south-west monsoon in India, so let's move on to that ok.

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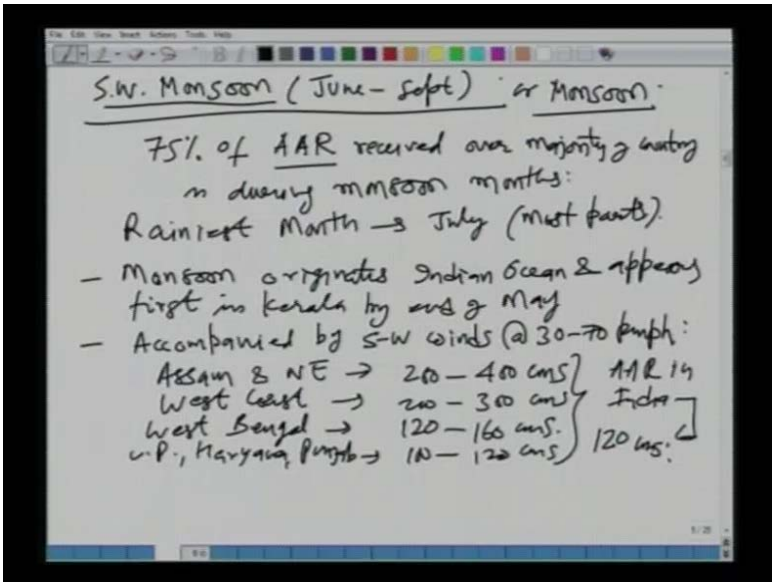

So let us look at the south west monsoon in India that is the only one we look at out of those four we have seen. South-west monsoon and which runs from like I just said June to September. These months and commonly it is just called monsoon.

Those of you who do not know there are 2 types of monsoon in India, one is just called actually the monsoon which is in fact the south-west monsoon all right, this other one after this monsoon which is concentrated mainly in this southern part of the in India. We will not concentrate much on that because majority of this rainfall which will receive is during the monsoon season in India. So before we have actually go to the dynamics of the monsoon in India or the south-west monsoon, I would like to just look at some basic

facts about this or some interesting numbers about this monsoon in India about. About 75 percent of average annual rainfall, what is AAR? It is the Average Annual Rainfall which is received over the majority of the country or India is during the monsoon months or during the monsoon season that is June to September; June July August September these are the 4 monsoon months.

So you see that the majority of the rainfall, almost 75 percent of the average annual rainfall is received during the monsoon. So you see that the rainfall is very unevenly distributed with respect to time in India and will see later that it is also very highly unevenly distributed over place also. The western part of Rajasthan in Gujarat you as you know are very deserted all right, it receive very little rainfall and some of the places in north-east like of Cherrapunji and some other north-east regions they receive maximum amount of rainfall; actually in the world all right. So the distribution of rainfall is highly uneven with respect to space but with respect to time also right, we receive most of so managing the water resources in India it becomes a very big challenge all right. So will not go into the details of that but will just look at some of these numbers. What is the rainiest month? It should be very easy for you to guess, it is July in most places or most parts of in India. In July you will see most of the rainfall part of these 4 months in most parts of the country.

The monsoon originates, where does it originate? In the Indian as you know; and where does it appear first? Where does it appear first? Well today is second of June the day on this which lecture is being taken and I just heard that the monsoon has just arrived in Kerala right. So the first place in India where the monsoon arises, Kerala right, it first appears in Kerala; the southern part of our country by the end of May normally. And then this monsoon is accompanied by south-west winds all right, of the order of or at approximately 30 to 70 kilometers per hour. So I will look at that, again looking at some numbers; the rainfall which we get, I was talking about the special variation of rainfall in India. In Assam and the north-east region they receive about 200 to 400 centimeters of rainfall over the whole year, these are on an average number of different Places in Assam and north-east.

The west coast including Mumbai, the rainfall is the order of 200 to 300 centimeters. The West Bengal and close by areas, the rainfall is small of order of 120 to 160 but nonetheless it is close to average rainfall. In UP, Haryana, Punjab the northern belt; it’s

slightly less than average about 100 to 120 centimeters all right. And what is the average annual rainfall of the whole country? I do not know if you know it is of the order of about 120 centimeters for the whole country. The average rainfall is about 120 centimeters in India, and you see that this is the distribution of rainfall with respect to space and we have seen that this is very high uneven, we have lot of rainfall in some places and very little rainfall in the other. So that why we have the problems of floods and droughts, at the same time we may have droughts in one part of the country and other part of the country may be experiencing floods.

Similarly, we have lot of rainfall, lot of water available in one particular place due to the highly uneven distribution with respect to time right during these 4 months but we do not have water for our needs the rest of the year. What I would like to do next is look at this south-west monsoon wind patterns all right, how it actually contributes rainfall over the majority of the nation.

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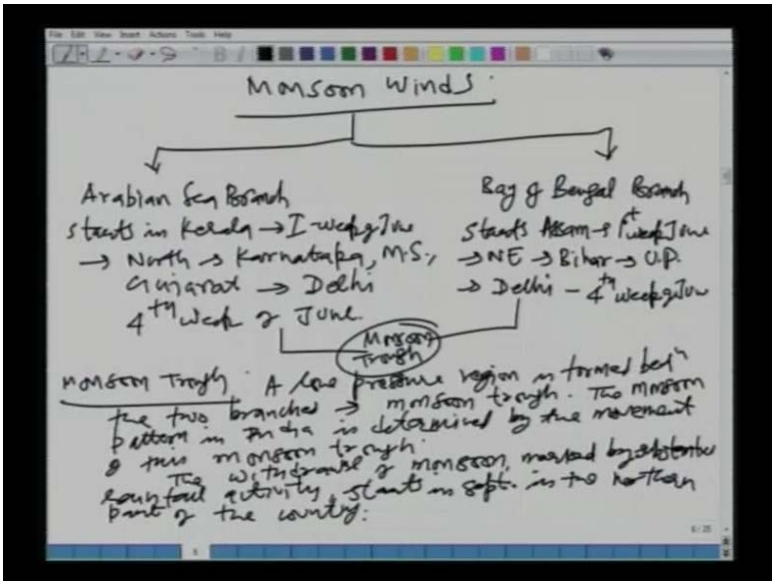

As we said they are monsoon winds which are responsible for bringing the moisture from the Indian Ocean all right on to the land masses all over the country that is India right. So these monsoon winds have 2 branches, you may have studied this earlier right; one is called the Arabian sea branch and other is called the Bay of Bengal branch coming from Bengal, the wind patterns. The Arabian Sea branch of the monsoon winds, its start in Kerala like I just said and then it travels well before I go to that during approximately

first week of June; that is when it starts. Then it travels to the north, goes towards north to Karnataka, Maharashtra, Gujarat and then finally it reaches the central portion or Delhi around the fourth week of June.

So this is the like pattern if you want to see or look at all the Arabian sea branch it goes to these parts of our country and reaches the centre portion of Delhi around fourth week of June. What happens to the other branch, well it starts in Assam, when? Around the same time; first week of June as the Arabian Sea branch which starts around the same time first week of June in Kerala. So the way of Bengal branch starts in the week of June, then it goes through or comes to the north-east region to Bihar through UP right and other places, and then this also reaches the central portion Delhi around same time fourth week of June. And then what happens is these 2 branches of the winds are coming towards the central portion of our country and then they formulate or they combine to form what is called a monsoon trough, it is a, it is a low pressure zone is called the monsoon trough. If I did that, you have monsoon trough and what happens then is this monsoon trough starts oscillating over the country right for some time.

It will be travel up and down, it will be bringing the, so it's like a steady and unsteady process. So the moisture is coming from these 2 branches from the Bay of Bengal and the Arabian Sea branch right, so they bring the moisture on to the country. This monsoon trough will be oscillating and its movement will dictate the kind of monsoon we will have on a particular year. So it is very highly dynamic the monsoon trough and how it withdraws back into the 2 different branches will also dictate the withdrawal of the monsoon. So let us look at this slightly more technically, what is a monsoon trough? It is a low pressure region, is formed between the 2 branches when they meet which is called the monsoon trough. The monsoon patterns in India is determined by the movement of this monsoon trough, and then withdrawal of monsoon which is marked by substantial rainfall activity starts in the withdrawal that is September in the northern part of the country, withdrawal also starts from the northern part of the country.

So you see that the monsoon is formed by these 2 different currents that come from 2 different places, one is the Arabian Sea branch other is the Bay of Bengal branch; they come and meet around the same time in the central portion and oscillation of this small monsoon trough basically dictates the monsoon pattern in India. So this is about the different seasons and the monsoon in India, the next thing which are going to look at; we

had seen the formation of the raindrops in the atmosphere. So what we will do next is how the drop of rainfall actually falls through the year right, and what will do is we will derive an expression of what is called the fall velocity or the terminal velocity.

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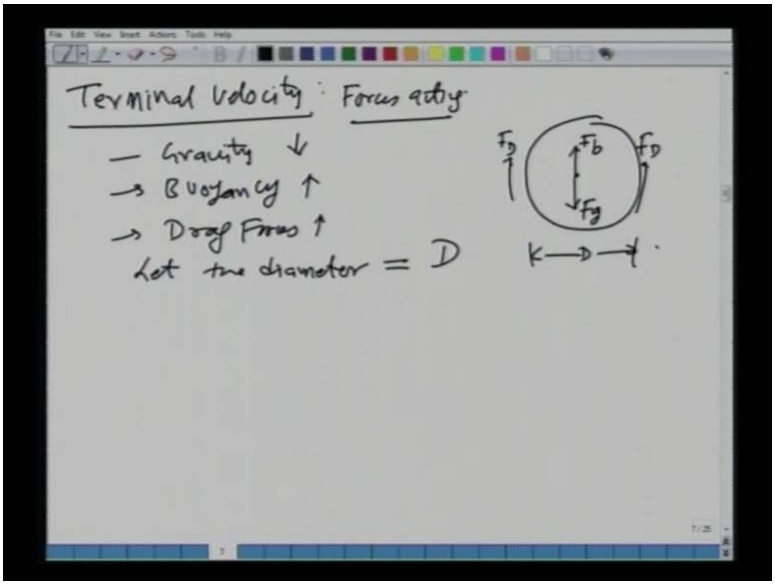

So that's the next thing we will do is what is called the terminal velocity of a raindrop. So I will first draw the figure.

Let us say this is our raindrop, I have drawn a big sufficiently large size raindrop and I am marking some of the forces that are acting on it. So what we will do is we look at the spherical raindrop and we will analyze the various forces that are acting on it right, and then we will balance these forces and once we balance will be able to find out what will be the fall velocity. So if you want to look at what are the forces that are acting on a raindrop when it is falling through the air, we will say that the 3 forces acting; gravity is acting downwards, various buoyancy forces acting upwards, there are drag forces acting upwards. So, this is our F of b acting upwards, this is your F of g and this is your F of D right. So, I think I may not have time to complete this but what will do is let's, let's say that the diameters of this spherical rain drop is let's say D all right.

So this one this D, so I would like to request you is to look at this as a free body diagram, you have 3 forces acting on a spherical raindrop and then you try to find out the expressions or you write these 3 forces that are acting; that is gravity, buoyancy and drag forces and then then the raindrop start to fall initially starts from 0. But after some times

when the forces is will balances it will starts falling with the constant velocity, so initially it accelerate but after some time it attends what is called the terminal velocity or the fall velocity right. So you think about what will be these expressions, and we will come and look at them in the next class.