Introduction to Atmospheric Science
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Lecture - 24
Normand's Rule - Chinook Winds

Okay, so Good Morning. So we will continue with our discussion on moist air thermodynamics. So we started defining many quantities okay; lifting condensation level, wet bulb. So we first started with moisture parameters mixing ratio, relative humidity and mixing ratio, specific humidity, relative humidity, dew point, lifting condensation level, wet bulb temperature, dew point temperature okay and then potential temperature which is the dry adiabat then the saturated adiabat corresponds to the equivalent potential temperature. I think we stopped at that.

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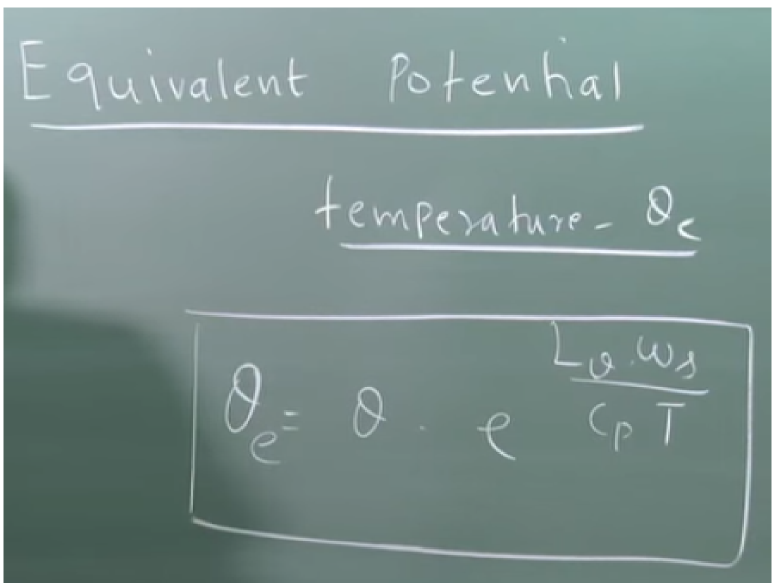

Lv into. What is theta? Theta is the potential temperature. So the theta e is the product of the potential temperature into e the L v omega s by C p into T okay. So L v is typically some 2250 kJ/kg. Omega s will be some 10 g/kg or 20 g/kg and so on. C p of air is 1005 or 1.005. Temperature will be 290 K. So this quantity will not be so will be not be such a very huge quantity. It should not be very huge and very small. Then it will be meaningless okay.

So this theta e is equivalent potential temperature lines of constant, equivalent potential temperature are curves which are available on the Skew-T ln P chart. So it is possible for you to calculate the equivalent potential temperature okay. So I think I gave you the definition. So the theta e is the temperature of an air parcel when all the water vapour has condensed such that its saturation mixing ratio becomes 0.

I think you missed some classes. Theta e is the potential temperature of a that is equivalent potential temperature is actually the potential temperature of an air parcel when all the water vapour has condensed so that its saturation mixing ratio is 0 alright. How do you find the equivalent potential temperature? The equivalent potential temperature of an air parcel may be found out by considering the lifting of the air parcel pseudo adiabatically until all the water vapour has condensed and released and the latent heat has fallen out.

The air is then compressed dry adiabatically to 1000 hPa okay at which point it will attain the temperature equal to theta e. Then wet bulb potential temperature we saw that also.

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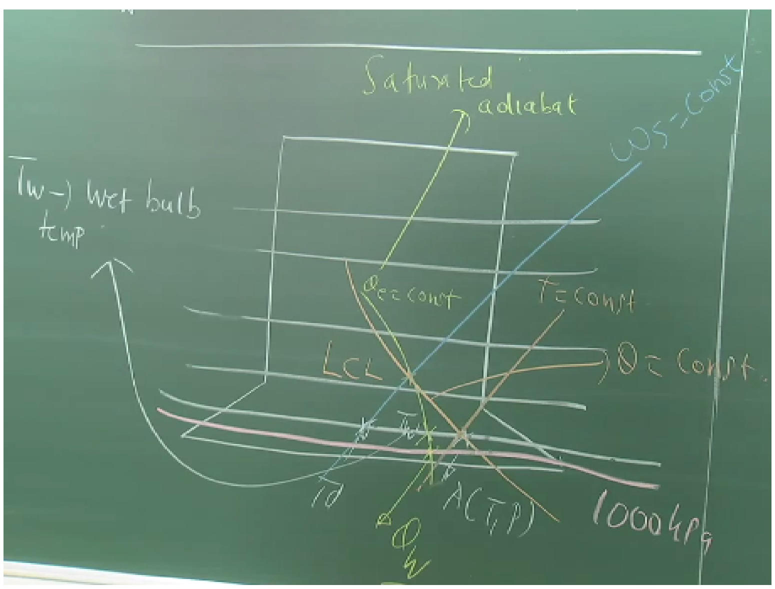

Point A, temperature and pressure. What is this? T d. These are curved, saturation mixing ratio is straight line? Straight line? How do you get this? Omega = omega s okay. What is this fellow? What is this point? Very good. Lifting condensation level. People who missed classes or people who have just missed the point is basically this is an isobar. There is a t is equal to constant line. So find out, first fix the point on this Skew-T ln P chart.

One moisture parameter will be given. If dew point is given already then there is no problem. Otherwise omega will be given. Otherwise RH will be given. Otherwise specific humidity will be given and converted into this such that you get that omega s. That omega s will intersect with your original isobar. That will be T d okay. Keep that blue line like that. From here find out where the theta is equal to constant, that is the potential temperature is a constant.

They will intersect and that is the lifting condensation level. Now, from the lifting condensation level you take a theta e is equal to constant. So this is a saturated adiabat or a pseudo-adiabat okay. He is cutting the original pressure at some point, what is that, very good that is T w. Please note that is wet bulb temperature. Now, I will go I will go down little further assuming that this original pressure is not the 1000 hPa and this is the 1000 hPa if the watch if the line joining, if the line joining the LCL and T w which is nothing but the theta is equal to constant which is the subject of our discussion yesterday's class and today's class.

If it is extended all the way such that it cuts the 1000 hPa then that temperature is called the wet bulb potential temperature. However, if the original point is already at 1000 hPa then the T w will be the same as theta w, agreed? So you can see first that T w the wet bulb temperature is between the dry bulb temperature and the sorry between the dew point temperature and the dry bulb temperature. If you are using a desert cooler or an air cooler it can reach adiabatic saturation only up to T w. You cannot reach the dew point.

But you can approach the dew point if you use an air conditioner okay. So adiabatic saturation. What is the difference between the saturation reached in T d and the saturation reached in T w? The saturation reached in T d is isobaric. Saturation in T w is adiabatic okay. Now wet bulb potential temperature is also there. So in the quiz, I will ask you a solid question where all the parameters are given. I will give you the condition. I can ask you n number of things right.

Get the dew point, get the relative, get the, I will give only one moisture parameter like let us say omega, ask you to find RH, ask you to find specific humidity, ask you to find dew point temperature, LCL, theta, theta w whatever. So you should have patience and do one by one. It is not very difficult but you have to be very meticulous and systematic okay. And you have to use the right line. After LCL if you again use theta is equal to constant you will go somewhere.

You will come back to the original point. After the LCL theta e is equal to constant alright. Now, I want to introduce one more quantity called MSE.

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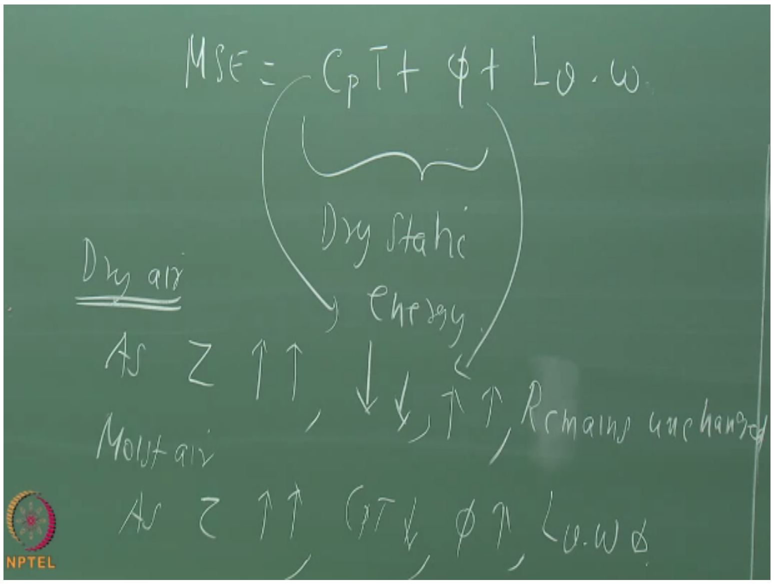

Any guesses what this could be, is the moist static energy of air okay. The MSE, can you identify the 3 terms? First term is, it gives you an idea of the total energy available with the air. The total energy of the air has got 3 components. Component one is please feel free what enthalpy. The component one is enthalpy. The component two is geopotential which is a reflection of its height okay potential energy and the third is the energy contained in the form of latent heat.

So which is the dry part and which is the wet part? First two are dry very good. So this is dry static energy. First two are dry parts right. What did I say dry static energy. Now, as Z increases what happens? Assuming that all the process in the atmosphere are adiabatic as Z increases please tell me what happens to each of the 3 components. T will C p into T will decrease. What about the second part, it increases.

For the dry, if it is for dry air if it is dry air the third part will also decrease correct. Is it correct or I am making a mistake okay. So the first two you are fine right. No, I made a mistake. For dry air what about this? It is not under consideration, remains unchanged right? Now for moist air now tell me what happens to third term. Decreases, correct okay. However, the sum of the three is a constant. So in atmospheric processes you can consider involving moist air.

You can treat MSE to be constant and work out problems with that if height is chosen as a coordinate. Height is chosen as a coordinate means phi is chosen as a coordinate. Are you getting the point. So that is also possible. Now, I will have to teach you something called Normand's rule. It is extremely useful. You already know about this but let us state it formally and then we will solve a massive problem which would take about half an hour for you to solve on this Skew-T ln P chart.

We will discuss something called the Chinook, we will discuss something called the Chinook wind in the Pacific which starts from the west of the Pacific. Chill air comes on the windward side of the mountain, gains moisture goes up and comes on the right side. You will see that you are getting surprising results okay. We will solve that in today's class.

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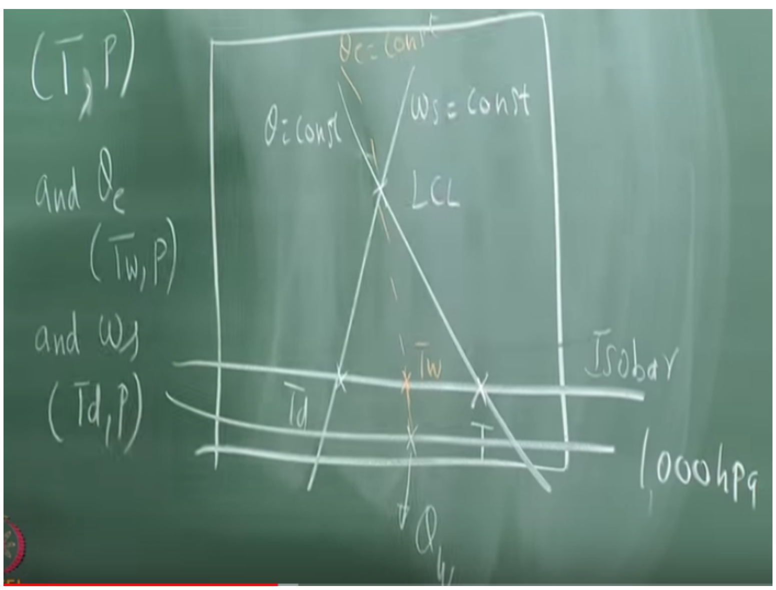

Okay. Please tell me what are these 2 points, T, LCL, T w. What is this? Theta w. So this is also an isobar but not equal to 1000 hPa. Have you taken this down, ya. Now I will tell you the rule. You already know this but it is good to have it in the notes. Please complete this. You can focus on that. I have already indicated on the right side but this is more. Shall I start speaking. Okay, please take down.

The Normand's rule, Normand's, the Normand's rule states that on a Skew-T ln P chart the LCL of an air parcel Normand's rule states that on a Skew-T ln P chart the LCL of an air parcel is located at the intersection the LCL of an air parcel is located at the intersection of the theta line located at the intersection of the theta line that passes through the T, P of the air parcel and the theta e line that passes through T w, P and the omega s line that passes through the T d, P not T d p that passes through the T d, P of the parcel.

It is I am just stating the obvious okay. So it is a 3-way interaction. You can start from wet bulb temperature or you can start from dew point or you can start from this thing and everywhere it will all converge to LCL alright. So, now I will show you two presentations. How to get the lifting condensation level okay.

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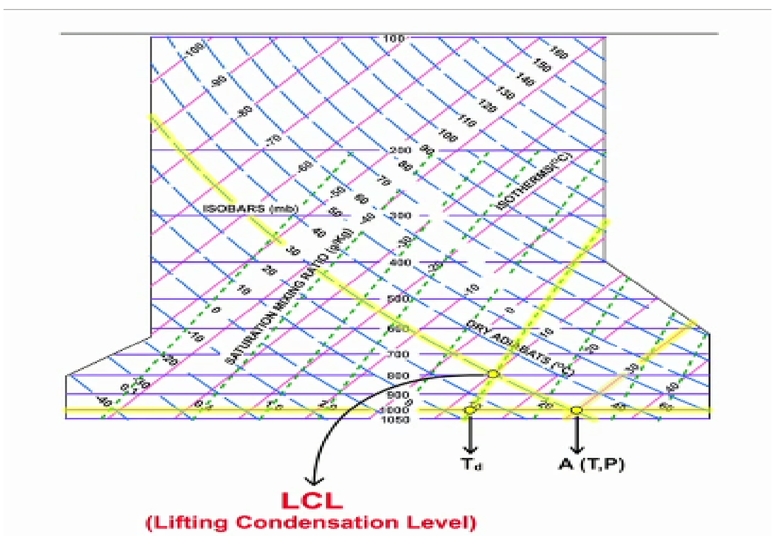

Coordinate system of the Skew-t, Log-p Diagram

On this Skew-T ln P chart first locate the isotherms okay, the isobars. With the help of the isobar and isotherm you know the point A which is given by T p. The 2 yellow lines will intersect and you will get the point A now. Point A whose coordinates are temperature and pressure fine. Now, please look for the saturation mixing ratio lines omega is equal to constant and omega is equal to omega s. Apart from temperature and pressure we will give you one quantity for A.

Let us assume that that is omega. Find out where omega equal to omega s and have that yellow line. So this is okay I will just I am I cannot write this presentation okay. Omega into omega s and identify that line. What happened? Now where the original isobar cuts the omega equal to omega s line that is the T d. Then look for the dry adiabat. Take the dry adiabat from A and locate it and then this dry adiabat this dry adiabat and this omega s which is cutting the isobar at T d they will intersect that is the lifting condensation okay. So how do you get the wet bulb temperature?

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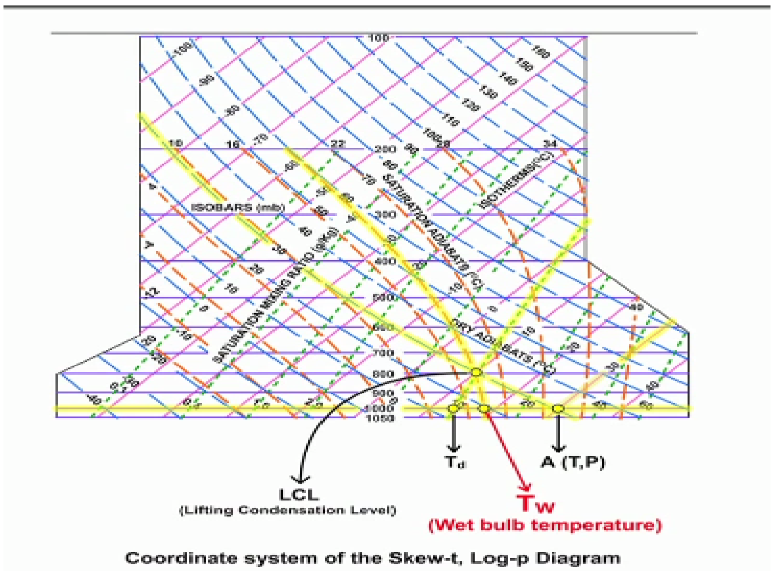

Look for the isotherms. Look for the isobars. Intersection. Fix the point. One more moisture parameter will be given. Look for the saturation mixing ratio. Find out where the saturation mixing ratio is equal to your omega which I have given 8 g/kg, 12 g/kg whatever. Fix that dew point. Look for the dry adiabat. Look for the one which is originating from A that is theta equal to constant and then look for this omega s line which is shooting off from T d. Get the lifting condensation level.

Now look for the orange colour line which are the saturation adiabats or theta e equivalent potential temperature is a constant that yellow line is fixed. Then that intersects this original isobar corresponding to A and T d and you get the wet bulb temperature. If you go down further assuming that at A the pressure is not 1000 hPa you will get the theta w. Is that okay? Please take down this problem. Problem number 38.

An air parcel at 1000 hPa, an air parcel please take down the problem, problem number 38. An air parcel at 1000 hPa has a temperature of 30 degree C. An air parcel at 1000 hPa has a temperature of 30 degree centigrade 30 and a mixing ratio of 14 g/kg. What is the T w of air? Now I will not ask what is the LCL. When I say now you are advanced now. What is the T w of air means you have to get LCL is it not? Okay, what is the T w of air? Problem continues.

The air parcel is lifted to the 700 hPa level. The air parcel is then lifted no not then the air parcel is lifted to the 700 hPa level by passing over a mountain. The air parcel is lifted to the 700 hPa level by passing over a mountain and 80% of the water vapour that is condensed out by the ascent that is with the ascent or the lifting right. So I come again, the air parcel is lifted to the 700 hPa level by passing over a mountain and 80% of the water vapour that is condensed out by the ascent is removed by precipitation. Determine the following quantities.

Temperature, potential temperature, mixing ratio and the wet bulb potential temperature. So determine temperature, potential temperature, mixing ratio and the wet bulb temperature of the air parcel after it has descended down. Determine the temperature, potential temperature, mixing ratio and wet bulb potential temperature of the air parcel after it has descended down to the 1000 hPa level on the other side of the mountain you understand. Why it is getting lifted up, some wind is there.

Let us not get into that story. So the wind is bringing air and then it is rising and then it is raining on the mountain top. Then the moisture is removed, wind is carrying it is going to the other side. Now the funda is you will get some surprising results. What is the final temperature of the air which is hitting the city or the town which is on the other side of the mountain? Originally the air is at 30 degree centigrade. You will get some surprising result okay.

So please start one by one. It is like a typical quiz question okay. Once you have learnt moist air thermodynamics this will be the, do not expect me to ask a 15 mark question of what is the LCL okay, alright.

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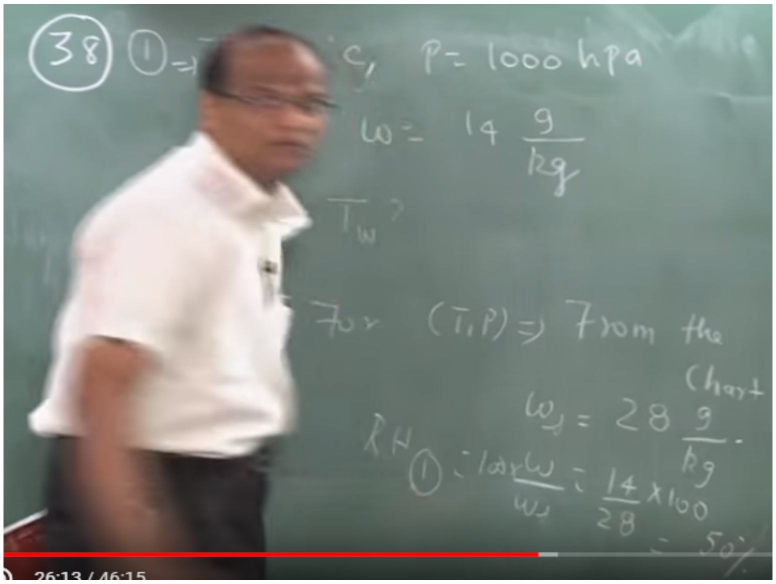

So T equal to P equal to. The first question was what is the wet bulb? How much did you get? I got 28, 28. So we call that point 1 a or whatever. I am calling it as 1. So the relative humidity of 1 is 50% okay. It is not required? But I will find out. Okay. Whatever can be found out we will find out alright.

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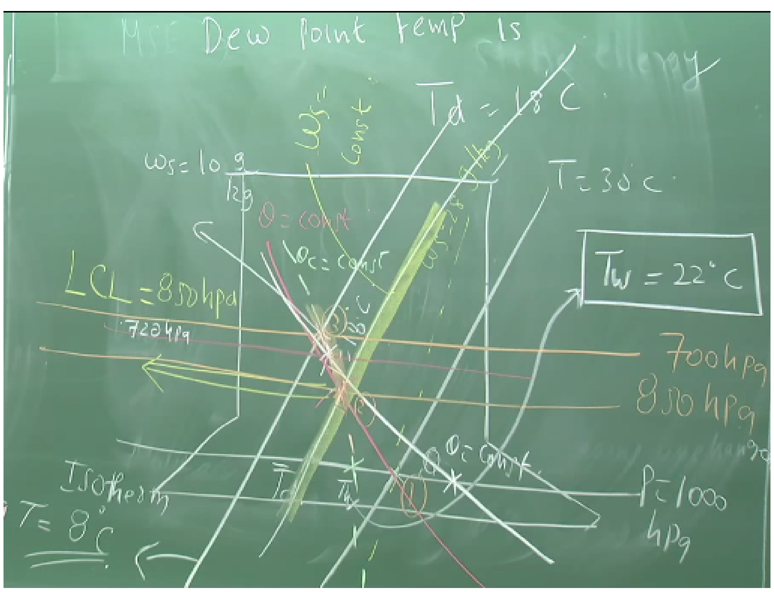

Now dew point temperature dew point temperature is, 18 correct. Okay, for the benefit of other people who are watching this we will just show it. Which is steeper? The omega s or the isotherm? So if I draw like this I am not making a mistake right okay. Okay I got this. So this is my it is too much, that is okay. This is point A, point 1. Then I go all the way here. This is my T d fine dew point. Now keep this. They are intersecting, 850. Alright. So the LCL is 850 hPa.

We have not even answered the first part of the question right. So we are still, quite an involved problem. Now let us try and answer the first part of the question which is find the wet bulb temperature. Let us find the wet bulb temperature. So I will use the green. Theta e is equal to constant. It cuts this somewhere, 22. It may correspond to Bangalore but the problem is it is not 1000 hPa in Bangalore. Bangalore is already at some height.

If you want to start with Bangalore you have to start some 920 hPa or 900 correct. Are you getting the point? Bangalore is not at 1000 hPa because Bangalore is at 900 meters above sea level no. Chennai is at 1000 hPa but 30 degrees is not Chennai. That problem is there. Maybe today maybe it is 32, 33 now. Okay. So the wet bulb temperature is 22. Out of 20 marks, you got 6 marks or 7 marks already. Now, the difficult part start.

Now it is further lifted, it is further lifted to 700 hPa. How will it get lifted? This is theta equal to constant. So from here will it follow the green line or the pink line? It will follow the green line. I will take the so now this is 850 hPa okay. Draw one more line 700 hPa. Okay for those people who are highly mathematically inclined with a scale height of 7.5 km what is the height of the mountain at 700 hPa. Just tell me 2 minutes. Use the hydrostatic equation.

Tell me the height of the mountain assuming that 0 or P not equal to 0 right at 1000 hPa. Can you calculate or not. You can right. 2.67 is reasonable. Western Ghats is 2 point; Ooty is 2200, 2300 meters. Anamudi is 2695. So 2.7 km is reasonable. Okay Western Ghats height is about so it has come up to 7000 700 hPa. So you must have this in mind. So 700 hPa. So the lifting condensation level will be 1.5 km right.

1.2 to 1.5 because you guys are telling me this is 2.6, 1000 is 0, 1000 hPa is 0, 700 hPa is 2.6 or assume that 850 will be around 1.2, 1.5. So that cloud base height will be around 1.5. Now from here you are taking it all the way up to 700 by using this. So I am following this okay. 1, 2, 3. Now what should you do. At 3 what is the temperature. That you can easily find. At 3 you have to find out isotherm. T equal to so it is very cold now. The air parcel has become very cold.

I will just check my answer. This is not asked. Okay anyway we will find okay. This is not asked because I asked on the other side of the mountain only but after it descends. But anyway whatever you can calculate you calculate. I know that you are proceeding on the right track. Now, some difficulty, now some difficulty arises because from its mixing ratio is how much. It is mixing ratio is always 14 g/kg.

But now when it has reached 700 hPa what is omega s. So how much it has to shed as precipitation, 4. But out of that 4 it is not shedding everything. How much is it shedding. 80%. How much is that 3.2 g. So the remaining 0.8 will stay with this. So what will be the omega, what will be the omega of the air parcel when it starts descending after it has hit the 700 hPa will be, the maximum it can take 10 g/kg plus whatever it has not precipitated.

Or I will come in some other route. Originally it had 14. At 700 hPa it is legally allowed to have only 10. The remaining must be thrown out that is 4. Out of that 4, 80% is actually precipitated. That means 3.2 g. So out of 14, 3.2 are thrown out. So the 10.8 is remaining, agreed. So 10.8 g/kg is remaining within the air parcel. With that 10.8 g/kg what will happen to that okay. It is coming down. Correct?

When it comes down which process will it follow, saturation adiabat. When it, it will follow the saturation adiabat till it reaches a height at which omega s is 10.8. Are you getting the point? After that all the moisture would have been removed. It will follow dry adiabat all the way up to 1000 hpa. Is that clear? Do you understand what I am saying? Vivek, you are following what I am saying. So some fundas are there. This 10.8 funda you understood right.

From the 10.8 what will happen? It will again come down. It will again come down to a pressure at which when it intersects the omega s will be 10.8. What is that height? I think it is 720; 720, 730 whatever. Thereafter when it goes down it would not follow a saturated adiabat, it will follow a dry adiabat correct. Then it will follow a dry adiabat all the way up to where 1000 hPa. Then if you see the temperature you will get a startling result.

Please do that. 40 degree C, 38 or 36 or 38. So what is actually happening. You get a cool you get cool air on one side of the mountain. The air the wind takes it up, it sheds its moisture. On the other side you get hot winds. This is called a Chinook wind. So it happens in the Rockies in the US. It also happens in the Alps in the in Europe okay. Some little bit should also happen in the leeward side of Western Ghats which will be some Tamilnadu.

I mean for example in, what is the other side of the Western Ghats if you look at Tamilnadu, maybe that Sivakasi, Virudhunagar and this side of Madurai and all that no, west of Madurai. The other side you will have all Kerala towns. What is that Vishwajeet, this all Western Ghats, Eastern Ghat is our I am going to west. So when you cross Kerala this side there is Tamilnadu right after the Western Ghats.

There is some portion that is why you have got this Sivakasi and all these places where they do this firecrackers. There are only 5 rainy days out of 365 days. Why are all the fire crackers factories situated in Sivakasi? 360 out of 365 guaranteed no rain because they are on the leeward side of the mountain. The Western Ghats protects them from rain. But on the other side it is raining like mad, other side. You know that.

The other side if you cross the Western Ghats it will be so green that is why Munnar and all those places okay. So what is the temperature you are getting? Now, I will write it. I think only in the next class we will be able to. It has become too complex now. So this is 720. Then from here okay.

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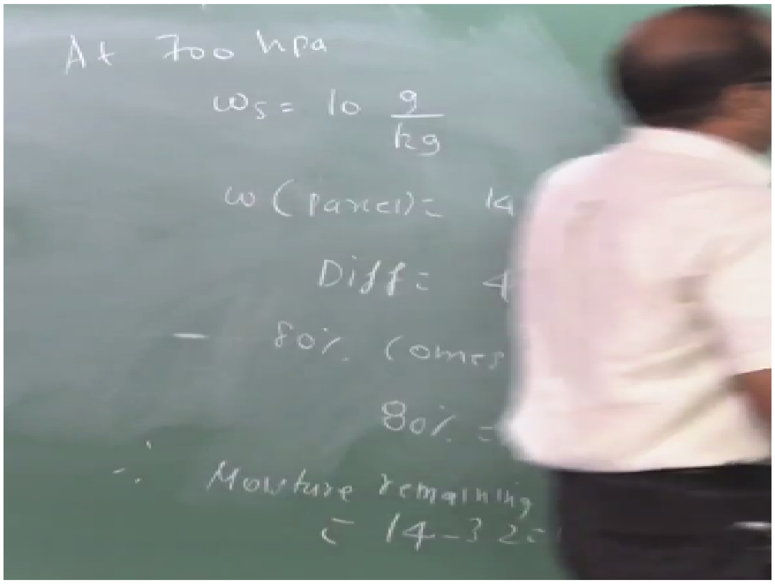

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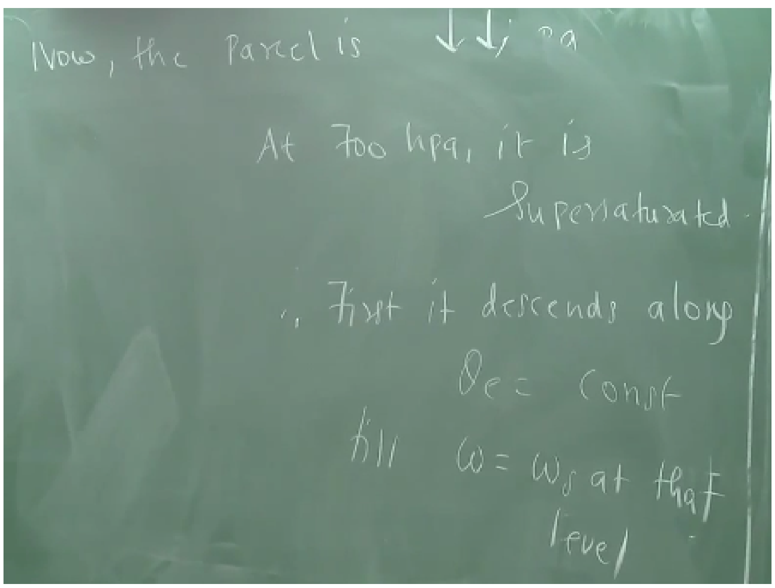

Now the parcel is going down. At 700 hPa unfortunately it is supersaturated correct? This is the funda okay. Now the parcel is descending. At 700 hPa it is supersaturated. First it descends along the theta equal to constant till omega equal to omega that level. This is, what is that level okay. I do not want to rub that okay.

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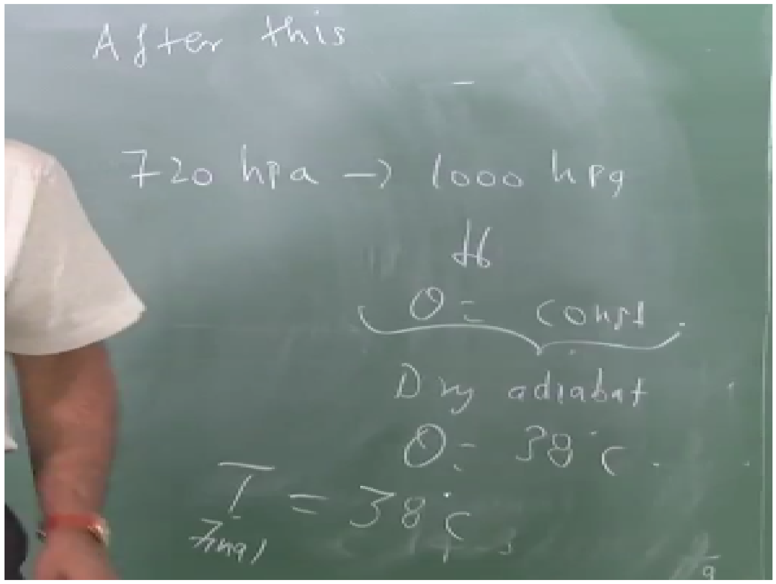

What is the theta, theta T is 36 no? What is theta 38 is it. Theta, potential temperature, 38. T final, same. So what did I ask? Determine the temperature, potential temperature mixing ratio is 10.2, 10.8; mixing ratio is 10.8. Wet bulb potential temperature, same 1000 hPa. Wet bulb temperature is the same as before correct. Wet bulb potential temperature does not change right. So ya now just one minute I think some people want to, Lakshmikanth, he wants to go to the next class.

So I will just quickly summarize. The net effect of an ascent followed by a descent is as follows. The net increase in the temperature and theta of the air parcel you have seen that decrease in omega, RH, T b, and T w. No change in theta e or theta w. Wet bulb potential is the same, potential temperature theta e is the same but why are you so surprised, net change in omega it started with 14, it has come down to 10.8.

So it has decreased. So relative humidity also has decreased. Moisture has decreased right. The relative humidity has decreased. You can check what will be the relative humidity at the final point. It would have decreased okay. Then the T w would also have decreased okay. But there is no change in the potential temperature or the wet bulb potential temperature. So you get a very hot air on the leeward side. So this phenomena is called Chinook wind.

I will show you some pictures and some we will get into the internet and look at Chinook winds for 5, 10 minutes and I will solve this problem on the Skew-T ln P chart for the first 15, 20 minutes. Then I will solve one more problem involving all this wet bulb and all that. Before we start on with the new sub chapter in this where we look at the stability of an air parcel. After it goes up will it go further, it will be uncontrolled or is it convectively stable, unstable, neutrally stable and all that. Thank you very much.