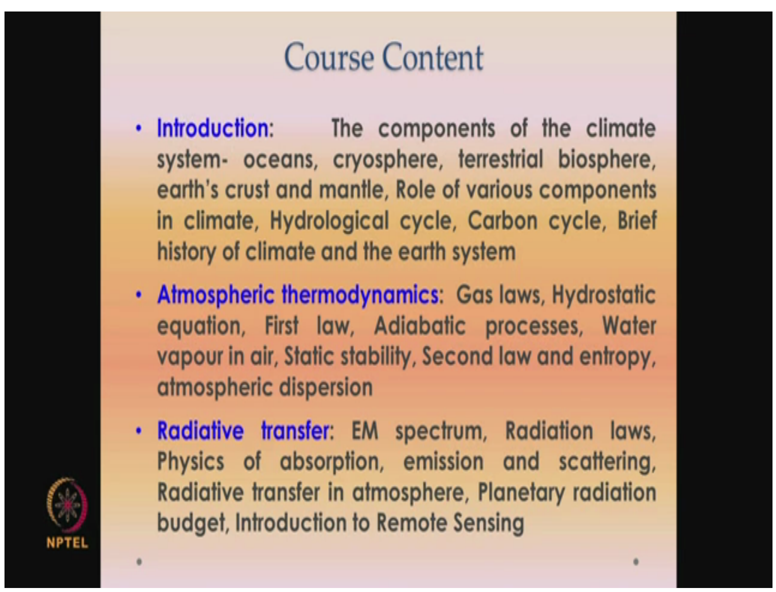
Introduction to Atmospheric Science
Prof. C. Balaji
Department of Mechanical Engineering
Indian Institute of Technology-Madras

Lecture-01
Introduction

Okay, so, good morning. Welcome to this course! ME-5530, Introduction to Atmospheric Science, I introduced this course in the year April-2008 because I have been working in this area for last 12 years or so and we wanted to give a general introduction to this subject to all branches, right. So, it is basically a 3 credit course, 3 lectures, no tutorial, no practical and 3 credits, the 3 meetings per week. But, of course, I will, will solve a lot of problems during this course.

So, the lectures will be interspersed with problems, okay. So, all the quizzes and exams will be open notes, not open book, open your notes without photocopying, okay. So, your notes and there is no tension, there is no need to memorize formulae and all that. And questions like with the need sketch you explained all this will not come in the exam basically you have to crack problems. So, it is a typical math oriented course, right. I have given you the course content. Let us quickly go through this.

(Refer Slide Time: 01:20)



The first few lectures we look at introduction, where we look at the various components of the climate system. Here we look not only at the atmosphere; we look at the oceans, okay. Why do you think the oceans are very important in the climate system of the earth? There is a big heat sync, right. The mass of the ocean is so much, the mass and the specific heat is so much that they can act as a thermal reservoir, okay. So, they will and therefore their response to any thermal disturbance will be accentuated or will be slowed down because of the high mass into specific into the oceans.

So, they are like a thermal buffer, okay. So, they are an important, oceans are an important actor in this whole drama of the climate and we are not going to study more about the oceans because it is not an Ocean Engineering it is not OE course but we will have to, we will have to look at it 2, 3 hours. So, that will be the perspective. So, all this will consider in the first chapter; then, the Cryosphere. The Cryosphere is that part of the earth system where everything is in the form of ice, right. So, Antarctica ice, Arctic ice and then subsurface ice and so on.

Terrestrial biosphere, vegetation and all this; Vegetation also controls evaporation, transpiration, temperature control. For example, you get into our campus is a distinct difference from Sardar Patel Road, you get in there is a 2 degree drop rate, is much better, right because of the vegetation, right. So, we look at this then the Earth's crust and mantle. The Earth's crust and mantle are also important. So, plate tectonics continental drift and all that there are many issues involved in that.

But this I will be able to look at will be looking at them as an overview kind of thing because the course is not on the earth system, right. It is not a geology course it is an atmospheric science but this is an important aspect so that will be covered in the first chapter. Role of all these various components the climate hydrological cycle is you have studied from basic geography. So, evaporation, then, this thing convection, rainfall, then, glaciers melting, rivers flowing down and all this;

Then, the carbon cycle is very important and then we will also look at the brief history of the Earth's climate and the earth system. For example, the ice age and all this and then, what about the changes in the solar radiation, how they affect the climate and all that and why the earth temperature is increasing now the average temperature is, is climate change real? Or this climate change is a very nee-jerk response; is it, is it scientific?

All those issues we look at it we look at them from we will try to put the whole thing down as a simple first order equation and okay or a 0 order equation and try to find out, okay; we will take a inertia or time constant of the system, we will see how long it will take for the earth to respond based on various what we call as force syncs, that is wave various forcing vectors these forcing vectors may be increase in carbon dioxide or this may be increase in carbon dioxide and this and many other things like that, okay.

And after going through the introduction we spend a considerable time on this atmospheric thermodynamics this is a very important part of the course, where we start from the basic, ME-1100 which all of you have undergone, all of you have taken this course, that is thermodynamics other colleges also they would have studied this thermodynamics. We start with gas laws hydrostatic equation. Then, we look at the first law of thermodynamics applicable to an atmosphere.

Then, the adiabatic process is a big deal, okay. Adiabatic process that is where there is no heat transfer adiabatic process is a big deal in the atmosphere and what is the difference, if you already thermodynamics is known to you, what is it big deal in studying thermodynamics again in this course. So, what is special in Atmospheric Thermo dynamics? You, that is okay, but looks beyond.

We are interested in thermodynamics of dry air or moist air? We are always interesting thermodynamics of moist air. There you did create cylinder and piston is always dry here. P is = Rho RT UD you did not worry much about the moisture content and all this excepting one course if you are mechanical student, refrigeration air conditioning where you looked at cyclone-metric chart, right where you looked at dry bulb temperature, wet bulb temperature and otherwise we have never studied moisture thermodynamics.

Moisture thermodynamics is very important, why moisture thermodynamics is very important because, let us take an air parcel, it is going up after sometime it will reach a temperature at which water will become ice. Okay. At that time, there is a chance that you can fall as rain or it can be a super saturated liquid, okay. So, there is something called lifting condensation level there are various terminologies which you have to understand, right. How this rising air parcel finally becomes precipitate sheds its moisture as precipitation and so on.

All these atmospheric processes will consider. Second law and entropy and we will also look at atmospheric dispersion, okay. Atmospheric dispersion is basically winds are carrying these aerosols and other things get dust for example there is something called the Asian brown cloud they are saying that we are pumping lot of gases from our power plants and all this; this is causing Asian Brown cloud over the whole. This thing and if somebody is seeing from the top using a satellite every, everything it is brown and they are saying that India is the culprit and all that.

But other people have already grown. We also have to grow, right so, right and our growth cannot be started stop this just because the others have achieved the growth but these are these are geopolitical consequences. So, let us not go into that. This, these are all policy issues, okay then, Radiative transfer the atmosphere, we look at the electromagnetic spectrum, radiation laws, then, physics of absorption, emission and scattering. This is very important, okay because the climate of the earth is controlled by the radiation balance.

The weather is mostly controlled by winds and other things, right. The climate is governed by the radiation balance now you have to understand the difference between weather and climate. Weather is basically, maximum up to one or 2 weeks. Climate is a long term you are looking at long term changes. So, if you have to so the frequently they will say why are you talking big about the supercomputers atmospheric science and modeling and all that.

You cannot even predict tomorrow's weather, how can you predict the Earth's climate after 30 years? This is a genuine question many people ask, right. You do not even tomorrow you say it rains, it does not rain. You cannot even predict tomorrow why are you staring at after 30 years this will be like that, all glaciers will melt, what do you think will be an appropriate response to that question or that criticism? Climate is an average quantity and climate is a mathematically prediction of climate is a boundary value problem, where the boundaries we know the conditions exactly.

The prediction of weather is an initial value problem in maths. So, it strongly depends on your initial condition. Suppose I have to forecast the weather tomorrow morning 8 o'clock in Chennai, I will use the present conditions as initial conditions and then, I will solve some non-linear governing equations, these are the laws of conservation of mass momentum energy or Navier-Stokes equation, equation of energy, equation of continuity and so on.

But if I have a problem with my initial conditions as you know nonlinear dynamics problem if there are any errors in the initial condition, the errors will propagate with time. So, if you predict for 24 hours, if you get some error, if you predict for 48 hours I will get even more error. If you predict for 72 hours even more error if you predict for one week it will be totally so what I predict will be completely, completely different from the truth.

But climate is lot easier to predict because it is average and climate is a boundary value problem, right because the solar suppose you, you are calculating the Earth's average temperature based on the solar radiation solar constant which is 1353 watts per meter square for example, amount of radiation per meter square falling on the earth it is not going to change from Monday to Tuesday to Wednesday, it will change but its time constant is so high. It is not going to change tomorrow or July or August or September.

So, it is it is easier to track the problem therefore when scientifically we study climate changes we are able to predict scenarios. Our confidence level is much more than the confidence level which we have in predicting weather events in 72 hours or 96 hours. So, regardless of our ability or the absence of ability to accurately predict weather, here we have to, we have to give it to the community, the atmospheric and climate modeler, that it is possible to predict the Earth's climate reasonably well, okay.

So, Radiative transfer in the atmosphere, planetary radiation budget, this is very, very important. So, many watts per meter square is entering, how many watts per meter square are going out as a reflection from the clouds, reflection from the surface, how many watts per meter square is going as evaporation, transpiration. So, if you do this energy balance then, we will work out quantities like how much is reflected that is called as a Planetary Albedo.

How much is reflected as a %age of incoming. So, if you can work out a planetary albedo for Mars, Jupiter, this thing and all that, and you can see whether the planetary albedo is changing and what is its influence on the Earth's climate, for example you can do calculations where if planetary albedo changes by 1%, 2%, 5%, what will be its effect on the Earth's average temperature in the five years, 10 years, 50 years, whatever, all right.

Then, this radiation is also important because the radiation can be used to the radiation of the Earth's surface can be used to remotely measure several things. For example if I keep a sensor on the top of a satellite and this sensor is a microwave sensor, the microwave sensor is capable, the microwave is capable of penetrating clouds, okay. So, if you look at the ocean from the top, even if there are heavy clouds the signature or the output which you are seeing at the top of the atmosphere gives a lot of information about the cloud structure and the water and the water vapor and ice, if any in the atmosphere.

Therefore it is possible for you to write down the radiative transfer equations assume some distribution of moisture and water and ice in the atmosphere and solve the radiative transfer equation and actually calculate what will be the theoretically measured radiance or radiation at the top of the satellite. But the satellite at that point is measuring something. These 2 will not match. Therefore, assuming that the measurement is correct I have to correct my assumption of the distribution of water, ice and all that.

I will keep on correcting till I get very good agreement between measurements and simulation. If there these 2 matches, then, whatever I have got, the profiles I have got are the correct profiles. So, this is basically a 2 minute course on remote sensing. This can be done using the infrared part of the spectrum. This can be done using the microwave part of the spectrum. Infrared cannot penetrate the clouds but infrared can give good information in partly cloudy situations and clear case situations. Microwave can good, can give good information in rainy situations.

This remote sensing originally in the 70's when people launched satellite, it was considered great to just look at pictures in the visible part of the spectrum. If you put images in newspapers and media and all that it was considered a great achievement, if I am able to see clouds from the top. But what is the difficulty with the visible imager? Just think. It is 2-dimensional is alright with all the things are 2 dimensional, that is correct. It is that is a good point. All are only 2D, any simple? You just see one layer may be the top.

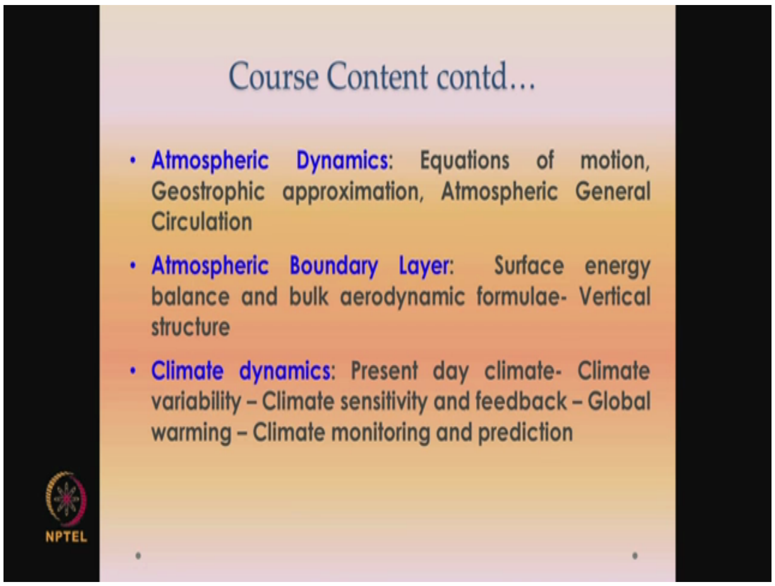
Third, night times you cannot see. Night them you cannot see. Infrared we will give 24 hours but infrared it cannot penetrate the clouds so infrared also we will see one top layer whatever is a top layer so we can get the temperature at the top layer if it is cloudy I can get the temperature at the top most cloud. Then I can from the topmost cloud, what can I do now? If I know the temperature at the topmost cloud now you think? Use a model what model yes it is not so difficult, totally good okay.

It is too early I will for you because you are not exposed to this. Assume that the surface of the earth is at 30 degrees okay you know there is called atmospheric lapse rate I will discuss this in later classes. That means in how many degrees centigrade per kilometer the temperature will fall. If it is known in that place, from the infrared, if you know the cloud top temperature that is the top of the cloud temperature, you know the surface temperature, you can actually work out the distance, based on this distance, you can find out whether it is high cloud, medium cloud or low cloud.

If it is a high cloud there is a chance that a lot of moisture will be there and therefore it is it there is a chance it will be a Thunder cloud or cumulonimbus or really heavily convicting precipitating cloud. If the top layer temperature is very high that means the cloud is very close to the earth then it may not rain so indirectly you can, you can figure out. So, like this and there are other things like invisible part of the spectrum also you can look at the same, you can look at for example the Western Ghats, and last 10 years you can find out whether vegetation has increased or decreased.

You can spot forest fires, okay. So, you can do lot of things with satellite technology, okay to understand satellite technology and use it in remote sensing you have to, you have to know get your basics and atmospheric science, right, All right. Then, Atmospheric dynamics;

(Refer Slide Time: 16:07)



Dynamics means how thunderstorm evolves? How does a tropical cyclone evolve, a typhoon, okay? Those kinds of things first you will have to find out. What are the governing equations what governs the dynamics of the atmosphere it is basically the fluid dynamic loss laws of conservation of mass momentum and energy then we briefly go through that. There is something called geostrophic approximation and then cyclostrophic approximation. We are in this big Navier-Stokes equation some inertia term some terms, you can omit.

And then make it simple and lead it lead to an approximation wherein first cut you can get how many meters per second will be the wind speed and all that, okay, if you are a, if you are very rich and if you have supercomputers, you can solve the problem in its full string. But sometimes wait take a AK-47 to kill a mosquito, right. So, if it is required, if it is required, you will have to solve it on the supercomputer.

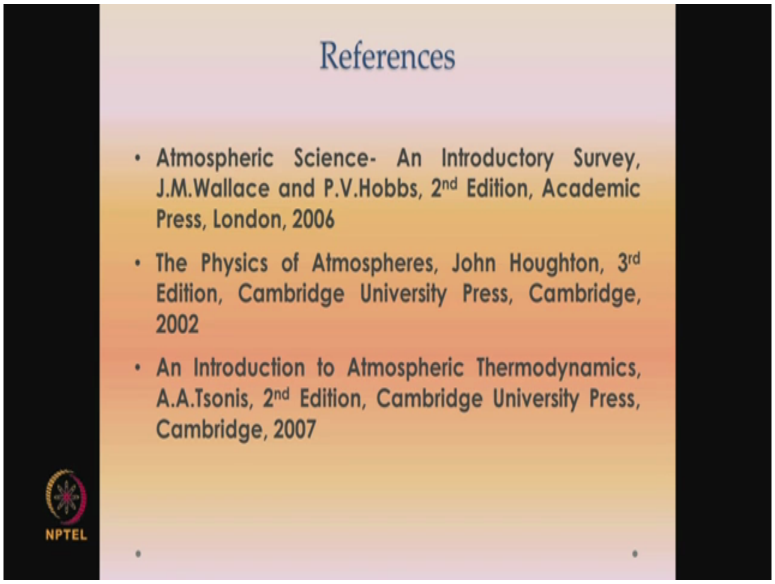
Otherwise can you do some intelligent back of the envelope calculations at approximately first order can you say whether it is 10 meters per second 100meters per second, ok. So, we need to get our fundas right in atmospheric dynamics. So, these ambitious I do not know how much we can cover in this 40 or 42 hours but this at least what should be taught in an atmospheric introduction to atmospheric science course.

Then an atmospheric boundary layer, you know that there is a boundary layer but the boundary layer the atmosphere. Any guess, what will be the height of the boundary layer? Normal boundary layer what will be the thickness 10 millimeter, 20 millimeter to the atmospheric boundary layer but 1 to 2 kilometers, ok. So, in that we will see we will kilometers, right in that boundary layer we love to look at various approximate formulas which can be used in the dynamics.

Then the last chapter is very important. The climate dynamics or the climate science or climate change, ok. First you have to look at what are the factors governing the present climate, what is climate variability and the sensitivity and feedback. That is what are the factors on which the climate is very sensitive to if we change these factors the climate will change, ok. So, we look at finally of course we will have to look at global warming; Global warming and then climate monitoring and prediction, all right.

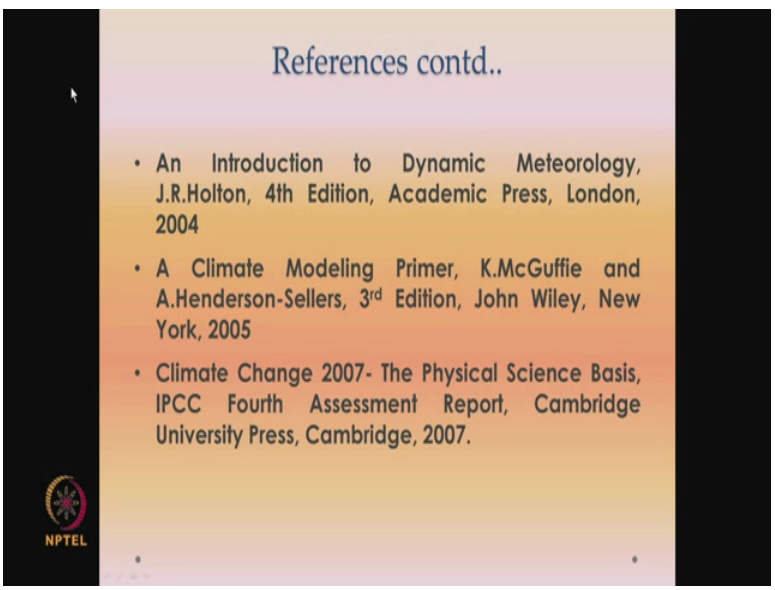
So, I have given this to you and I also sent it as email to the people who already registered, right. So, at the end of the, at the end of today's class I will note down names of people who have just joined. So, the references are:

(Refer Slide Time: 18:35)



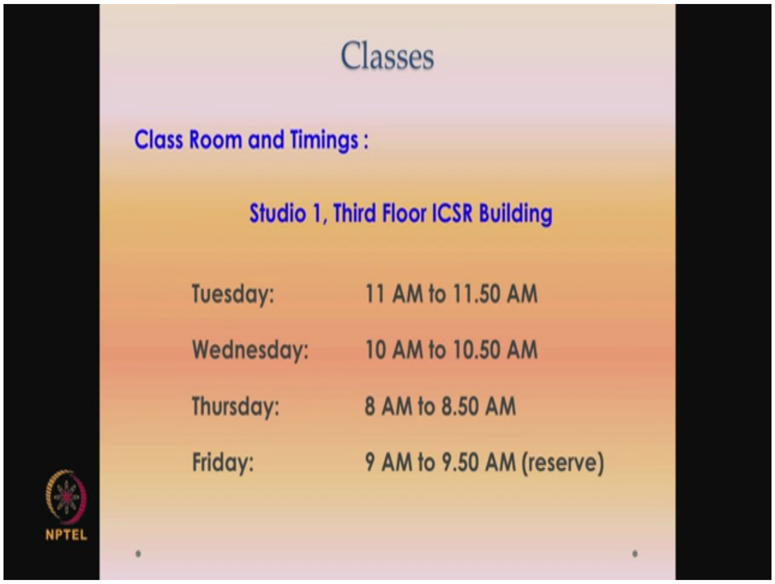
It is a very good book Wallace and Hobbs. It is like a Bible. I do not know whether enough copies are there in the library. So, if you get one just latch onto this any of these books, very good book. Then, the Physics of Atmospheres, John Houghton is also very respected meteorologist Introduction to Atmospheric Thermodynamics by Tsonis, any book on atmospheric physics of thermodynamics, we get it in the library just take it on long term.

(Refer Slide Time: 19:00)



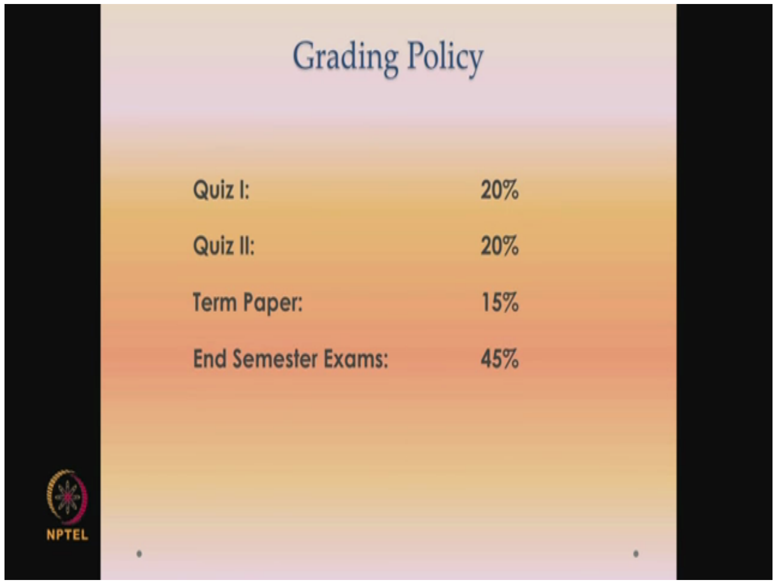
Introduction to Dynamic Meteorology where he looks at dynamics J R Holton, A Climate modeling primer, this will be, the last 2 books will be for the last chapter, okay. Then, there is something called the IPCC right Intergovernmental Panel on Climate Change IPCC. They give this assessment reports about climate prediction, climate change and all that. So, this 2007 climate change, 2007 the physical science basis book is also available, I have one copy if somebody wants you just you can take it for 1 or 2 weeks and return it back to me so that your other friends can use it. So, this climate change 2007 you can borrow it from me, if you want, okay.

(Refer Slide Time: 19:38)



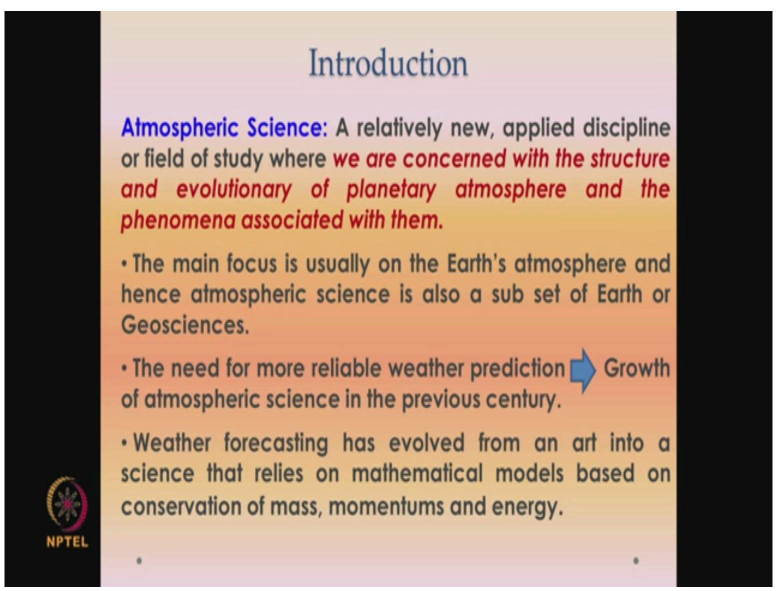
So, the classroom is basically studio one so Tuesday 11:00 to 11:50, Wednesday 10:00 to 1050 Thursday 8:00 to 8:50, Friday 9:00 to 9:50 is the reserved, okay. Do not give it to anybody else because of travel and other things if you miss classes we have to make it, make up okay but I will give you at least 2 3 days notice I would not tell on a Thursday that tomorrow please come, alright. Generally, it is 3 lecture meetings per week.

(Refer Slide Time: 20:05)



So, the grading policy for this course will be the first quiz will be 20% the second quiz will be 20% we you will all present a term paper I will divide it into groups of 2 or 3 I will select some topics I will give you some topics then you choose among the one among this and then you will have to present you will have to give a term paper and also give a presentation. And everybody else will be there so we will evaluate you and that will be for 15% and End semester will be 45, okay. All quizzes and end semester will be open notes, okay.

(Refer Slide Time: 20:35)



Now let us get into this Atmospheric science. I am using the PowerPoint basically today to cover ground introductory material, material otherwise I have to write a lot. We will quickly switch to chalk and talk so that is my preferred mode and then please bring calculators to every class mostly we every class will be working on problems, all right. So, atmospheric science is a relatively new applied discipline. It is not as old as civil engineering or mechanical engineering or so on. So, atmospheric science courses might have started out maybe last 50, 60, 70 years. It is not even a century old, right.

So, where for example the Guindy Engineering College is 250 years old, you know, right across the Civil engineering in Anna University is about 250 years old, okay. So, they read rain it started as a survey school by the British, alright. So what is the atmospheric science? You can take down this if you want. Atmospheric science is concerned with the structure and evolutionary and evolution, evolution of planetary atmosphere, where is this delete now, where we are concerned with the structure and evolution of planetary atmosphere and the phenomena associated with them, okay.

So, you can do atmospheric science of Mars, Venus, Neptune and Pluto, whatever. But in this course, we are looking at the atmosphere of the earth okay. So, that is interplanetary science or planetary science, that is beyond the, if you want to do that, you have to go to some other place. We cannot do that in India. If you want to if you want to research an atmosphere of the Mars, of Jupiter you have to go to Oxford or Cambridge or some of these schools, all right.

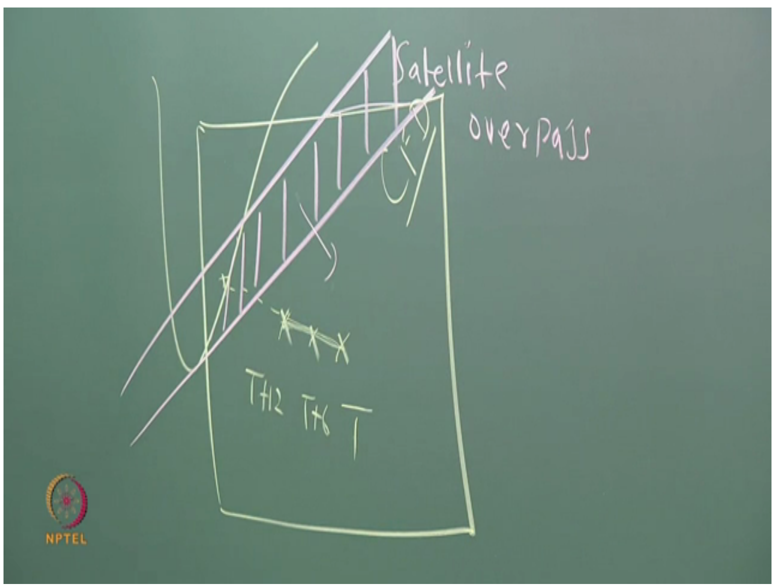
So, the main focus is usually on the Earth's atmosphere. In atmospheric science is also a subset of Earth or geosciences. Earth science is a much broader term because the earth science will include several things, okay. Geology, geochemistry, geophysics, atmospheric science, ocean engineering, ocean sciences, atmosphere, ocean coupling, all this, right; Why did the atmospheric science, why did that matter how did the atmospheric science develop as a separate subject?

The answer is already there. There was a requirement of reliable and accurate weather prediction may be over cricket matches or something, I do not know. Our agricultural production, monsoon whatever but that is Indian but West I do not know why they wanted it. So, but people wanted to know about the weather, okay. So, the demand started, the study started with the demand for a knowledge or need for reliable weather prediction.

So, weather prediction has hopefully evolved from an art into a science, okay. Now, weather prediction is based heavily on mathematical models it is not just based on some instruments and charts and it is not an extrapolation of the previous year's this thing. Are you getting the point? There is one way of; for example I will give you another 2 minute course on statistical forecasting, okay. Now, let us say we want to there is a cyclone which is formed in the Bay of Bengal. There is a satellite which is seeing this.

So the eye of the cyclone is the place in at the center, the eye of the storm is the place of the lowest pressure, where all the winds are converging so, right so that from where you can you have seen satellite pictures of what X and all that. Now let us say that every 6 hours or every 4 hours you are seeing the satellite picture and then in 24 hours you are actually recording, ok.

(Refer Slide Time: 24:43)



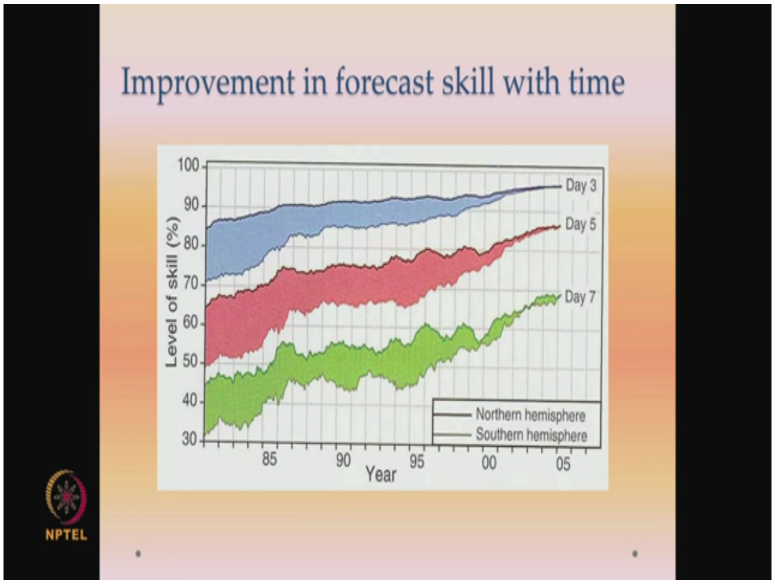
T so this is the position of the eye, at time T. T+6, T+12. Then, they are joint base straight line. Like 2 points and you do not paint me that serve you can join the best straight line right otherwise 2 points are in straight line. Now statistical forecasting is, if you have these points, last hundred years you looked at cyclones and if you look at the average and then in 12 hours if something has gone like this then they will extrapolate this and say that T+18, T+24 it will be like that based on an ensemble average of already available data.

This is brute force statistics. That is a statistical forecasting but suppose you have this you have this position you ingest this position and then let us say you take this domain on solve CFD equations on your supercomputer then you are doing mathematical modeling and weather forecasting, okay. So, this is a quick fix. This is a crossing for every fever, this is this little more there is a antibiotic and even more deeper I think you find out what is this. But even then here also there are lots of approximations okay.

And the whole idea of suppose there is a, there is a satellite overpass, microwave satellite so in this region it is giving good information right on microwave. Suppose you incorporate this information into the model then you are doing even better. That is called assimilation. You assimilate or ingest or inject observations whenever you have whenever you inject observations which are closer to truth or the truth itself.

When you are into a mathematical model, generally, it is it is expected to improve things, okay. So, weather forecasting has now evolved from an art into a science that relies on mathematical models based on conservation laws of mass momentum and energy.

(Refer Slide Time: 27:27)



A very important slide: This is from Wallace and Hobbs the level of skill is is determined by how accurately are able to predict it event. How will you measure quantify this level of skill? They usually done by something called not forecast, Hindcast.

(Refer Slide Time: 27:51)

Last 10 years you look at all tropical cyclones use your models and predict actual truth will be there after the cyclone has crossed. So, this can be your variable can be the quantity you are using may be where the cyclone hits the Indian coast? What is the error in the geographical location of the okay? This is called landfall. That means where it hits the land so you can take the error so in the kilometers, okay, so then, if you see error in kilometer by this thing that will be this % that will be the skill.

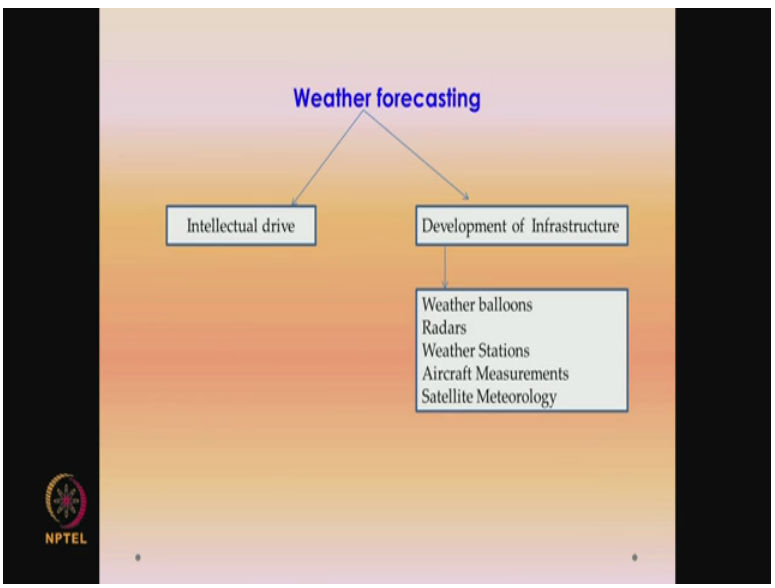
100 % skill will represent 0 error, okay. So, you can see that the day 3 forecast it can be for a precipitating system, monsoon or average climate or average weather whatever. So, day 3 forecast has increased like this. Day 5 is increased like this. Day 7 is increased like this from the 80s to the data is up to 2007 or 08. Now, a couple of quick questions: What do you think it is like this? Why is day 7 lower? Error propagates with time, very good right.

Now, northern hemisphere is more southern hemisphere is less with the within the day 3, day 5 and this Babu, is there any pointer? Mouse. So, this is the northern hemisphere, this is a southern hemisphere. Now, tell me why is it like more landmass in northern image so what? Do not say mean land northern hemisphere is more advanced that is correct actually. Northern hemisphere is more developed that is okay.

Because of that they have more instruments more measuring instruments and all that and that is one thing. Secondly, more landmass in the northern hemisphere so more weather stations. Data is deficient in the southern hemisphere, okay. I would not talk about funda level and all that that will again this thing we cannot have convergence on that.

So, generally but now that is also decreasing, right. So, once satellite technology is coming and high hype or mathematical modeling is coming all these differences are going down, okay right. I will send you this if you can identify a class rep I will send you this PDF to one other persons one student in the class then who can just send it as a group mail to all the students, right. If any PowerPoint I am using I will share it, alright.

(Refer Slide Time: 30:40)



Weather forecasting basically you want to know the future; forecasting is very intellectually stimulating, right. So, it gives you some intellectual drive. And also there is an absolute need from governments and economies and this thing, policymakers. For example, India's gross domestic product is a strong function of how good this monsoon is. So, the government wants to be ma modulus and meteorologist to accurately predict beforehand so that they can take some emergency measures.

A Food Corporation of India you can store more grain, this thing, all this is possible. We are not talking about geo-engineering where we take planes and put silver iodide and create rain and all that. We do not know what those solutions will work or not. But for preparedness, in the case of a drought or in the case of a heavy rain, heavy monsoon, floods, loss of property, loss of life, in all these cases. So, we want to be able to predict the future reasonably accurately. So to do that, you have to develop infrastructure.

What is the infrastructure which is required for weather forecasting, weather balloons okay? The World Meteorological Organization had set a standard. There are 2 times once in the morning and evening the same time all over the world. The same time all over the world all weather stations will launch balloons. This balloon will have instruments which will measure the humidity, temperature and so on.

There will be error because from Chennai Meenambakkam Airport, you send the balloon what is the problem after some height, it will drift but we do not go to Malaysia or Singapore, right. So, it will be a few hundred meters or okay depending upon the wind and all that. But so, so it will reach some level and you will get those readings. And these are sent to the ground stations, okay and WMO ensures that all weather stations in the world share this information.

So, this information is available this basics, okay. Then, radar, the radar is an active instrument where you send it radiation and from the reflection, you try to understand the situation, okay. Now, there is a radar on the marina, next time when you go, you should see. It is on the Chennai port trust building opposite to the Reserve Bank of India on the Marina Road. If you see there will be a white colour spherical dome. You have seen on the Marina Beach next time you see that is the DWR Doppler weather radar of Chennai, okay.

So it will open up and then it will scan when it scans, okay so it will send some radiation from its place to the sky. Now, if no radiation comes back what will be what is the rain? No clouds, no rain, very simple. If there is heavy rain it will get reflected so depending on the size of the raindrops and the thickness of this layer so you will get a different signature of the reflected radiation. So, radar is radar can also be used to hunt down aircrafts, this thing, missiles and all this.

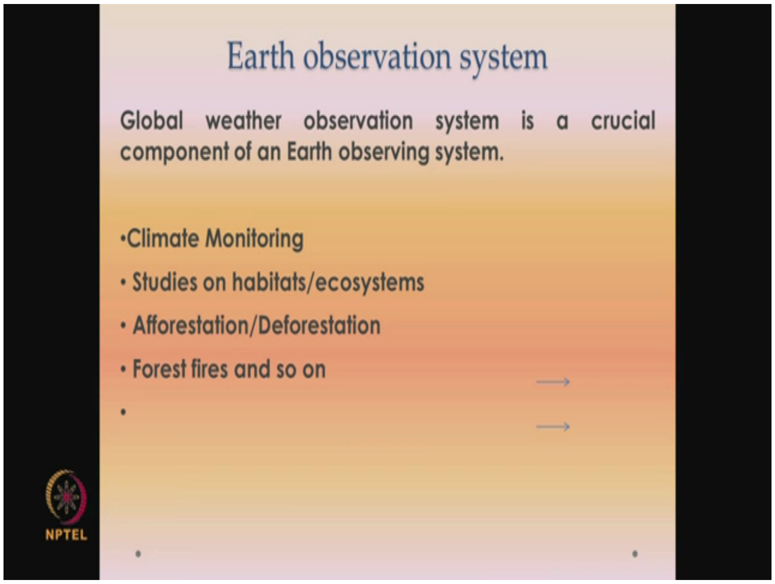
But for civilian for weather application this is very useful to, very useful for short-term weather prediction called now-casting. All commercial airplanes have this radar okay. When they are going through turbulence, the pilot will get an idea whether he can pass through that or he has to take a detour, okay. Radar weather stations, okay.

There is one weather station near the stadium our stadium IIT Stadium, okay. That now we also have what is called AWS automated weather station where it will measure basic parameters like humidity, wind speed, temperature and so on and transmit this data to some server, okay. Aircraft measurements, okay: You can have you can actually go in airplane and make measurements.

And actually, you can I, you can actually open out and then take a sample, take a sample and measure, all this, error so all this thing, in all this, there are also hurricane hunters in the United States where they get into the storm. Indian Air Force we have not done so far. They get into the tornado or the storm and then they collect vital measurements these are very important to improve our models because models assume them microphysics models assume how these droplets are coalescing and right.

How the rain starts and all these physical processes which are represented in those equations depend on these measurements. Of course satellite meteorology, if you are studying weather through satellites it is called satellite meteorology so this weather forecasting has led to lot of develop, development of infrastructure in all this. Apart from models we use all this to study weather.

(Refer Slide Time: 35:40)



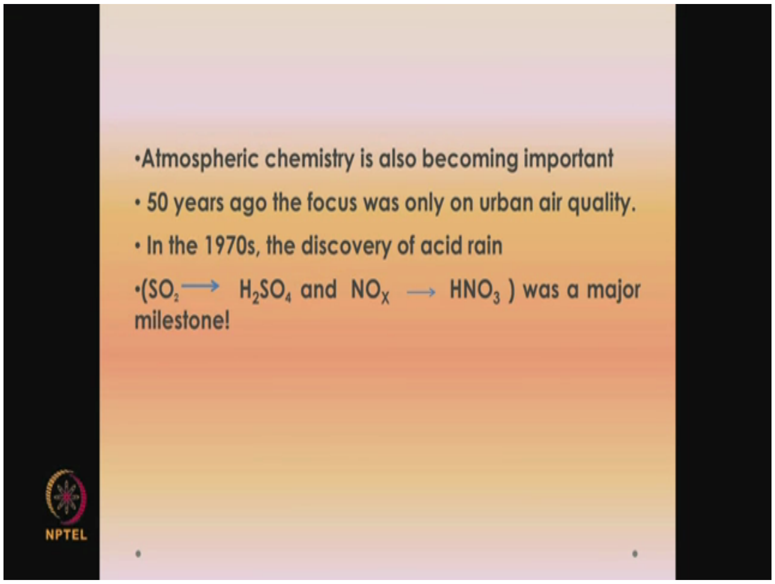
So, in so, if you look at a holistic picture of a earth observation system, the weather is the weather observation system is very, very important component. But it is not the only component for the Earth's climate monitoring system. That is climate monitoring system you have to for many, many decades you have to monitor the carbon dioxide concentration and you can also look at isotopes, okay or you can go down and get samples of ice.

Carbon dioxide will be trapped in that okay. Depending upon the height, you will the height of the ice, can be correlated with the time, okay. And then, against this time, if you measure the carbon dioxide you can see how carbon dioxide has changed with time. So, a lot of fundas are there. Then, if you look at isotopes and you can go back to ice age and this thing this study is called Paleo-climatology.

So, this is vast this thing it is not just balloon and satellite and that is weather system. Earth observation system is much more; okay much more detail, right. So what are these various components of this? You can do climate monitoring that is a part of the earth observation system. You can, ecologists are interested in studies on habitats. Habitats of light or a habitat of elephants in the Nilgiris, there is some Professor Sukumar from IIT Bangalore. Whole life, he is studying elephants.

The professor of ecology, elephant habitat how our human intervention, how they have been marginalized, why they are away they are coming out and sometimes they come to the middle of the road of the rain, okay. So, studies on habitats, ecosystems, afforestation, deforestation, forest fires, how these things are linked to rainfall or droughts and so on forest fires, right. Forest fires and all these are part of the earth observation system.

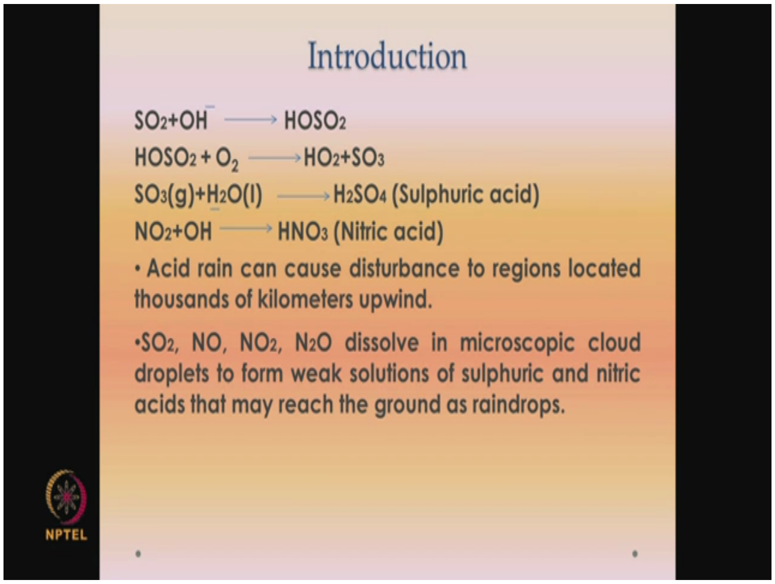
(Refer Slide Time: 37:33)



Atmospheric chemistry now if you see I am just giving a broad overview of the various facets of this science. Atmospheric chemistry is also important; you must have studied in your chemistry that acid rain, right okay. We look at what this acid rain is 50 years ago the focus was only on urban air quality. You say that people are looking at respiratory diseases, okay.

That was the only concern afterwards in the 70s the discovery of acid rain the sulfur dioxide becoming sulfuric acid and the NOx the nitrous nitric or nitrous oxide becoming the nitric acid this was a major milestone is an important thing, okay.

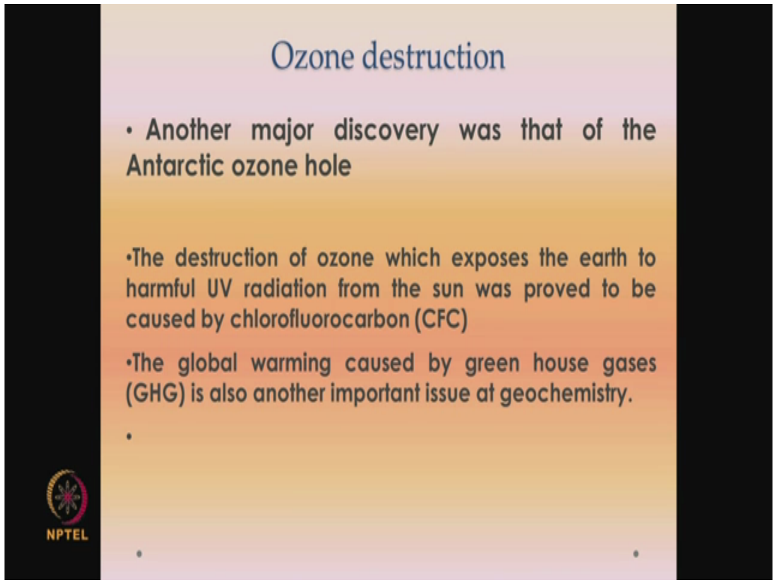
(Refer Slide Time: 38:15)



These reactions you know SO2+OH - gives HOSO2. HOSO2+O2 gives this HO2+SO3 and finally it becomes Sulphuric acid then NO2+OH gives HNO3 nitric acid. So, acid rain can cause disturbance to Regions located thousands of kilometers upwind because there is no visa required by clouds. They can form in Arabia come to India from India they can go to Singapore anywhere no visa required no fly plate flight ticket is required. They just move with the winds, okay.

So, therefore acid rain is an international problem, okay. So, SO2, NO, NO2, N2O what we endured dissolve in why is acid rain form because these gases which are mostly released okay which are mostly released out of power plants and all this, they dissolve in very small cloud droplets to form weak solutions of sulphuric and nitric acid and then when they rain along with the rain they also come down as acid okay.

(Refer Slide Time: 39:17)



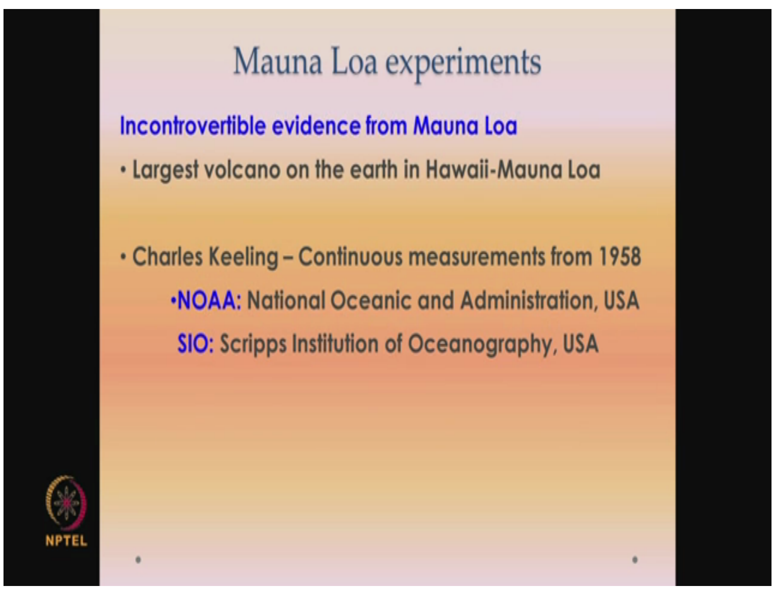
Ozone destruction, all of you are aware of this, another major discovery was that of the Antarctic ozone hole. The destruction of ozone hole which exposes the earth because ozone protects us from the harmful ultraviolet radiation correct from the Sun was proved to be caused by chlorofluorocarbon and then they had an agreement and then CFCs were removed from our Refrigerators. Now, you have got cfc-free refrigerators like R134A refrigerator is something which is new. Previously they were using R12 or R22 after this. This is Montreal Protocol is it?

I do not remember some Montreal Protocol they all agree, everybody agree that we should have cfc-free refrigerant and the global warming now it is making lot of noise. Global warming is caused by green house gases. Greenhouse gases are frequently referred to as GHG greenhouse gases and group they cause global warming. It is also another important issue affecting geochemistry.

(Refer Slide Time: 40:12)

Emergence of new fields: Climate dynamics is also an emerging field within the broad area of atmospheric science and availability of realistic data and evidence is the need of the hour. I think there is a problem. Cores and computers, we require lot of this, have all contributed to climate modeling and climate change becoming available to real estate data and evidence. What is this? My system typed it. I have to fix it okay.

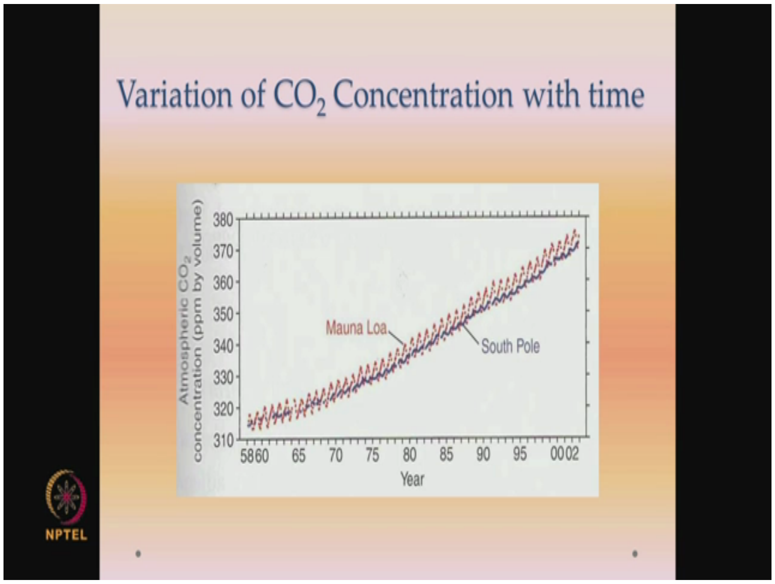
(Refer Slide Time: 40:43)



Now, let us, the last part of this lecture, there are measurements of carbon dioxide machine continuously from 1958 by a person called Charles Keeling okay and now because at most carbon dioxide is very dispersed in the atmosphere it is proved that if you measure carbon dioxide at one place, in the atmosphere, it is the same more or less anywhere in the earth.

Therefore a measurement at one place can serve as a proxy as a globally average carbon dioxide concentration. So this place is in Hawaii called Mauna Loa. What does this say?

(Refer Slide Time: 41:25)



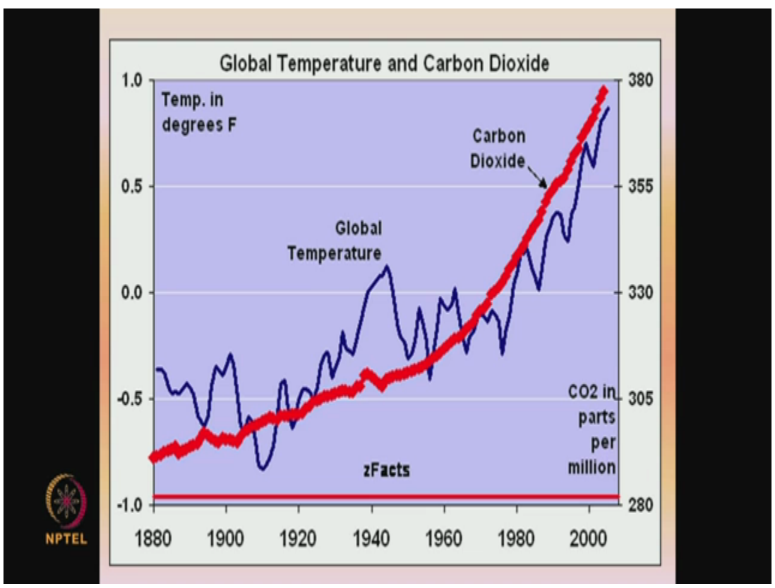
This is from 1958, okay. So, Mauna Loa on South Pole; both are the same and why is it fluctuating within that. This is a small fluctuation now within a year, there is a, what is the reason for that? Not weather. The seasons; photosynthesis and this thing some in autumn there is no there is no relation on photosynthesis and all that so that causes the carbon dioxide within limits. But you can see the atmospheric concentration which was 310 parts per million ppm in 1958 is now 370.

So, when you are actually doing weather models, radiative transfer modeling, now we have to use this 370 when a when you run the model after 10 years you may use 400 or something, okay. So, this is the variation of CO2 concentration with time, okay. So what?

(Refer Slide Time: 42:23)

Okay sir let it let it increase generally everything increases, so what how can you say that how can you prove it, yes the answer is here.

(Refer Slide Time: 42:54)



The global increase of carbon dioxide is given by the red line the main global temperature of the earth if you take the mean global temperature you have some averaging procedure properly average that follows the blue line. The trouble is they are very strongly correlated they follow a very similar trend. Therefore there is enough reason to there are enough reasons to believe that there is a strong correlation between the carbon dioxide and the global temperature increase.

And this carbon dioxide concentration now is much, much more than the last 2000 years and it is only in the last hundred years that we have invented the IC engine, the power plants, the aircraft all of which use fossil fuels therefore more fossil fuel burning has led to more carbon dioxide concentration more carbon dioxide concentration has led to more absorption which we can prove from radiative transfer principles and this causes this core so called greenhouse effect.

And therefore this is a the writing is on the wall it is a clear message that we will have to somehow have carbon dioxide mitigating technologies, carbon dioxide sequestration whatever you should have technologies which will limit the emission of carbon dioxide battery cars, hybrid cars whatever right. So, foot of solar photovoltaic technology where we where we actually RG mechanical engineering that is you bypass you bypass the heat engine okay.

So, you do not burn a fossil fuel and try to do that right. So, this is a very important this is actually a very important figure where we are able to correlate global temperature with carbon dioxide okay thank you so we will close. So, we will meet on Tuesday 11 o'clock any questions. So, what is so what I am saying is the carbon dioxide concentration I can put it in the radiator transfer model in the radiator because of carbon dioxide it will increase some property like absorptivity of this thing emissivity whatever.

Then we can show that with increase in carbon dioxide this emissivity absorption increases with increase in absorption this it will that we can prove okay, any near the question okay, thank you.