Introduction to Atmospheric Science
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Lecture - 40
Climate Change

So in today's class, I will present to you a quick overview of the science of climate change. Some of the aspects of climate, weather, climate sensitivity, feedback and all that we have already seen on the blackboard. So this will just give an overview and summarize the whole thing and the research, which has been going on.

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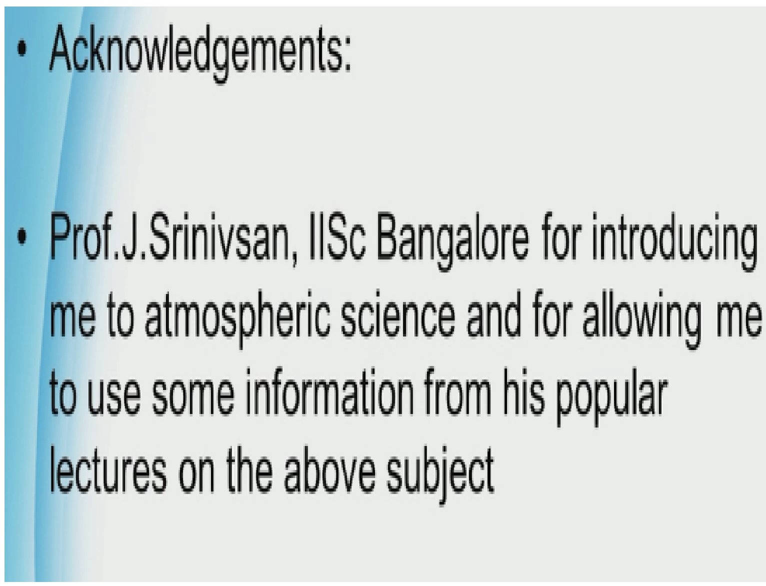

So I would like to acknowledge the support of process J. Srinivasan of the Indian Institute of Science, Bangalore with whom I have been spending many of my summers, the last 10 years of my research life for introducing me to atmospheric science and for allowing me to use some information from his popular lectures. A significant portion of today's lecture is from his slides and he has allowed me to use this.

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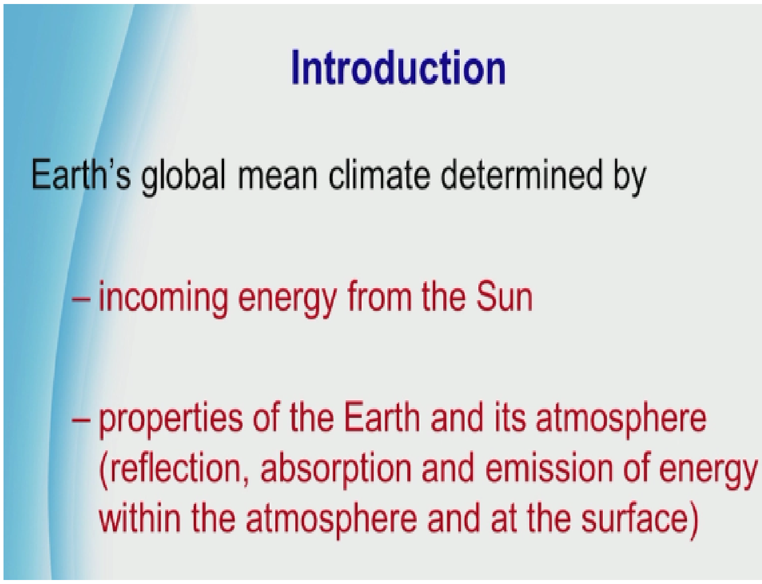

So the Earth's global mean climate is determined by the incoming energy from the sun. We have already saw this yesterday and properties of the earth and its atmosphere largely the albedo, the reflection, absorption and emission of energy within the atmosphere and at the surface.

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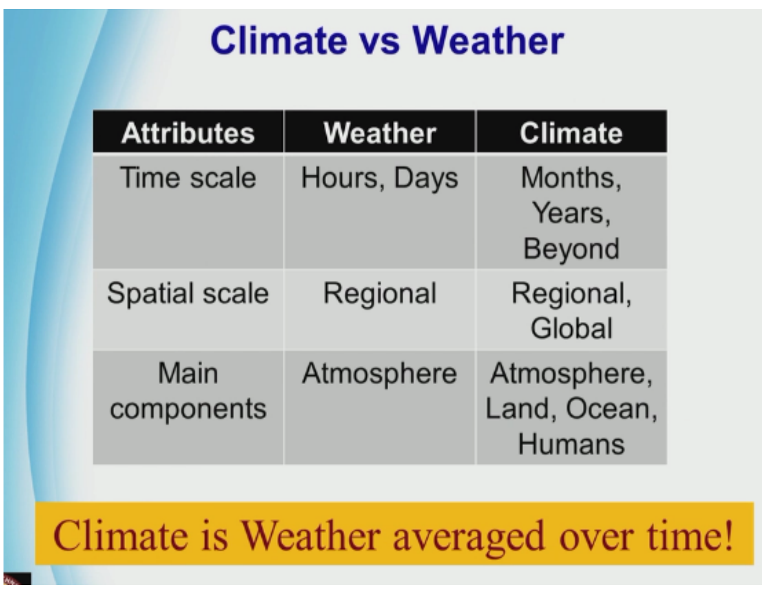

So if you look at the attributes, spatial scale and main components and try to study both climate and weather with regard to these attributes, time scale as far as weather is concerned is a few hours or days. Climate you generally talk about timescales of months, years and beyond. The spatial scale is basically regional. The climate is a regional and it can be global also. The main components which of the earth system which determines the weather is basically the atmosphere.

But the main components, which determine the climate are apart from atmosphere, the land, ocean, human beings and so on. So in simple English, in simple terms climate is weather average over time. The integrating period is sufficiently longer, at least two weeks.

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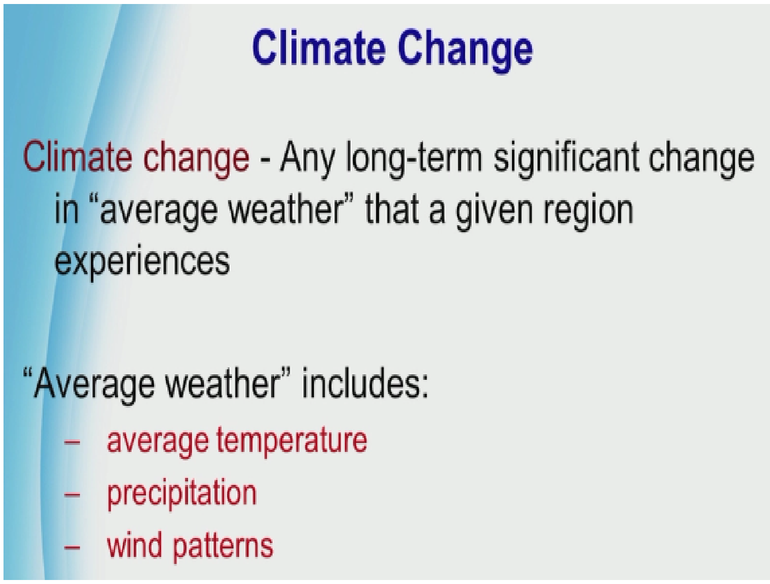

So what is climate change, any long term significant change in average weather that a given the region experiences. So climate change means you take the averages and suddenly there is a change in the averages, then you talk about climate change. The average weather includes average temperature, average precipitation and wind patterns. So this is the average weather in a particular place.

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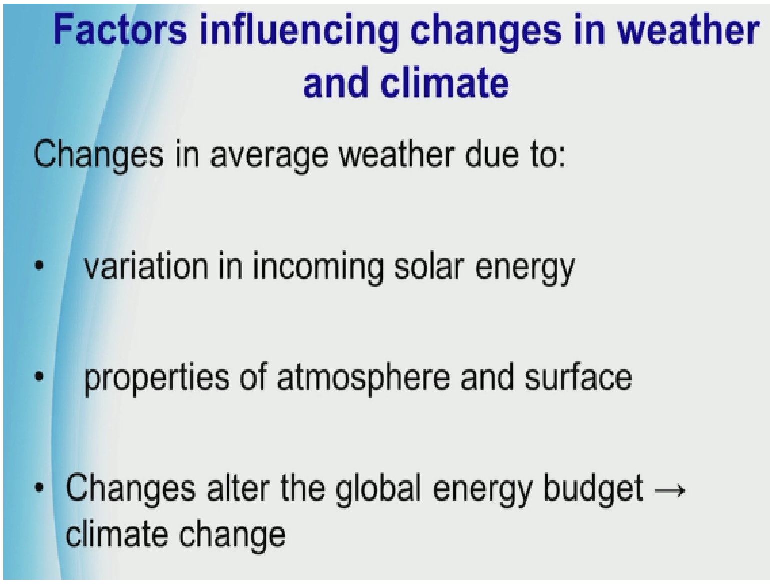

What are the factors influencing changes in weather and climate the changes in average weather are due to variation incoming energy, that is the sun's radiation either the eccentricity is changing or you have sunspots which lead to reduced temperature of the photosphere or the earth-sun distance is changing for whatever reason? So then so there is variation incoming solar energy. The properties of the atmosphere and the surface if they are changing.

Why is the properties the atmosphere can change? Carbon dioxide can change, water vapor can change, methane can change, why should the surface change. More ice can melt, albedo can change and forests can be cut, the green cover can be reduced. Many possibilities are there. These changes actually alter the global energy budget. The global energy budget is how many watts per meter square, 239 watts per meter square is coming or 340 divided by 0.7 342 is coming, what is happening to this?

So this radiation budget, if it is altered then it results in climate change.

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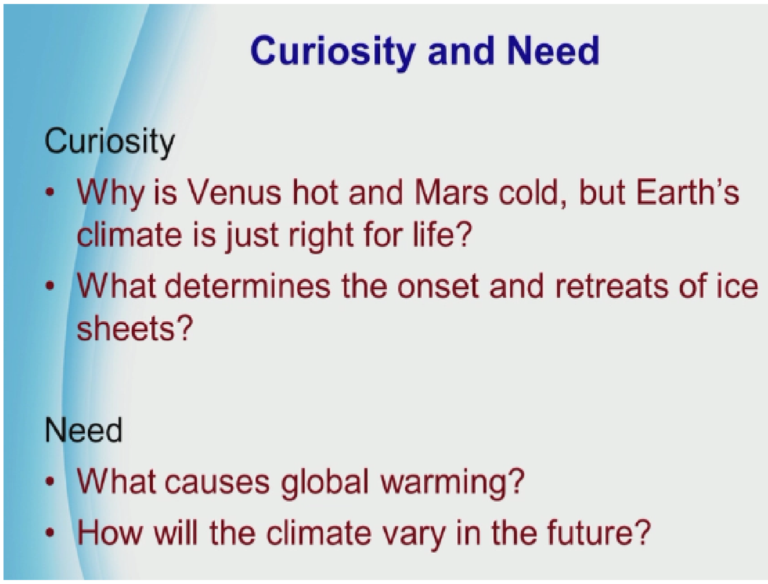

Why do you want to study climate science and climate change? Basically there are 2 things, the first the scientific curiosity and there is also a need. First let us see the scientific curiosity. We want to answer questions like why is Venus hot? Why is Mars cold, but the Earth's climate is just right for life? Why should it be so? Why should the earth's temperature to be like this? What determines the onsets and retreats of ice sheets? Why is the snowball earth not taking place?

Will the ice age return? Apart from being subjects of movies, we also want to feel curious in trying to find answers to these questions and there is also a need what causes global warming and if we are able to identify what causes global warming, can we put them together in a model and then project future scenarios based on some, the world's economy is going at this GDP rate for increased GDP rate.

The fellows will continue to burn fuel fossil fuel at this rate, the reduced rate, increased rate. So you have various scenarios and project into the future. So what will be the temperature in 2050, 2075, 2100, then you are talking about the science of climate change, not 2015 or 2016. That means it is just an extrapolation. You are talking about 30 years, 40 years, 60 years, 80 years from now. How will the climate vary in the future?

We want to be able to understand and predict how the climate will vary in the future?

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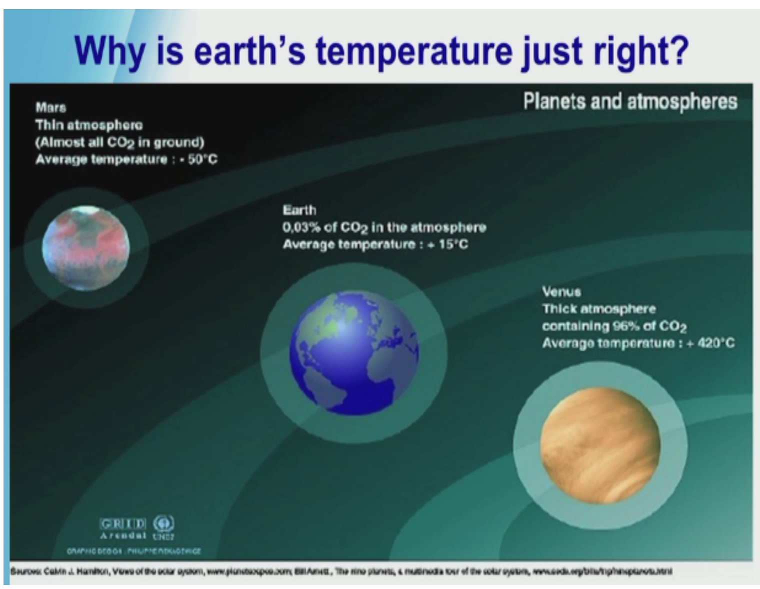

Why the earth's temperature is just right? The Mars has a very thin atmosphere almost all the CO2 in the ground. So since the CO2 is not there much in the atmosphere, the average temperature is -50 degrees centigrade. If you go to Venus, it has a very thick atmosphere. It is containing 96% carbon dioxide, because of which the average temperature is +420 degrees centigrade. Both -50 and +420 or not conducive for the sustenance of life, plant life and animal life.

If you look at the earth, 0.03% of carbon dioxide in the atmosphere which is like 300 ppm, now it is like point 0.39%, average temperature is +15 degree centigrade. So a lot has to do with the carbon dioxide. So for carbon dioxide to form not only should carbon be there oxygen should also be there. If enough oxygen has to be there, sometimes where is oxygen coming from? We figured out that oxygen cannot come from photosynthesis alone.

There is some redox reaction which is taking place in the Earth's mantle. We went through all this. So there are theories of it. So there's something called abiological earth. In the abiological earth, the oxygen was very less. Originally, the earth was forming the oxygen is very less and this photosynthesis, blah, blah, blah we are not in a position to account for all the oxygen or we are not able to account for the current oxidation state of the earth.

So we solved problems you remember. So if we consider all these to be initial value problems in physics or engineering where in, they all started cooling from some initial condition, why would the initial conditions of Earth be so chosen that now we are having +15 degree centigrade, which is so conducive to human life. Is it George's probability or there was somebody who decided that this will be the initial condition. We do not know all that.

So the factory means that if the initial conditions were different. Things could have been much different now. Who decided the initial condition? I do not know. If I say the next sentence, then it may be going out of science.

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TABLE II. ATMOSPHERIC COMPOSITIONS OF MARS AND VENUS COMPARED WITH AN ABIOLOGICAL MODEL EARTH.

COMPONENT	MARS	ABIOLOGICAL EARTH	VENUS
CARBON DIOXIDE	3-7	0.3 - 1,000	6×10^4
NITROGEN	0-5	TRACE	< 400
OXYGEN	$< 10^{-2}$	TRACE	NONE
WATER VAPOR	≤ 0.1 (VARIABLE)	0.3 - 100	1-100

PARTIAL PRESSURES ARE IN MILLIBARS AND ARE APPROXIMATE.

All right, so this table gives you an overview of the atmospheric compositions of Mars and Venus compared with an abiological model Earth. Mars 3-7% carbon dioxide. Venus is in ajar 6 *10 to the power of 4, nitrogen, oxygen. Nitrogen is 0-5 for Mars. abiological earth it is trace and Venus is >400. Oxygen >10 to the power of -2, on Venus it is none, abiological earth it is trace. Now water vapor also is given. So the partial pressures are in millibars and that they are approximate.

Do not worry about this, this some abiological model earth. Immediately do not say 77% is there, 78%. Very important slide.

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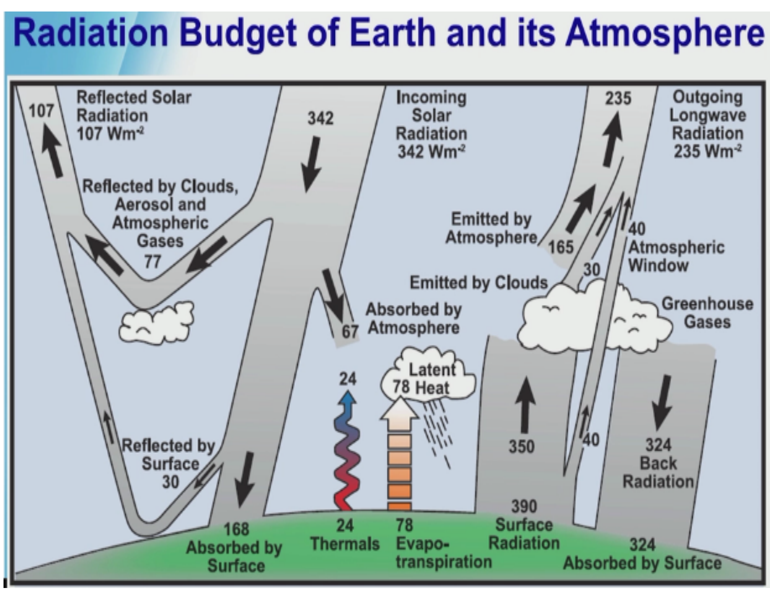

I will have it converted to PDF and I will post it to you. Take a look at it, the incoming solar radiation is 342 watts per meter square. We are always using 239.4 in the calculation, 239.4 is 342*0.7. All right, out of the 342, 107 is reflected, so which makes it 235 or 239 whatever. That is the incoming. So this 107 is the reflected solar radiation. I am looking at this incoming solar radiation is 342. This is called the radiation budget of the earth and its atmosphere. 342 watts per meter square is incoming, reflected is 107, 1/3 where is this reflection coming from?

77 is reflection by clouds, aerosols and atmospheric gases and the remaining 30 is reflection or this thing from the clouds. Where is the surface? Reflected by surface. So 77+30 is 107. 107/342 is basic to the reflectivity. All right then again this if 107 goes, remaining 235 is there, then 168 is absorbed, then 67 is absorbed by the atmosphere, 168 is absorbed by the surface. Then there is a lot of things, which are going on at the surface.

Thermals hot winds 24, evapo-transpiration from plants, latent heat, then surface radiation, then emitted by the atmosphere, emitted by the clouds, emitted from the surface through the atmospheric window which is unobstructed, then this will give 165+30+40, which is 235. 235 is the OLR, outgoing long-wave radiation. So this is the energy balance of the earth. So if the carbon dioxide concentration changes, if the aerosol concentration changes, if the incoming solar radiation changes, if the absorptivity changes, everything will change.

Everything will change; the equilibrium temperature will change. So you already saw how it will change, 3.76 watts per meter square are required for 1 Kelvin, but this 3.76 watts per meter square at 10:15 if you apply 10:16 the temperature will not change. How it will change also we have seen in yesterday's class. So there is a MCP. I did not take the MCP of the atmosphere in yesterday’s class. We took MCP of some ocean mix layer, but we figured out there are 2 parts of the curve.

Initially the response is very fast, then it becomes sluggish. So there is a time constant associated with this. So this Q dash into lambda the full effect will be felt only at that in finite time. This infinite time can be few months for our atmosphere, a few decades or centuries or so for, four years for ocean and centuries for ice. So we can keep on talking about this, but now I hope you got an idea incoming and outgoing balanced.

How you have portioned it into various processes. So this basically temperature versus pressure equilibrium diagram.

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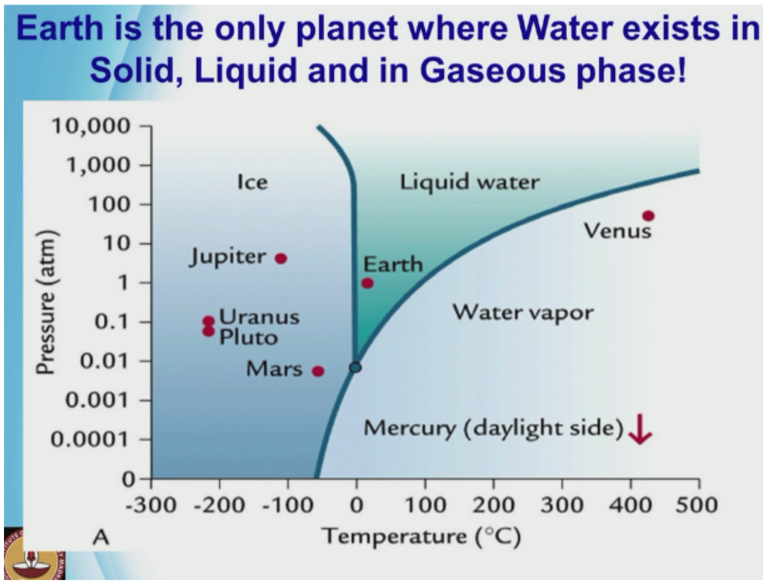

Earth is the only planet where water exists in all the 3 phases, did you know that? Solid, liquid and vapor, ice, water, water vapor. So that is here. So it can earth it can be like this. Liquid water ice and Venus. Venus is far here. So everything is only water vapor. Jupiter, Uranus, Pluto, Mars all these are existing. Everything is existing ice.

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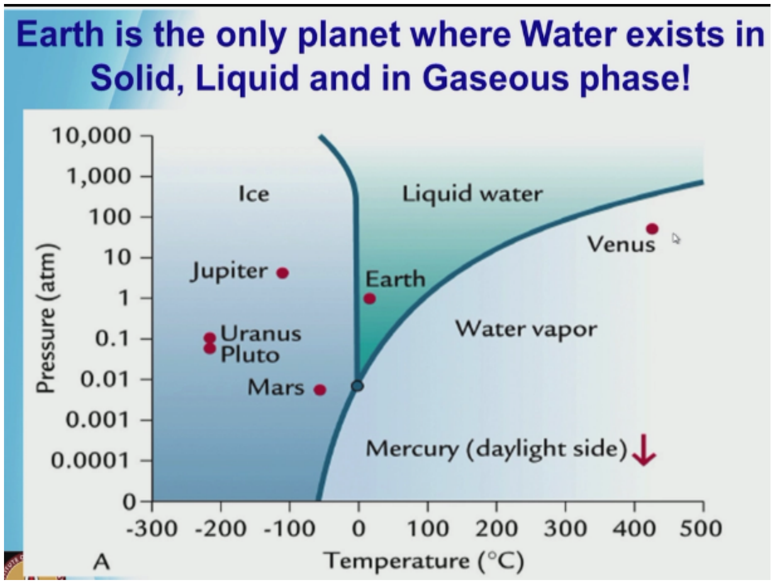

Earth, the habitable planet, let us see why the earth is a habitable planet. The range of temperatures on Earth has allowed the possibility of oceans to remain unfrozen during most of Earth's history. Oceans as you have seen because of the large mass and specific heat an excellent chemical and thermal buffer. If you dump your heated cooling water of power plants into the ocean, we keep on doing it, because it is so big. Its temperature is not changing much.

That is the assumption. Earth’s distance from the Sun has allowed most of the hydrogen to escape. We have seen that. This has allowed oxidation of minerals in the crust and the mantle and this redox reaction is crucial for the abundance of oxygen, which is of 21% or 23% depending on whether you do volumetric or a gravimetric analysis without this 21 or 23%, it is not possible for sustenance of life.

The earth also sustains an active hydrological cycle. Water gets evaporated becomes cloud, then winds bringing it back, rain this thing rivers runoff. All these things are possible. Because of the temperature conditions also that it is possible for it to exist in 3 phases. The bigger planets are outer planets, deflect away comets from the earth. The strong gravitational pull of the moon limits the obliquity of the axis of the Earth's rotation. It is under control.

It has a rotation rate just right to prevent extreme daytime and nighttime temperatures 24 hours on an average 12-hour day and 12-hour night. Active tectonics below to renew the atmosphere every now and then, some volcano goes into fix and then it releases SO2 and this thing aerosols and then it is redistributed, it changes the concentration and also counters the effect of greenhouse gases, you know that right.

So all these things are naturally taking place and there is nobody to control it is naturally happening. The history of the global climate. So past also there the Earth's climate has gone up and down. The idea is not to tell that it has not gone up and down. Yes, it has gone up and down, but we have to look at it carefully, but we will present all the facts. So there have been times and the earth has been very cold, that there have been times when it has been hot.

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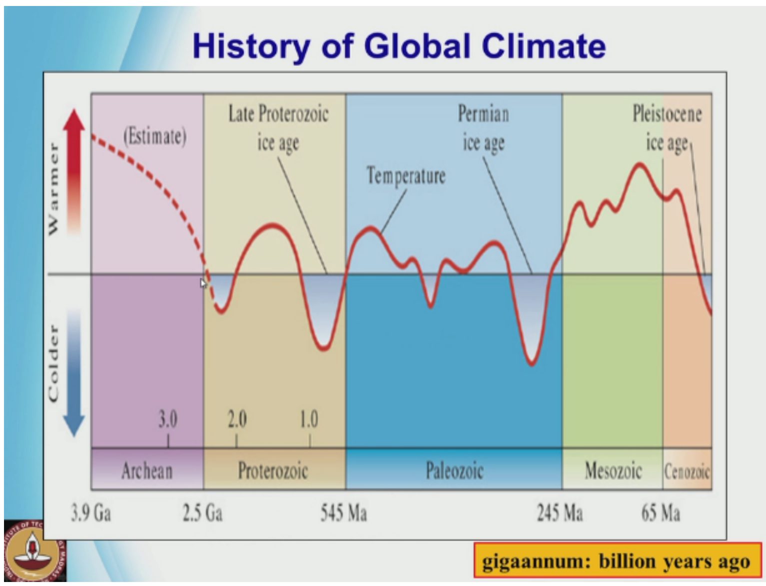

So these are all various here. So this is the temperature versus time and Giga annum is basically billion years, Ma is million years.

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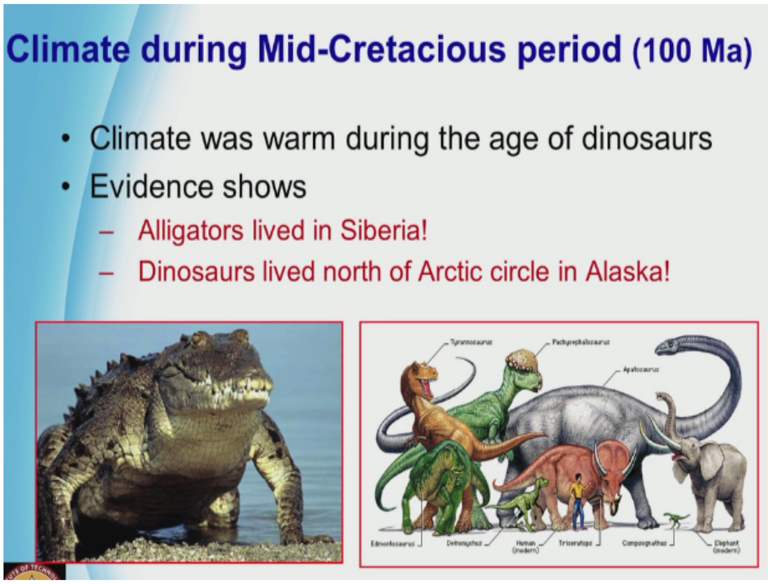

Climate during mid-cretaceous period about 100 million years ago. Climate was warm during the Age of dinosaurs. There are proofs fossil, there's evidence to suggest that alligators lived in Siberia and dinosaurs have lived north of the 66 degrees latitude in Alaska. So that means it was not Alaska, not the fact Arctic Circle in Siberia are not fully covered with the ice at some point in time. There are 3 equilibria state, this you already know.

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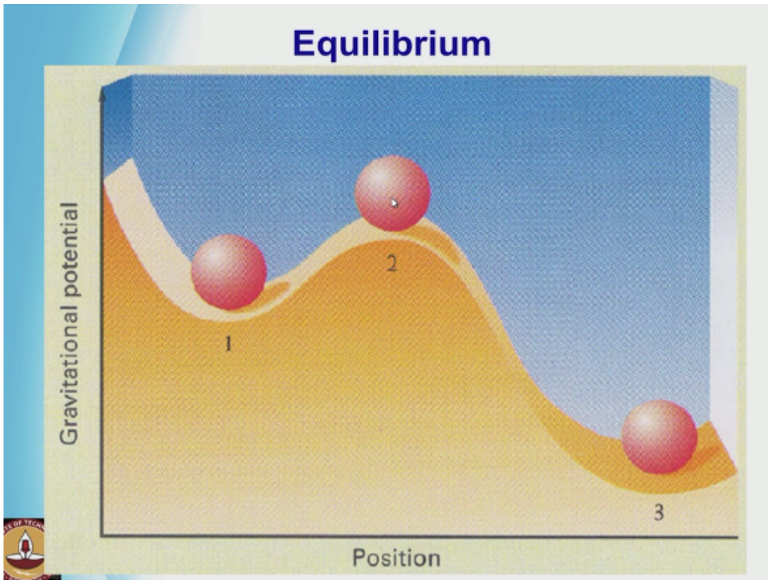

One is a stable equilibrium, 2 is unstable, 3 is conditional or neutral equilibrium.

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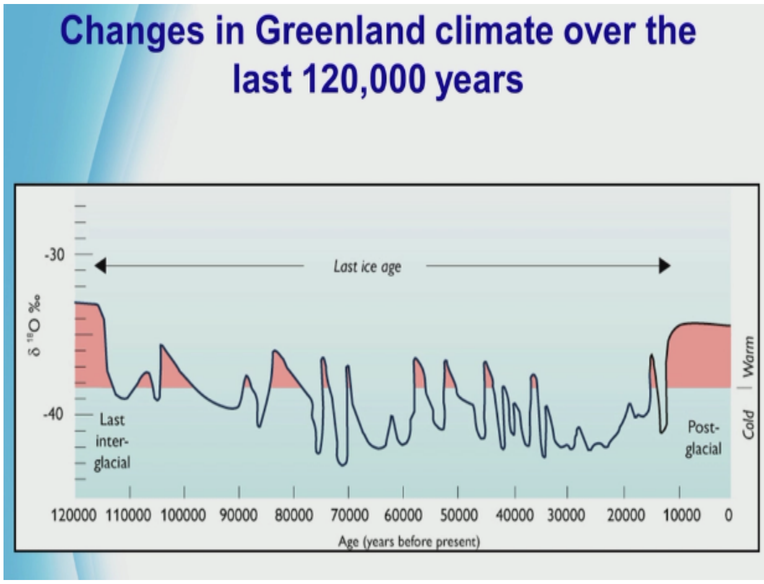

This is a gravitational potential and position. Now changes in the Greenland climate over the last 120,000 years, basically this change in O16 is a normal, O18 is some isotope, that can be used as a proxy for the climate change. There are various proxies. The change in volume of a mercury-in-glass thermometer is a proxy for the temperature of the patient. The change in height of the manometer column when the doctor puts it, it is a proxy for the blood pressure.

You are not actually measuring the blood pressure that means you are to put 2 holes and put a pitot tube or a manometer and you are not doing that. So he is putting some pressure and there it is counteracting the blood pressure is counteracting the pressure, they are cancelling out something and then he is finding out. So this is called a transducer effect you already saw that. You already know about this.

So what we are trying to say is, yes, agreed climate has been going up and down, then what are you talking. So we have to answer that question systematically. Normally when they presenting these arguments, first we will all present the data which goes against us. Even in philosophy they do that, why other people have said it is wrong, it is wrong, it is wrong, it is wrong, it is wrong, it is wrong, they will present and then they will say, why what all they said is wrong.

And then they will present this thing. This is standard approach use. Now we present all the data without hiding anything.

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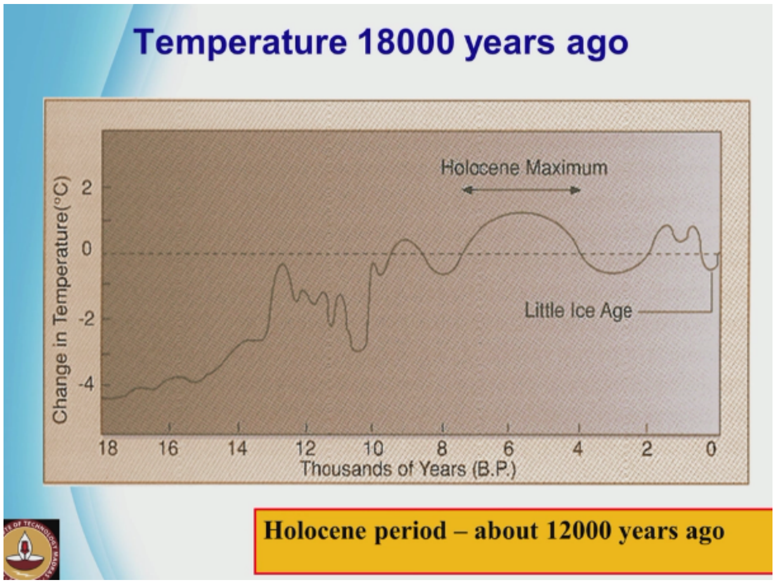

Temperature 18,000 years ago, what is this temperature 120,000 years ago, temperature 18,000. They are also up and down. There is a Holocene maximum. There is a little ice age, here there is a Holocene period about 12,000 years back where it is quite high. They will say 12,000 years back also it was very high then also we survived, why is this climate change, fossil fuel, let us enjoy petrol vehicles and let us do what we want. That is also one argument.

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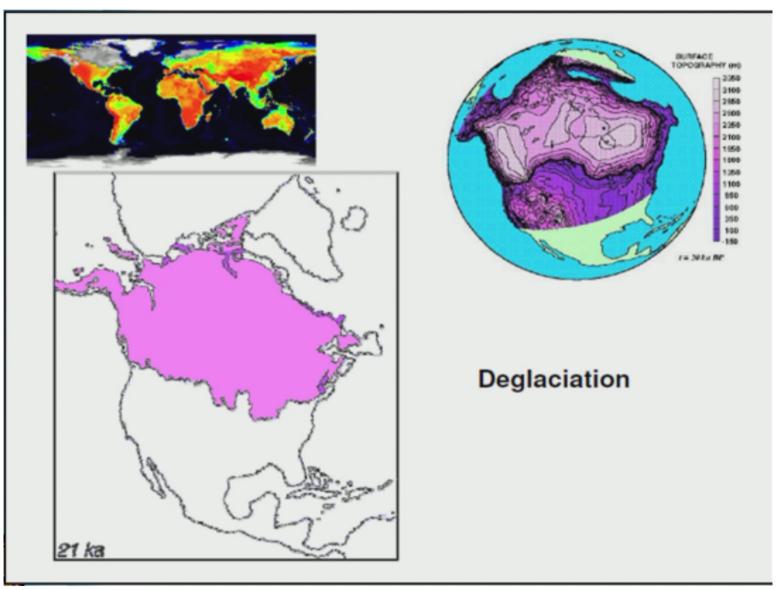

Now we are just presenting the data. Deglaciation or the reduction in the glacier area is evident from satellite pictures and all this. So this is the what is this Canada? Canada so you can see that this is not very clear. The next one is very clear now. After some time, I will show you, the Gangotri glacier. So the idea of this is basically glacier area is also shrinking.

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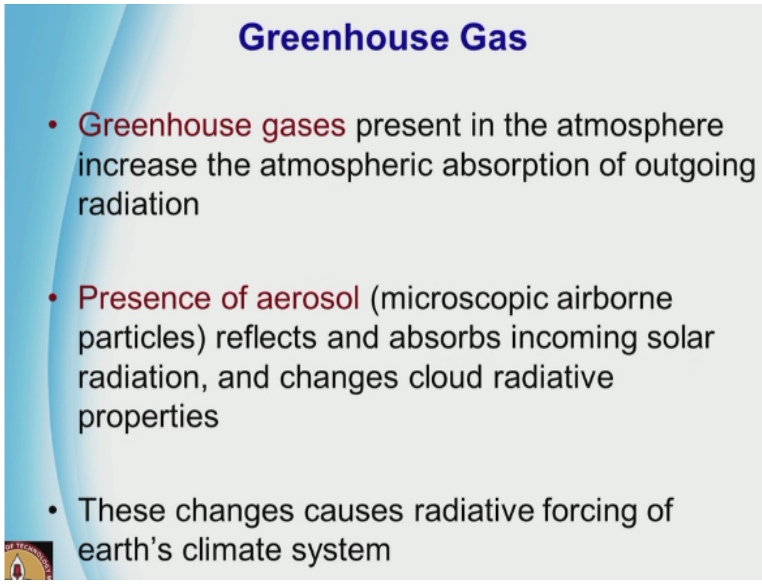

What about greenhouse gases? The greenhouse gases present the atmosphere increase the absorption of outgoing radiation. We have already saw that. The presence of the aerosols, microscopic airborne particles reflects and absorbs incoming radiation and it changes the cloud radiative properties. So these changes cause radiative forcing of the Earth's climate system. So the greenhouse gases and the aerosols act in opposite way.

If there are more aerosols, then they can counter the effect of greenhouse gases. Aerosols also released whenever there is a volcanic eruption. The aerosols can also be in due, can also be put into the atmosphere, but that is going to be very expensive. That is geo-engineering, if you want to do that. If you want to engineer the weather and climate, so then it is called geo-engineering. So it will be very expensive.

We have to go play, take some 100s of airplanes and then fill the whole atmosphere. So you can Geo-engineer a local weather. Chinese did it for the Olympics and they removed, they just dispersed the clouds. They did the opposite of cloud seeding.

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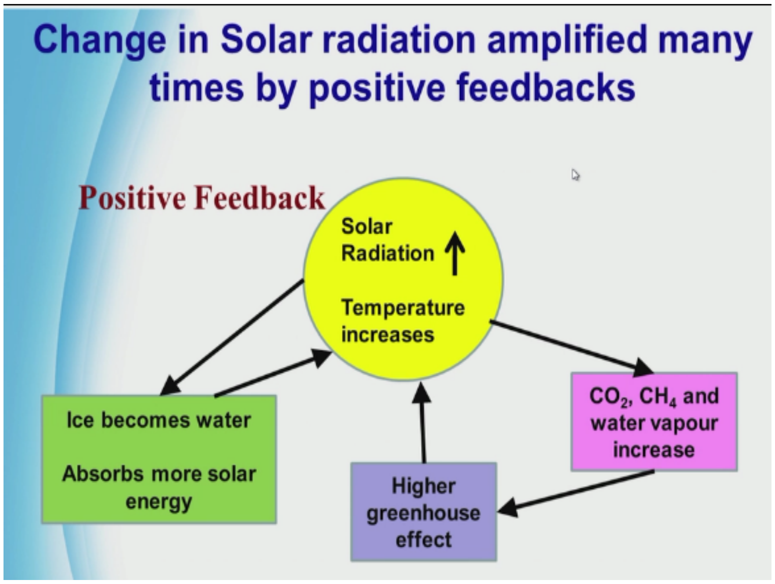

The changes in the solar radiation amplified many times with positive feedback. Now we have to look at this, look at the circle, as solar radiation increases the temperature increases, as the temperature increases, CO2, CH4 and water vapor increase, higher greenhouse effect. Ice becomes water. It absorbs more energy, then temperature increases. So it has a positive feedback. Now these are basically from ice core and modern data.

So if you see carbon dioxide concentration with time, so this is the insight so 1802-1900, it is green.

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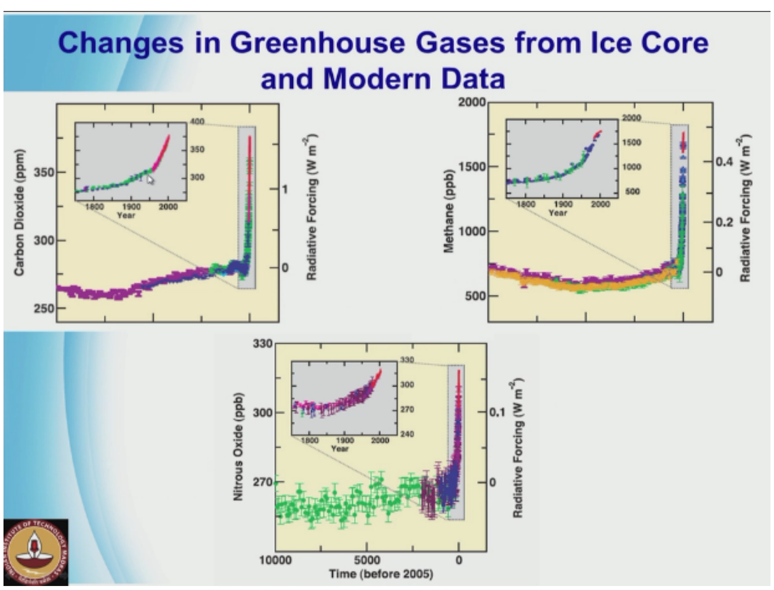

Suddenly from 1950 onwards, the slope is suddenly different. Look at this, methane also it is suddenly high. The left side the ordinate is ppm, the right side is radiative forcing in watts per meter square. All right nitrous oxide also suddenly, there has been increase in the last 100 years.

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So this is how ice core sample is extracted. You drill holes and then you get a sample like this.

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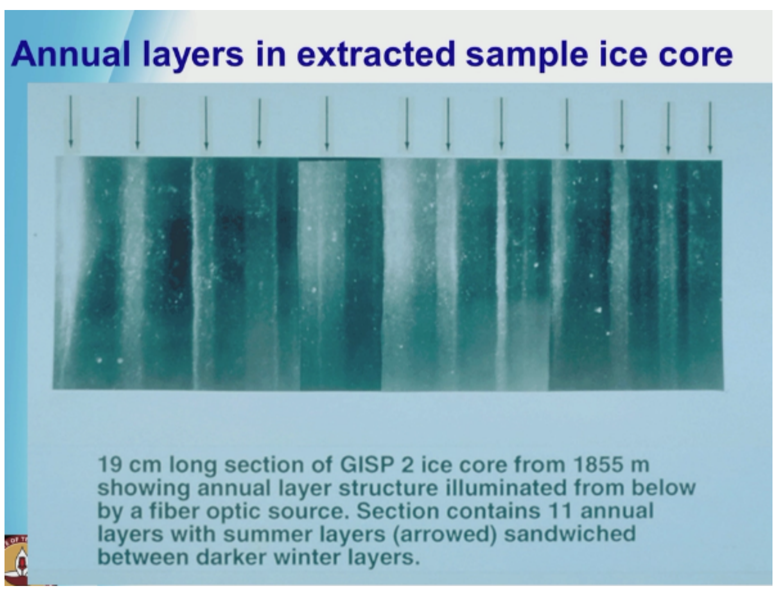

So there is a 19-centimeter-long section of ice core from 1855. So you can see that section contains 11 annual layers 1, 2, 3, 4, 5, 6, 7, 8, 9 it contains in between these 12 arrows, 11 layers and with summer layers sandwiched between darker winter layers. The summer layers are this white ones, winter layers and so in any section, you can look at the air trapped and then you can measure the concentration of various gases in that air.

So if this is the depth, if your y-axis is the depth of the ice sheet, this is the surface here air freely moves through ice then between 50 and 50 meters, air diffuses slowly through ice, but below 50 meters' air is sealed firmly in ice. So if you know the rate of deposition as you go deeper and deeper the height, the depth to which you go as a direct correlation with the age, with the year and then you take an air sample and find out the carbon dioxide.

All those things oxygen, nitrogen and all that that is a proxy for the atmospheric air which existed at the time and which was covered by this snow and ice. This is a well accepted procedure.

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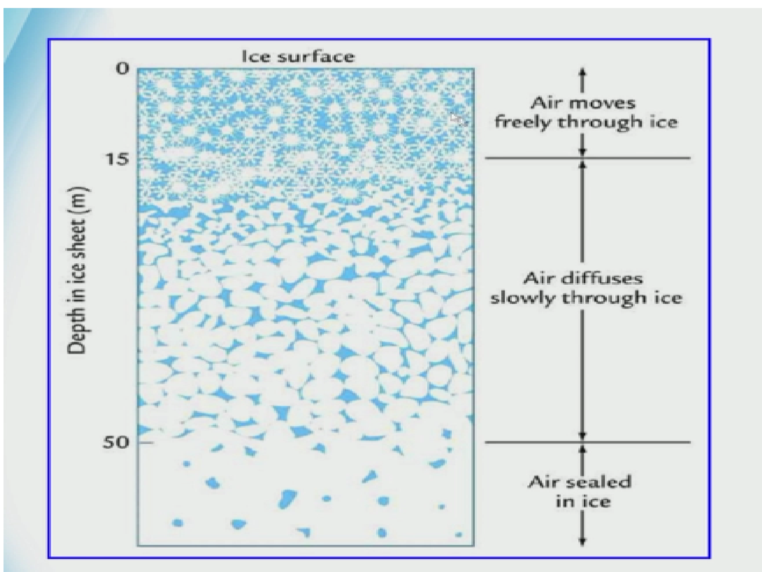

So these are recorded in Vostok ice cores, I think Vostok is in Russia, yes Vostok is in Russia. So these ice core data, some 5 colors are there. Deuterium is a proxy for local temperature that is in blue color, carbon dioxide is in black color, methane is in red color, the dust is purple, the green line is a measure of the Chinese Lois deposition. Lois deposition is the wind this thing. I have shown you something now. This is somewhere in Mississippi.

So these mountains, there will be some wind deposition. So that you can actually date those things and then get the concentration and so these are all basically done by paleo-climatologist, archaeologists and all these people know. They are pulling out data from the past when actual measurements were not there. So you always look at some proxies, alright. No, no, no all this may not be correct. The Sun itself may not be giving the same 342 watts per meter square.

We agreed, that is also a wonderful argument. Now let us see how much that is true.

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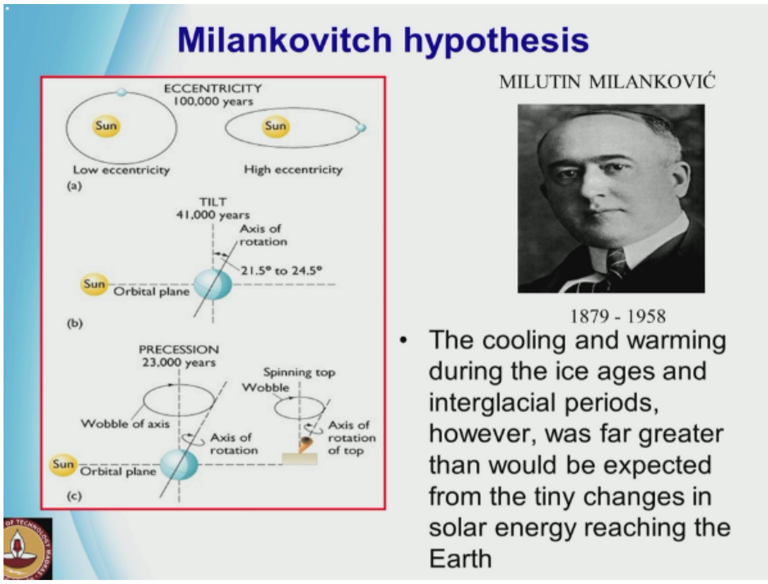

So this was investigated by Milutin Milankovitch whose picture is given 1879 to 1958. So he said that the eccentricity of the Sun can change in a time period 100,000 years. So it can have low eccentricity or high eccentricity and the tilt can change once in 41,000 years. So the axis of rotation can actually change from 21.5 to 24.5 from the vertical. We generally assume it to be some 23. Something. But it can vary from 21.5 to axis of rotation.

So this is the earth, this is the Sun, this is the orbital plane, then with respect to the vertical the axis of rotation, how much is it? 23.5 is it, then the precession also changes once in 23,000 years. So this is the Sun, this is the earth, this is the axis of rotation, this is the orbital plane and then this is wobbling. So the spinning top, so this also changes. So the cooling and warming during ice ages and interglacial periods, however was far greater than would be expected from the tiny changes in the solar energy reaching the earth.

So if you assume all these Milankovitch hypothesis all that and then change the 342 watts per meter square, run a model and find out for 1000s of years what would be the change in climate. The climate change which is actually observed, we saw the climate change which you get from running the model with changed solar loading, solar input based on the Milankovitch hypothesis, they are not matching.

That means you cannot attribute all of the changes in the Earth's climate to just the change in the eccentricity and all that. It has a forcing of some 0.25 watts per meter square or something.

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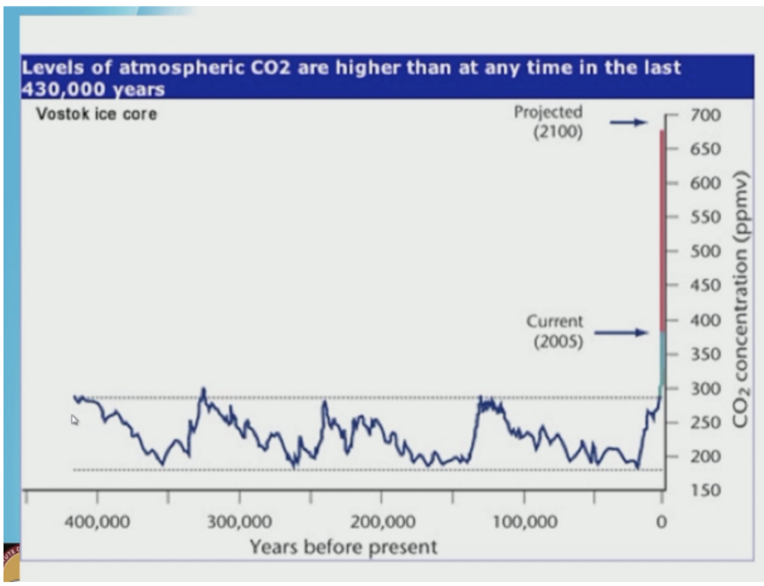

All right so the levels of atmospheric carbon dioxide are going like this. If you plot from 400,000 years ago, which is coming from ice core and all that so you can see that the concentration has increased dramatically, if you look at the temperature anomaly.

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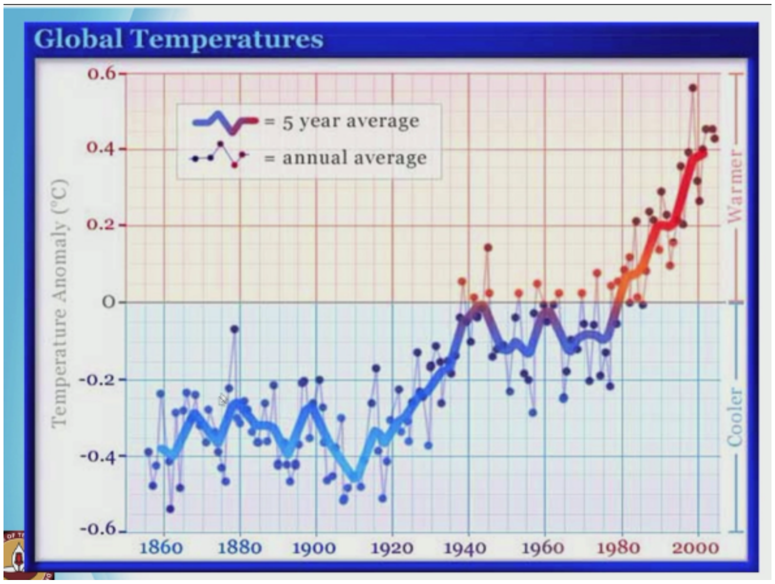

So annual average is given by these lines connected by dots and then the thick lines are the 5-year average. You can see suddenly from 1918 onwards is a red line whose slope is very, very high. It is positive. It is very, very high, so you may argue some 1900 to 1940 also something was there, but already some explanations have also been given. In the interest of time, I am not going through that.

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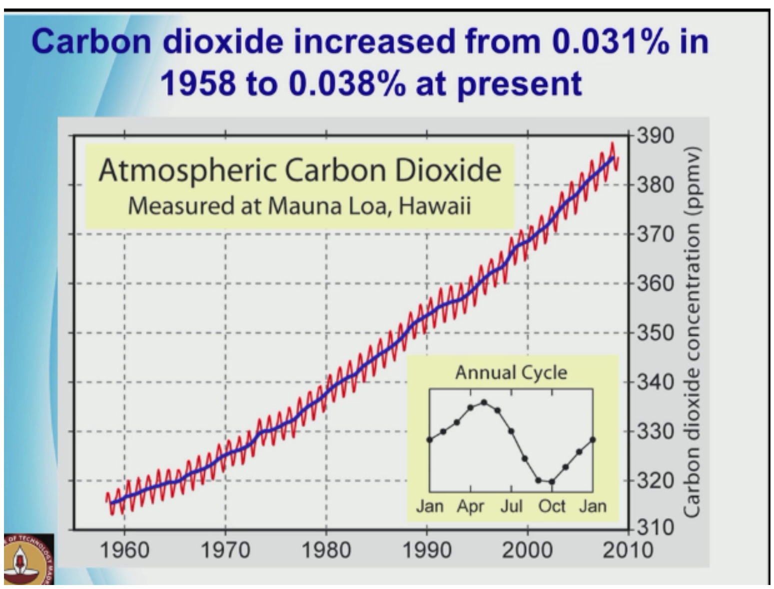

This we have already seen this is Mauna Loa in Hawaii. So you can see that there is a dip and the rise basically because of the summer and the winter. Spring and summer lot of plants are in full bloom. The photosynthesis activity is there during summer, that is subdued during winter. So there is a cycle and you can see that the concentration now 380/390 ppm. So this atmospheric CO_2. Superimposed is atmospheric CO_2 to global temperature.

It is most likely that the 2 are very strongly correlated and actually if we run the radiative transfer model with CO_2 concentration, this is also confirmed, but there is very important thing, which we have to be very careful is we should not suffer from what is called the fallacy of the single cause. Fever is only the effect. The fever may have a 100 causes. A good doctor should get the correct cause. So he has to run some algorithm.

He will either run some tests or he will say whether you are having cold, you are having cough, you have stomach this thing. So he runs of algorithms. So essentially a diagnosis of a fever is an ill-posed inverse problem. We have to find the cause. That is only the effect, like this the climate has changed. So we are trying to ascertain the causes, so that if there are some causes which can be changed and we can slow down this we want to be able to do this.

That is like responsible engineering or responsible science. That is why Milankovitch all this we are seeing, so that we are not accused of this bias of this falling under the trap of the fallacy of the single cause. That means over generalizing everything and trying to ascribe 1 cause to an effect or there may be cross correlation between the various causes. First you have to list out X_1, X_2, X_3, to X_n. How are you say Y is a function only of X_1. So that is why there is something called LOSU.

What is LOSU? LOSU is level of scientific understanding. Now the LOSU with this is high, LOSU with water vapor, methane may not be high. Carbon dioxide strong correlation LOSU is very high. So that is why the IPCC the Intergovernmental Panel on Climate Change, when they are ascribing various causes, they are saying they will put 1 column called LOSU column, very high, high, medium, low that means the confidence with which you declare this.

Otherwise it is not proper science. Are you getting the point? So remember this LOSU. All right increase in CO_2 will be amplified many times gave positive feedbacks. I am repeating the slide again. So as the temperature increases the water vapor increases or as water the higher greenhouse effect, as temperature increases ice becomes water, it absorbs solar energy and then CO2 increase, everything.

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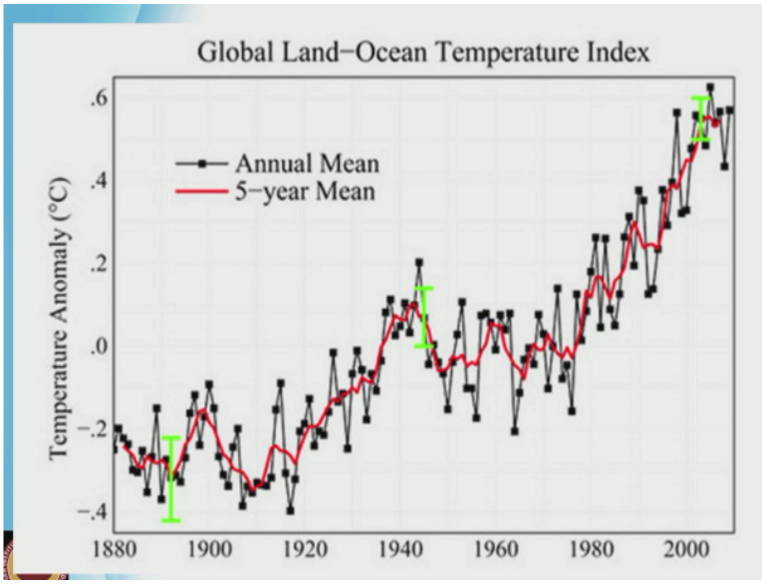

Global land-ocean temperature index, temperature anomaly same thing, everything is increasing trends, carry plot.

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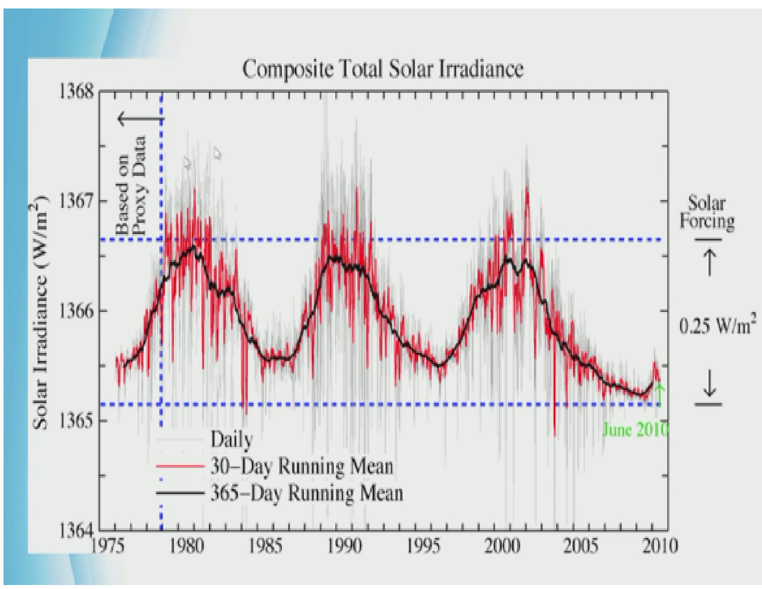

Now solar irradiance before 1978 based on proxy data, solar forcing now the whole idea is it is only 0.25 watts per meter square. If it is only 0.25 watts per meter square, 3.76 watts per meter square are required to cause 1 Kelvin change, 0.25 will be very less that cannot be even detected by all this. Therefore, it should be more than this 0.25. There is some forcing which is why otherwise why is the climate changing. How are you sure that the climate scene.

We have World Meteorological Organization is there, Bombay, Thane, Nasik, Surat, Vishakhapatnam, Chennai, Nungambakkam, Kodambakkam, Meenambakkam, everywhere we are measuring temperature. Everywhere it is calibrated and all the people are reporting, then you are taking a geographical average like that, every day every month, every season, every year you are compiling, compiling, compelling. You have so much of data.

There is so much of data when you are doing the average, when something is going up like this. So as a scientist we have to investigate why it is going like this and then we do not want to blame ourselves, we blame the Sun, but the Sun is giving only 0.25 watts per meter square. So that curve this is only this much, so we have to bridge the gap all right. Solar radiance is only 0.25. Now temperature is that dark brown, CO2 is that Mauna Loa, then the sunspot.

What is that sunspot? Some changes are taking place in the Sun, there are some spots in the Sun which reduce their photosphere temperature. Some people say no, no, no 5700 it is possible it became 5605 or some arguments. So some with the help of physics people, cosmologists, astronomers all this, we can study all this and account for the sunspot also. The sunspot also is not able to explain.

The Milankovitch cycle is also not able to explain, but CO2 is increasing that we have measured and positive feedback we can get from radiative transfer models and all this, but there is a cooling which is taking place in the lower stratosphere.

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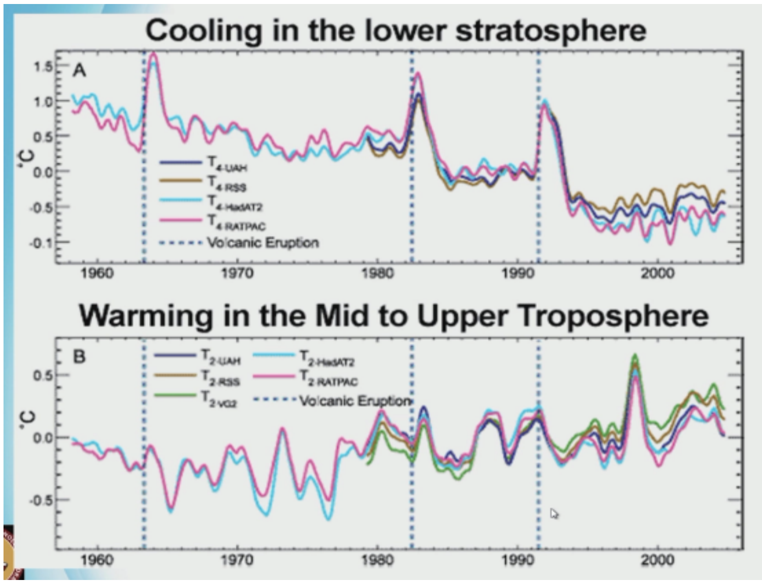

That we know, so the cooling in the lower stratosphere is taking place like this, but warming in the mid to upper troposphere is taking place. This is from 1960 to 2000.

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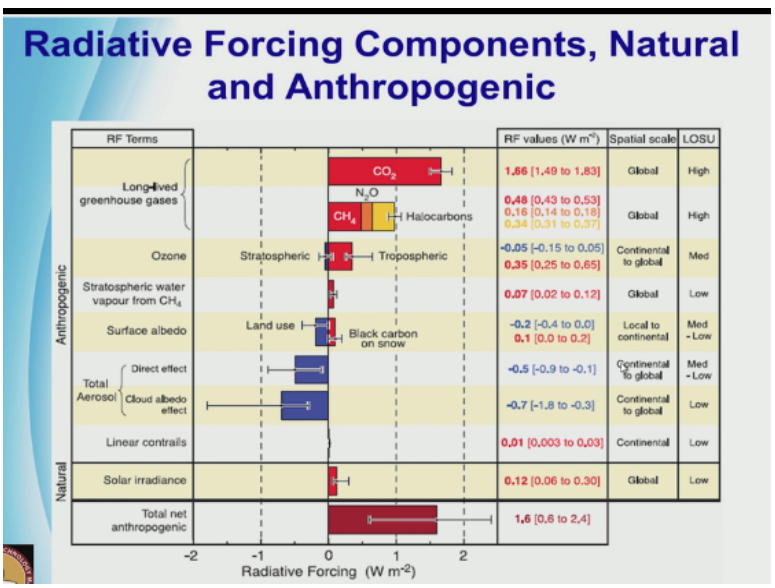

So the radiative forcing components can be 2, can be natural and can be manmade. A manmade cause is called anthropogenic induced by humans, anthropogenic. There is a natural cause. The natural cause is our Milankovitch and all that. Let us look at this carefully. Carbon dioxide RF values not radiofrequency, radiative forcing. It can vary from 1.49-1.83, but the mean is 1.69. Spatial scale carbon dioxide is global. LOSU is high, that understanding is very high.

We have very high confidence in this. Next methane and halocarbons 0.48, 0.16, 0.34, it is also global. It is very high. Stratosphere ozone we are saying -0.05, troposphere it is 0.35, it is continental to global. The LOSU is going down the confidence is medium. Land-use medium to low. So this is 0.2-0.1, total aerosol we have not understood. That is why lot of research is going on in aerosol of people. It happened sometime in fluid mechanics turbulence 20 years, 30 years back.

Everybody was working in turbulence and adding to the confusion. In my model, your model, this model everybody is having one, one model, but the fluid does not know that it is being subjected to that model, that it is being tortured. It will behave according to itself. It has a will of its own, is not it? If you put it at 170 meters per second or 50 meters per second in a pipe, it follows its dharma. It is for you to figure out K epsilon, K Omega and all that.

Finally, the idea is your model must match to the experiment, but let us not get sidetracked. This aerosol, aerosol chemistry this thing you can have a radiative transfer and you can have instruments to measure aerosol concentrations by satellites and then invert it and lot of such activities are going on. That remote sense, it is an in-thing aerosols. Big guys are there, chemistry people. For aerosol chemistry, Crutzen, Nobel Prize has been awarded and all that.

Solar irradiance. LOSU is low, but overall total net anthropogenic is like this is 1.6 watts per meter square. There is a sigma of all this. Natural is only 0.25 and see this is all man-made ozone, methane, surface albedo, aerosol all this is anthropogenic. The only natural is basically the solar irradiance. So the total net anthropogenic is 1.6.

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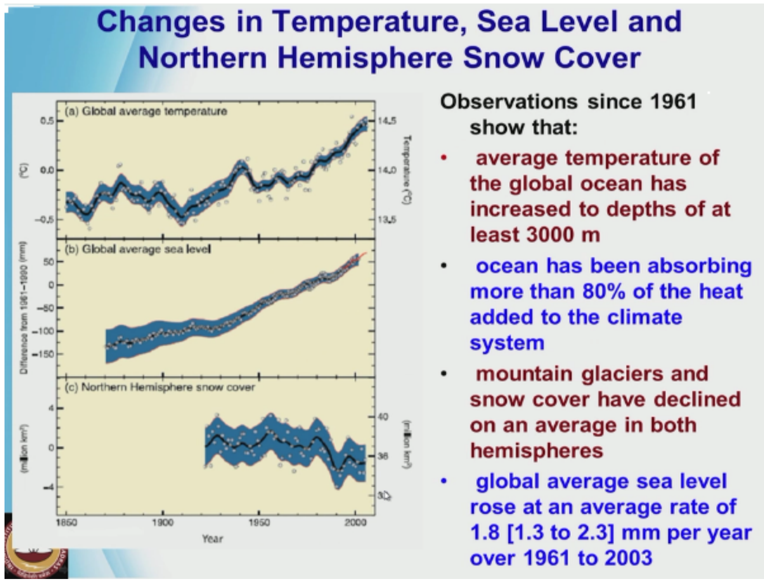

Now changes in temperature, sea level and Northern hemisphere snow cover. Average temperature of the oceans has increased to depths of at least 3000 meters. Ocean has been absorbing more than 80% of the heat added to the climate system. Mountain glaciers and snow cover have declined on an average. We know what happened in Kedarnath, but we do not know whether it is directly attributed to climate change, but these disaster type events are increasing.

Kashmir like rain like nobody's business. This is summer, like we have never experienced that kind of rain or a global average sea level rose at a rate of 2 mm per year, what is 2 mm per year multiply by 100 years. Do not say that 2 mm cannot be properly measured also. If you multiply by the time, because climate is basically we are talking about long term. So observed rate of sea level rise, source of sea level rise, thermal expansion, glacier ice gaps and all that.

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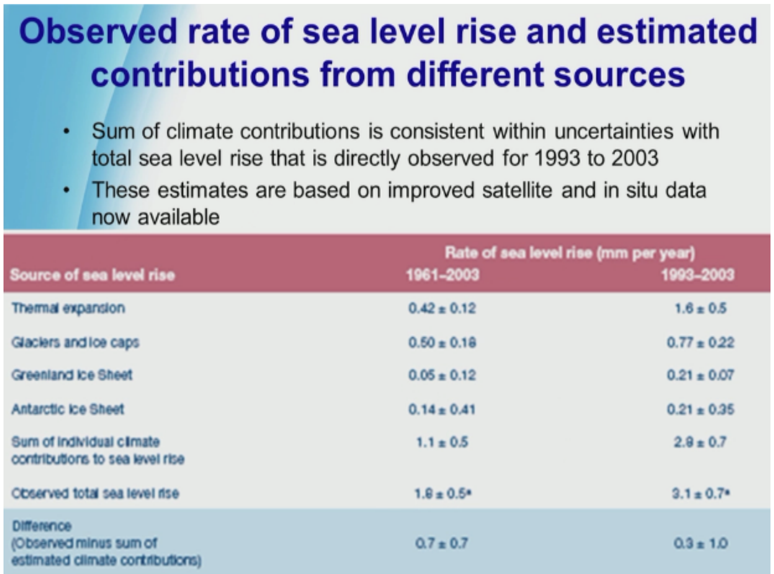

Source of sea level rise	Rate of sea level rise (mm per year) 1961–2003	1993–2003
Thermal expansion	0.42 ± 0.12	1.6 ± 0.5
Glaciers and ice caps	0.50 ± 0.18	0.77 ± 0.22
Greenland Ice Sheet	0.05 ± 0.12	0.21 ± 0.07
Antarctic Ice Sheet	0.14 ± 0.41	0.21 ± 0.35
Sum of individual climate contributions to sea level rise	1.1 ± 0.5	2.8 ± 0.7
Observed total sea level rise	1.8 ± 0.5[a]	3.1 ± 0.7[a]
Difference (Observed minus sum of estimated climate contributions)	0.7 ± 0.7	0.3 ± 1.0

1961, this column gives 1961 to 2003 and this is 93 to 2003, you can see that last 10 years there will be lot of changes.

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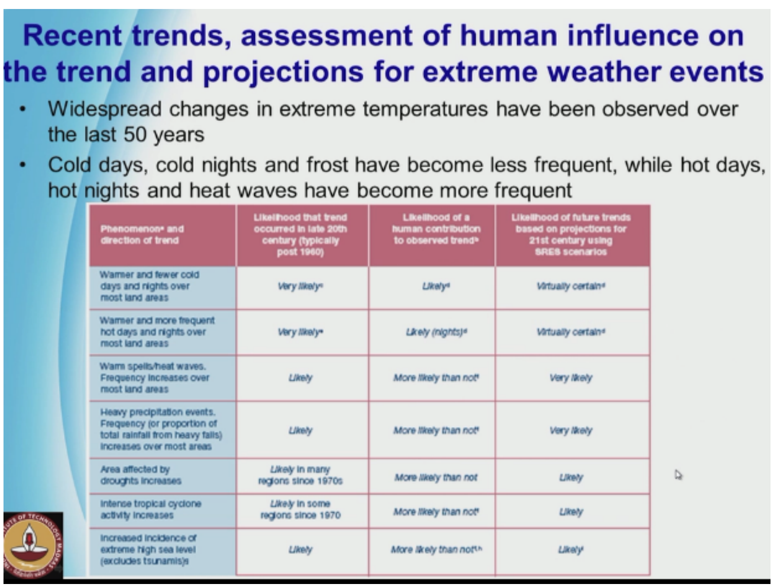

Phenomenon and direction of trend	Likelihood that trend occurred in late 20th century (typically post 1960)	Likelihood of a human contribution to observed trend	Likelihood of future trends based on projections for 21st century using SRES scenarios
Warmer and fewer cold days and nights over most land areas	*Very likely*	*Likely*	*Virtually certain*
Warmer and more frequent hot days and nights over most land areas	*Very likely*	*Likely (nights)*	*Virtually certain*
Warm spells/heat waves. Frequency increases over most land areas	*Likely*	*More likely than not*	*Very likely*
Heavy precipitation events. Frequency (or proportion of total rainfall from heavy falls) increases over most areas	*Likely*	*More likely than not*	*Very likely*
Area affected by droughts increases	*Likely* in many regions since 1970s	*More likely than not*	*Likely*
Intense tropical cyclone activity increases	*Likely* in some regions since 1970	*More likely than not*	*Likely*
Increased incidence of extreme high sea level (excludes tsunamis)	*Likely*	*More likely than not*	*Likely*

So warmer and fewer cold days very likely, likelihood of human contribution likely, likelihood the trend occurred in the late 21st century, very likely. So these are the various scenarios, virtually certain, very likely that is LOSU, virtually certain, very likely, not very confident likely. They are classified like this.

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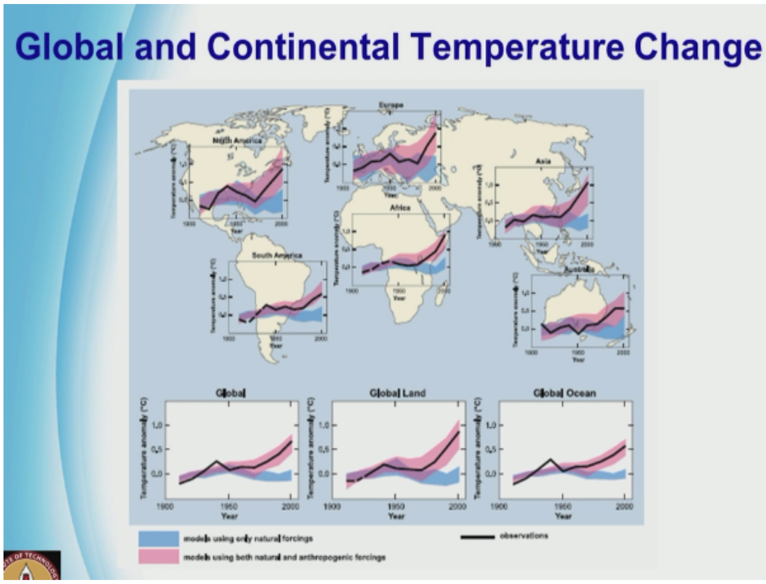

Then this is a global and continental temperature change. You can see Asia is also like this, temperature is changing.

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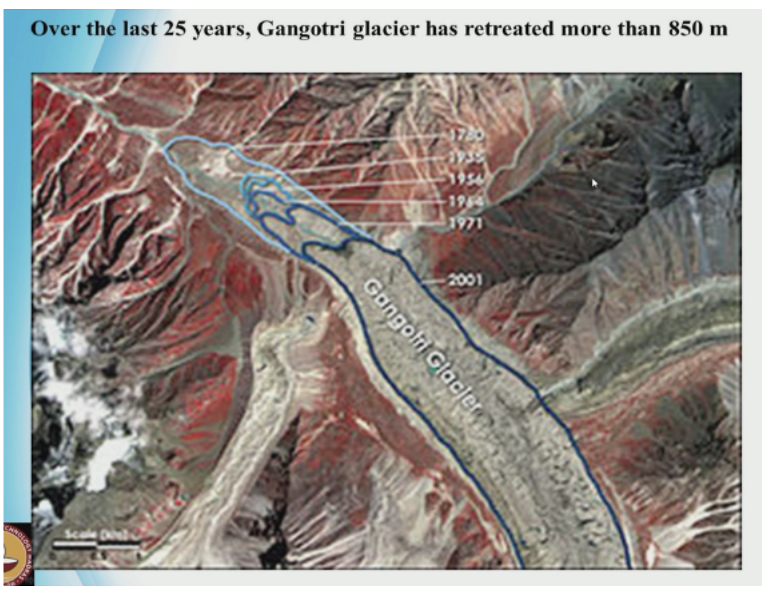

This is a Gangotri glacier over the last 25 years. Over the last 25, it really retreated. This is like 17 this thing now Gangotri glacier has receded up to this. So this much we have lost the glacier has retreated this much.

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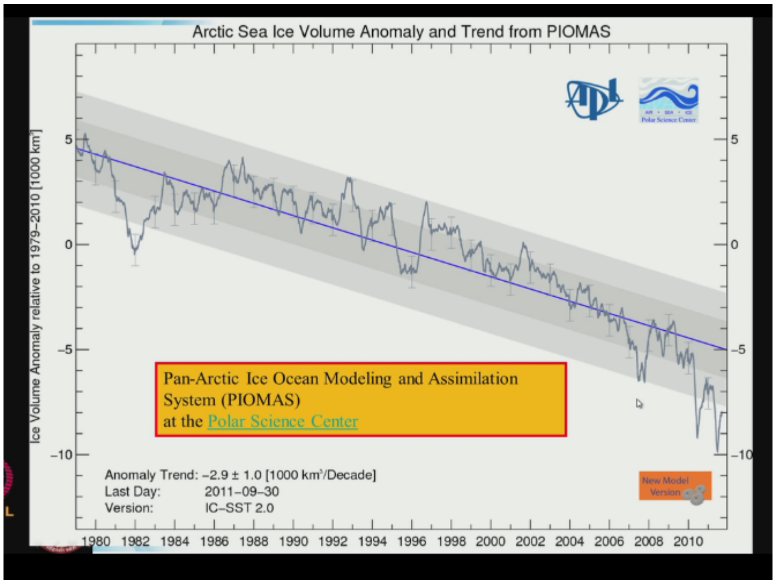

The Arctic sea ice volume has also shrunk. This directly from pan Arctic ice ocean modelling and assimilation system. Some programs have been developed to study this. What does the models predict? widespread increase in extreme temperatures and rainfall. We are already seeing it, cold days, cold nights, and frost will be less frequent. Hot days, hot nights and heat waves will be more frequent. This is a paper by Goswami.

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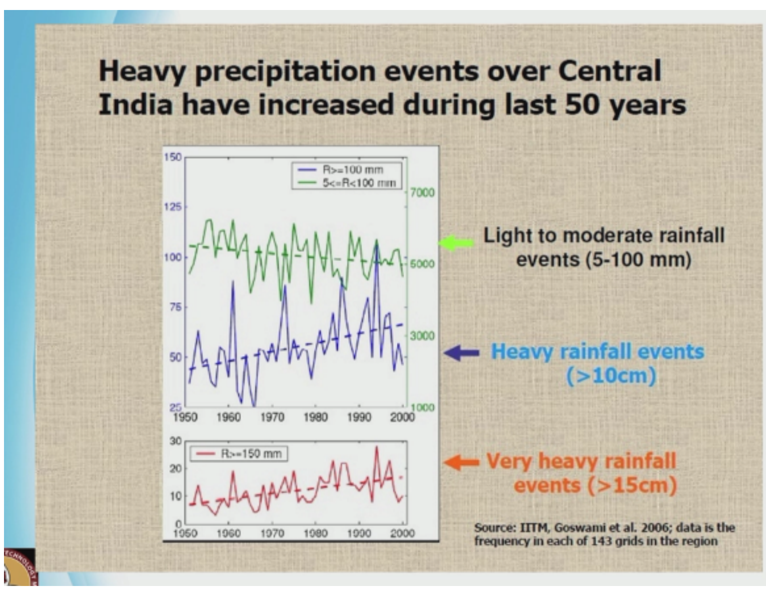

Professor Goswami and others from the Indian Institute of Science, Bangalore, which appeared in that journal Science, where they are saying light to moderate rainfall events will decrease. Heavy rainfall events will increase and very heavy rainfall events will also increase. So you will get lot of rain in a short span of time, which will be very destructive. That has what happened in Kedarnath, again that same Kashmir, that same Chennai what it is raining now, it is very nice.

Suppose last 20 days, we are getting some. If everything will happen Friday afternoon 2 o'clock to 6 o'clock what will happen that is the problem. Many days of no rain, 1 or 2 days of crazy rain, so these are the various aspects of climate change, ocean acidification and chemical pollution, aerosol loading.

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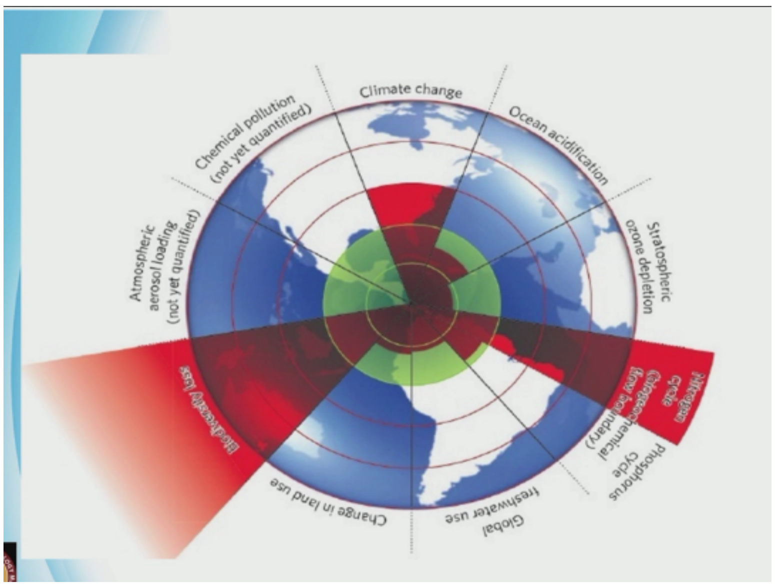

What is this global fresh water use and all this.

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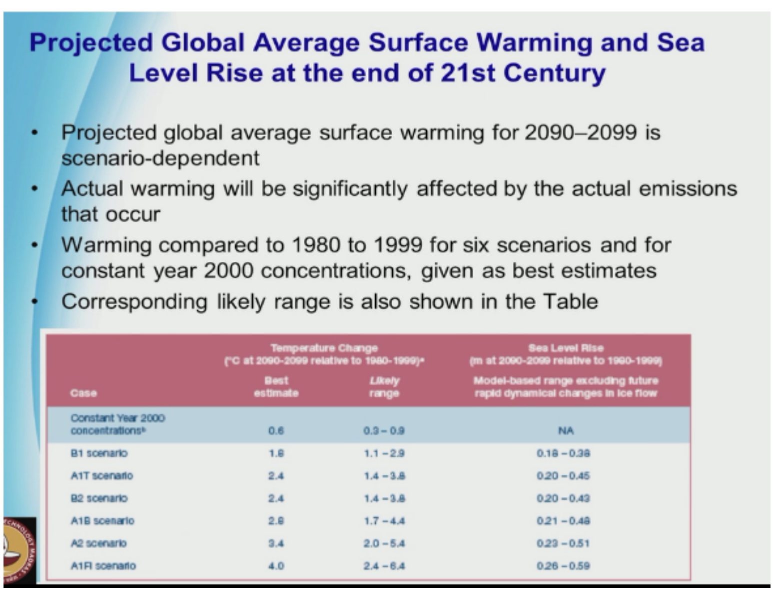

Projected Global Average Surface Warming and Sea Level Rise at the end of 21st Century

- Projected global average surface warming for 2090–2099 is scenario-dependent
- Actual warming will be significantly affected by the actual emissions that occur
- Warming compared to 1980 to 1999 for six scenarios and for constant year 2000 concentrations, given as best estimates
- Corresponding likely range is also shown in the Table

Case	Temperature Change (°C at 2090-2099 relative to 1980-1999)[a] Best estimate	Likely range	Sea Level Rise (m at 2090-2099 relative to 1980-1999) Model-based range excluding future rapid dynamical changes in ice flow
Constant Year 2000 concentrations[b]	0.6	0.3 – 0.9	NA
B1 scenario	1.8	1.1 – 2.9	0.18 – 0.38
A1T scenario	2.4	1.4 – 3.8	0.20 – 0.45
B2 scenario	2.4	1.4 – 3.8	0.20 – 0.43
A1B scenario	2.8	1.7 – 4.4	0.21 – 0.48
A2 scenario	3.4	2.0 – 5.4	0.23 – 0.51
A1FI scenario	4.0	2.4 – 6.4	0.26 – 0.59

So I am just taking out, pulling out from the IPCC report, the third assessment report. What IPCC has done is, it has assumed various scenarios, B1 scenario, A2 scenario, B2 scenario all these are various scenarios. Fossil fuel will be cut and this thing, economy will go at this rate and so for various models, it gives projections for the future.

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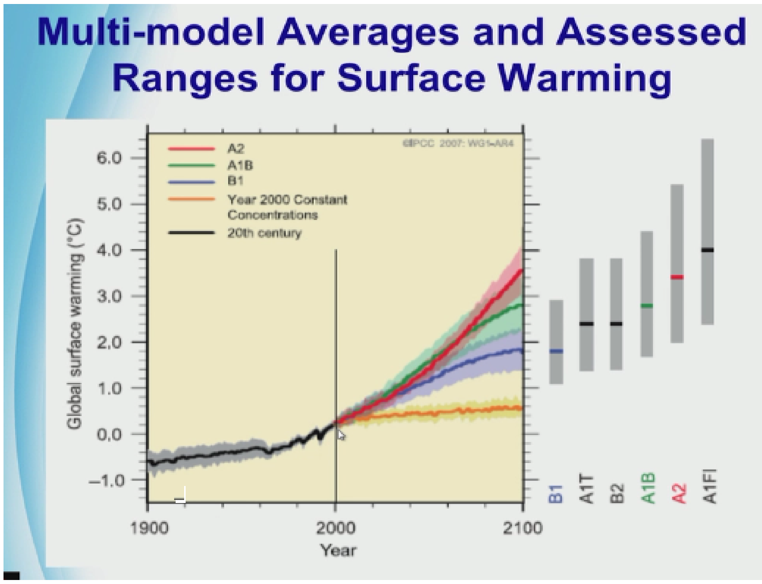

Now from 2000 onwards, it is all projection. 1900 to 2000 is data. So there will be several lines from 2000 onwards because they are based on A2, A1, B1 and all that. So you can see that the global surface warming takes place A2 is a very crazy, like 3 degrees it will have. Another 86 years, it will go by 3 degrees. Then year 2000 constant concentrations if everything stays, the carbon dioxide stays at 390, even then we have a committed heating.

There is already a fixed amount of commitment. With that scenario if you go also, there will be a mild to moderate increase. So you have to take a call. Government or the world has to take a call on which of the scenarios will follow. That will decide the fate of the climate in the year 2100.

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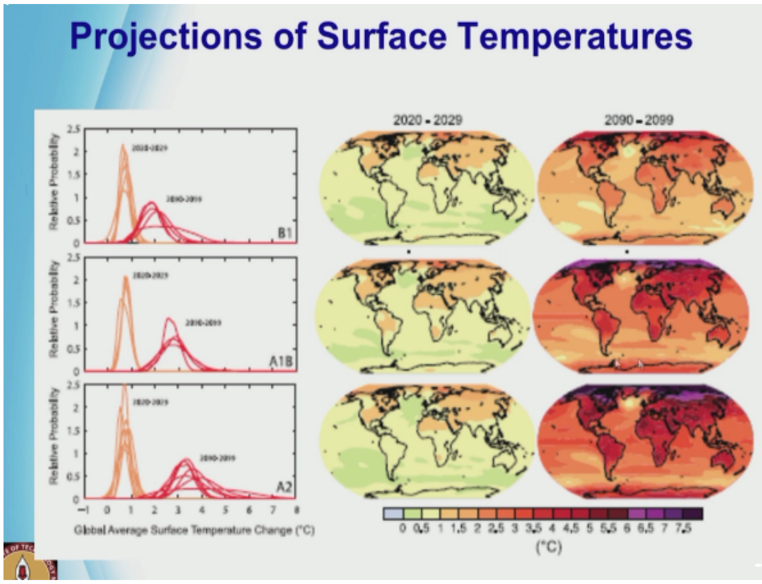

So projections of surface temperature, all scary everything is becoming hotter. You can see the red color is all this thing.

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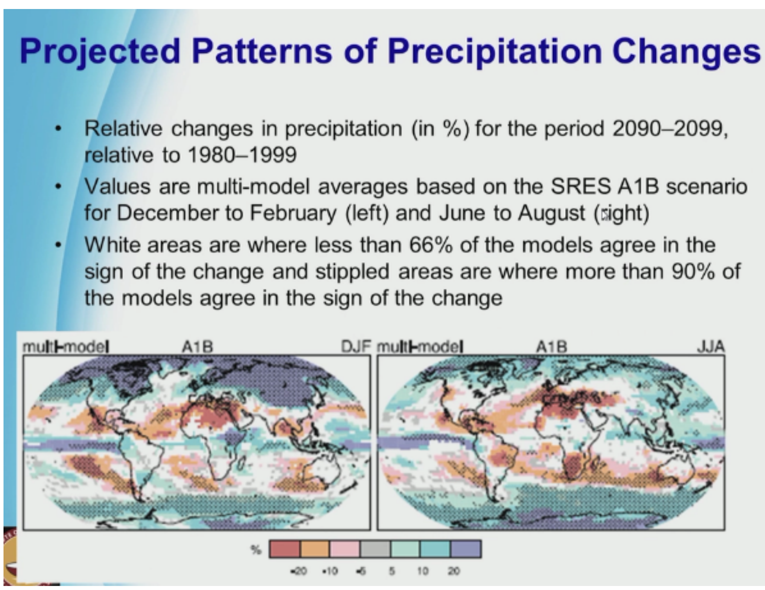

Then projected patterns of precipitations changes. You can see that white areas are, so this will be A1B. So you can see that is multi model that means you run several climate models and take an average. It is like an ensemble model or ensemble forecasts. So values are multi model averages based on A1B scenario. White areas are where >66% of the models agree in the sign of the change and stippled areas, that means areas with dots are where more than 90% of the models agree in the sign of change.

More than 90% of models agree in a large amount of area. Changes in greenhouse gases, carbon dioxide, nitrous. I am sorry for showing this slide again and again, because I want to drive home the point. Methane and then rate of change, radiative forcing.

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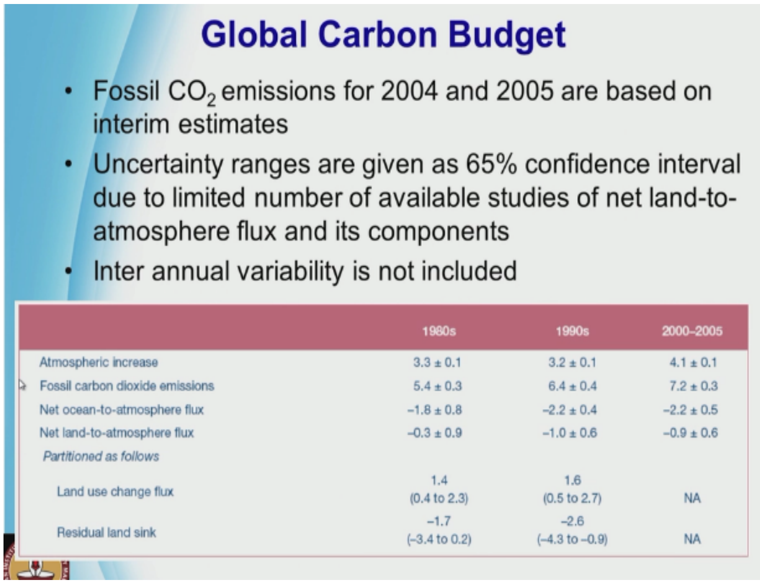

	1980s	1990s	2000–2005
Atmospheric increase	3.3 ± 0.1	3.2 ± 0.1	4.1 ± 0.1
Fossil carbon dioxide emissions	5.4 ± 0.3	6.4 ± 0.4	7.2 ± 0.3
Net ocean-to-atmosphere flux	–1.8 ± 0.8	–2.2 ± 0.4	–2.2 ± 0.5
Net land-to-atmosphere flux	–0.3 ± 0.9	–1.0 ± 0.6	–0.9 ± 0.6
Partitioned as follows			
Land use change flux	1.4 (0.4 to 2.3)	1.6 (0.5 to 2.7)	NA
Residual land sink	–1.7 (–3.4 to 0.2)	–2.6 (–4.3 to –0.9)	NA

Global carbon budget also you can see. It increases in the atmosphere, fossil fuel, carbon dioxide emission, net ocean to atmosphere flux, land to atmosphere flux and so on. You can see that things are increasing 3.38-4.1, 5.4-7.2 and everything is increasing.

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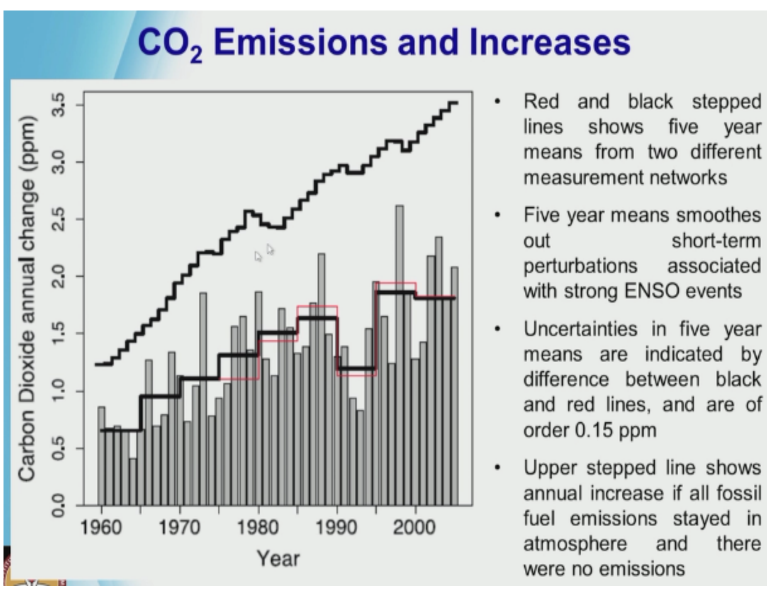

CO2 emission increases from 1960 last 40 years itself is so high. Sea level increase, so basically 1870 onwards we reconstructed the fields. Tide gauge measurements, you have tide gauges to measure. They are available from 1950. Satellite altimetry is available. You can measure the global mean sea level from the top of the atmosphere and that is in black. So everything is they are all falling in one place.

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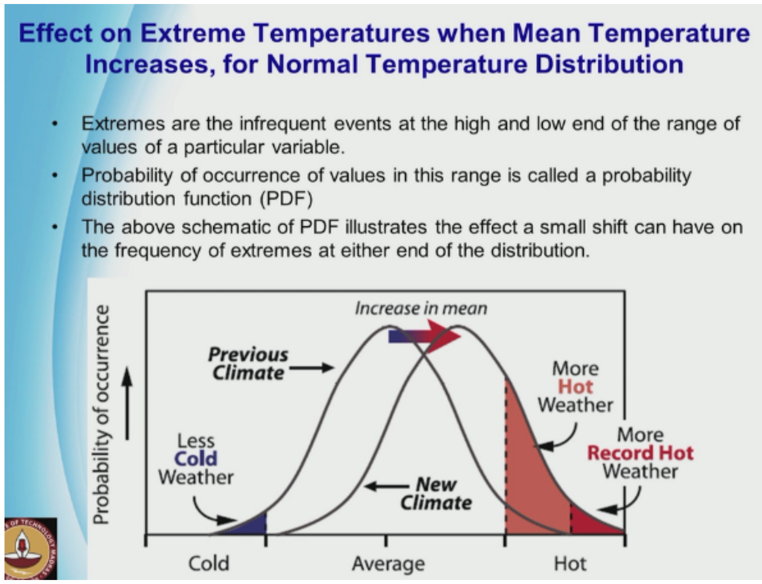

So this is a probability of occurrence. This is very scary picture. The old climate is the left-hand side; the previous climate is like this. Now they are saying because of climate change and all that this equilibrium is shifted to the right. If it is shifted to the right, left side is cold climate, middle is average, the right side is hot climate, so the cold climate is decreasing. This curve is moving to the right. You are able to follow that.

So this less cold weather more hot weather record more hot weather. This is the likely scenario. So the above schematic of the PDF the probability distribution function illustrates that the effect of a small shift can have a lot of effect in the frequency of the extremes. It is only a small shift, what will happen? What will happen is the extremes are this catastrophic ones, Orissa super-cyclone, Bombay rain, Kedarnath rain, Jammu and Kashmir rain and so on.

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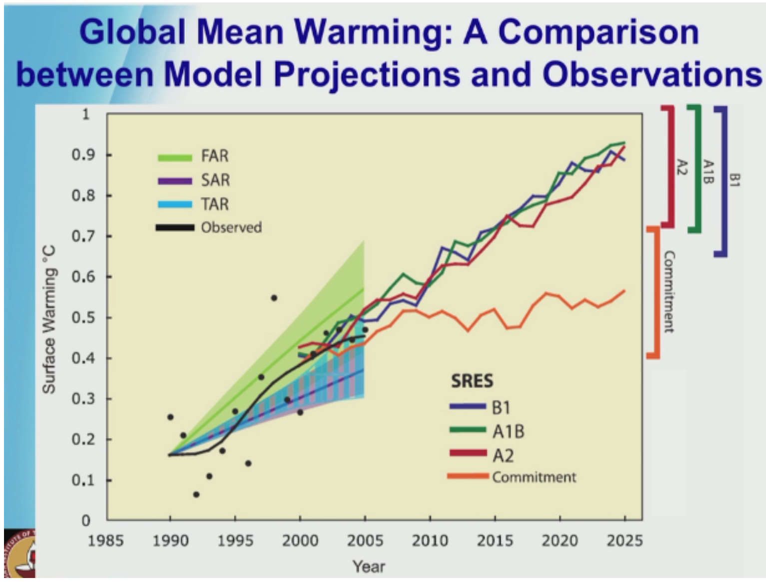

FAR, SAR, TAR observed is what, first assessment report, second assessment report, third assessment report of the IPCC, Intergovernmental Panel on Climate Change. So after all this, now you can see that the commitment if you stay with the commitment also, the temperature will increase, but you have any of these scenarios now you can see that with respect to the observed is only up to 2005.

You can see that many of these models are agreeing and you can see that it will by 2025 itself, you can see some 1-degree change, global mean warming. So we are looking at the global mean warming.

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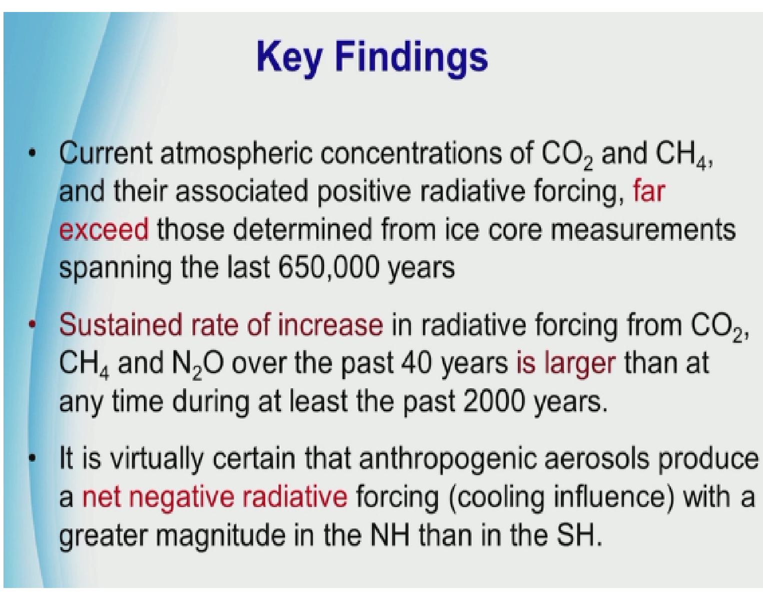

So to summarize, what are the key findings current atmospheric concentration of carbon dioxide and methane and their radiative forcing far exceed those for which we have records or you extrapolated or whatever back dated for the last 650,000 years. Sustained rate of increase in radiative forcing from the greenhouse gases over the past 40 years is larger than any time during the last 2000 years. We have seen consistently plots 1960 to 2000, it is all showing a steep increase.

It is virtually certain that man induced aerosols produced a net negative forcing, which is good news and they are more in the Northern Hemisphere than in the Southern Hemisphere because Northern Hemisphere is more developed.

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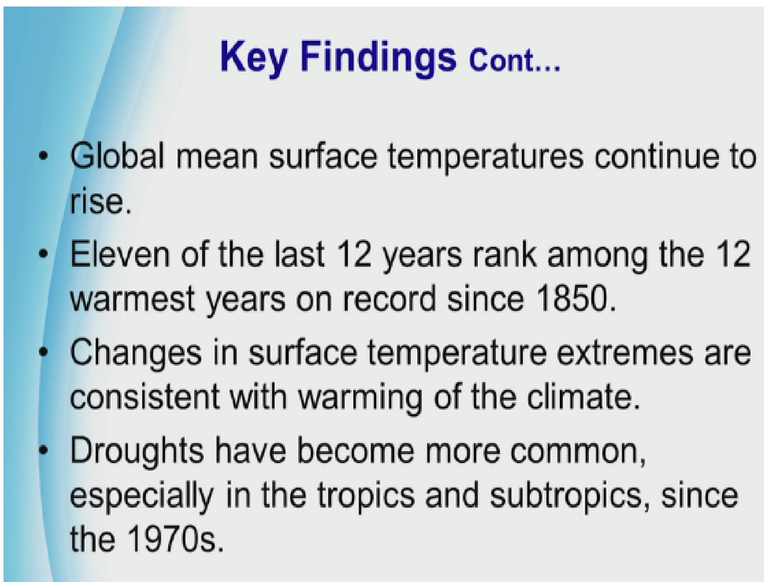

Global mean surface temperatures continue to increase, rise, level over the last 12 years ranked among the 12 warmest on the planet since 1850. Changes in surface temperature extremes are consistent with warming of the climate. Droughts have become more common, especially in the tropics and the sub tropics since 1970.

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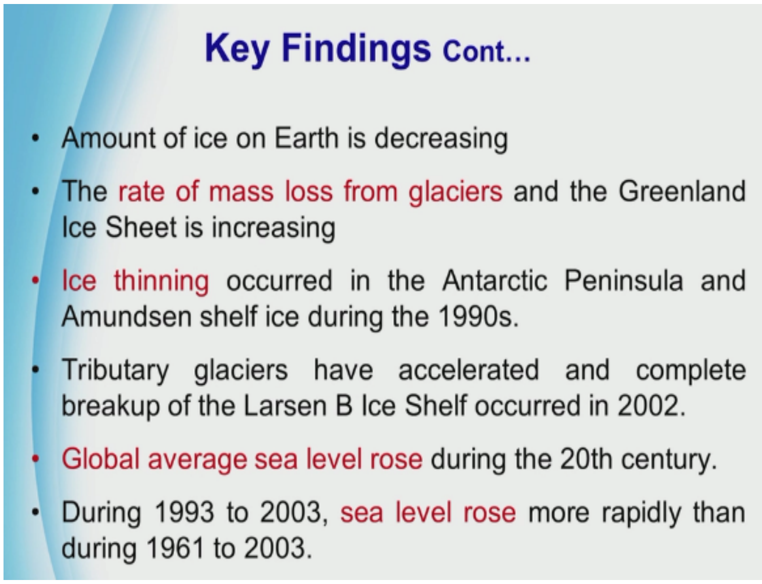

Amount of ice on the earth is decreasing. The rate of mass loss from glaciers and the Greenland ice sheet is increasing. Ice thinning occurred in the Antarctic peninsula during the 1990s. Tributary glaciers have accelerated and there has been a complete breakup of the Larson B ice shelf, this we can look up the Wiki Larsen B ice shelf something occurred in 2002. Global average sea level rose during the 20th century, but last 10 years it is much more rapid.

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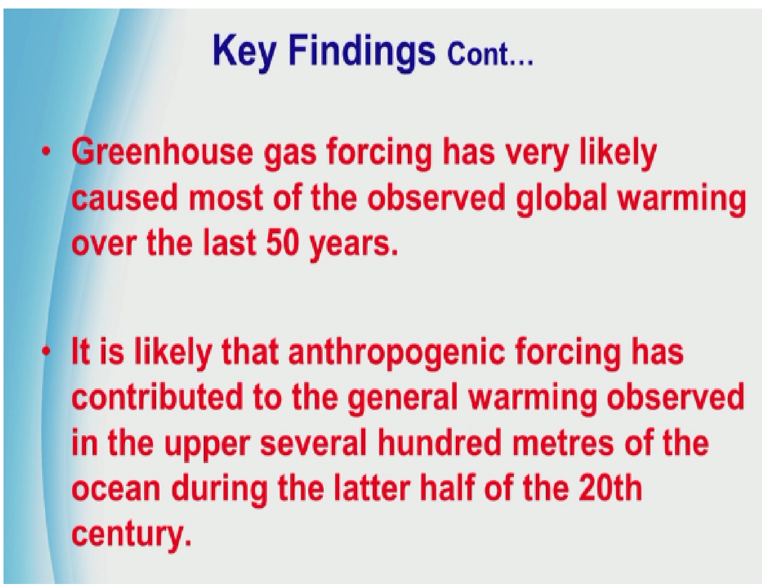

So the greenhouse gas forcing is very likely. That is what we are saying the greenhouse gas forcing have very likely caused most of these observed changes, it is also likely that man induced forcing has contributed to the general warming observed in the upper several 100 meters of the ocean during the last 50 years. So all is all very bad pictures, carry picture what do we do? That is a separate topic by itself called adaptation and mitigation.

They are separate topics by themselves and also they have got geopolitical ramifications. Scientists only cannot do solution; society has to accept those solutions. However, it is good to know that it is already a committed climate change because of our past actions.

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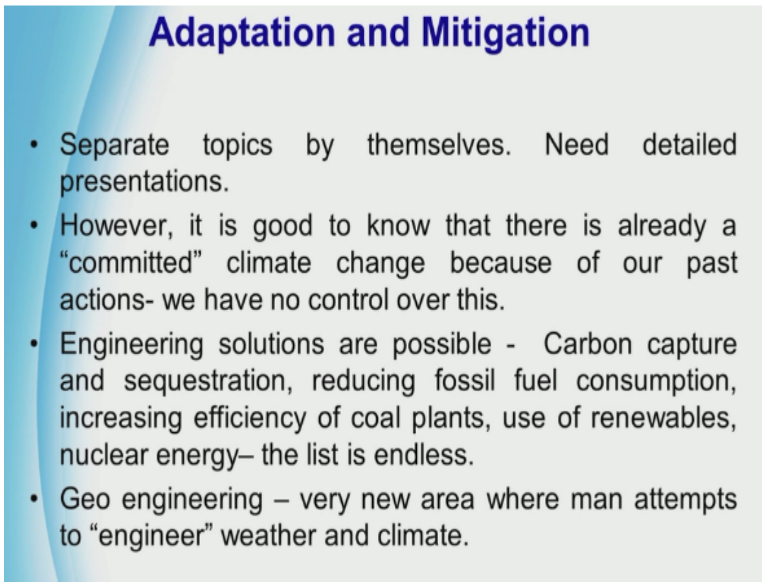

We have no control over this. Temperature will continue to increase because already it is 390 ppm, that forcing you know that equilibrium response with time it will increase, but the various sceneries, we can alter. Engineering solutions are possible carbon capture and sequestration putting the carbon dioxide into the ocean reducing, fossil fuel consumption, increasing the efficiency of the plant load factors of your power plants, going for LED solutions.

The LED people got the Nobel Prize this time, use of renewable, nuclear energy, the list is endless. Geoengineering a very new area where man attempts to engineer weather and climate where he tries to play God.

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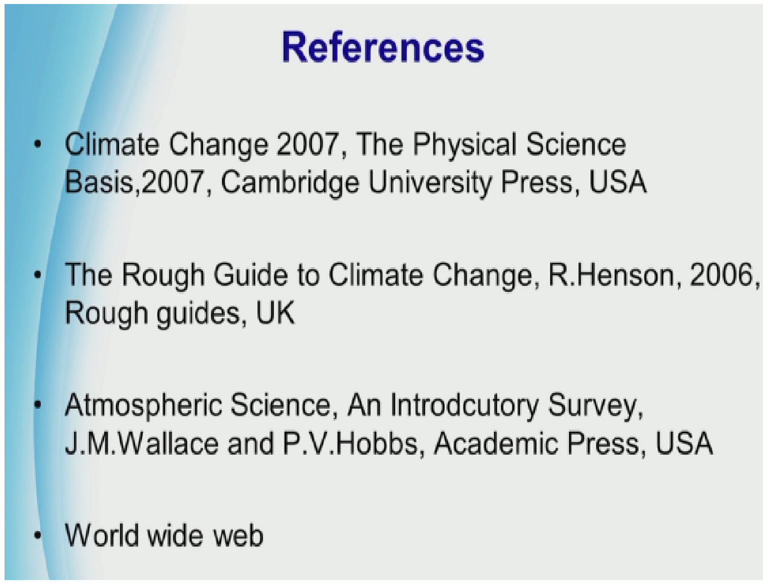

So I have used this references, climate change 2007. I have this with me the IPCC report and also some popular books and the World Wide Web. Thank you for attention. The class ends here. If you have any doubts. I will answer. (()) (45:40) professor-student conversation. That is based on this how long. Is it possible to say? Yeah 650,000 years. And then if there is life anymore, if you try to get deeper, why is it not possible to try and imply 1 million years back.

You know we do not know whether the technology is available to go that deep or, and also the errors may also creep. Here correlation between the ice and the age, everything will right, so under that LOSU we can still predict the level of scientific understanding may go down.