INDIAN INSTITUTE OF TECHNOLOGY MADRAS

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ECOLOGY AND ENVIRONMENT

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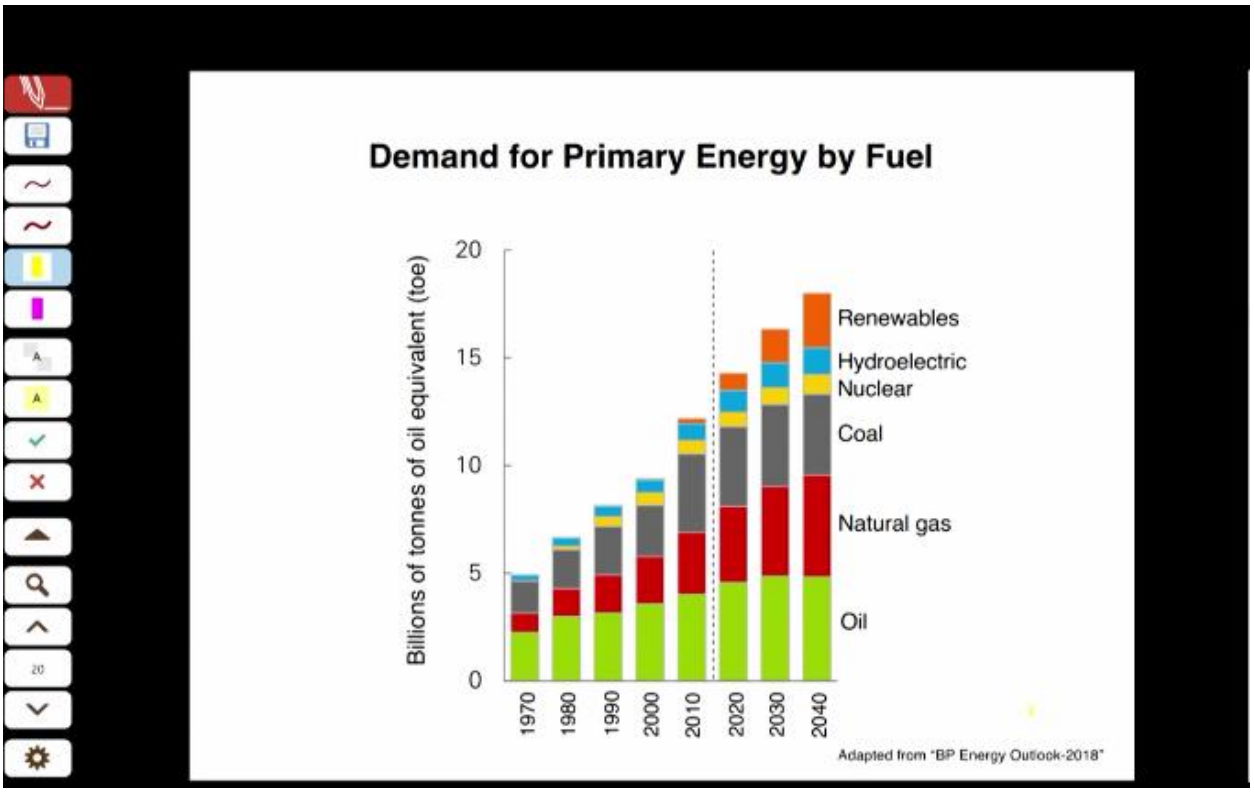
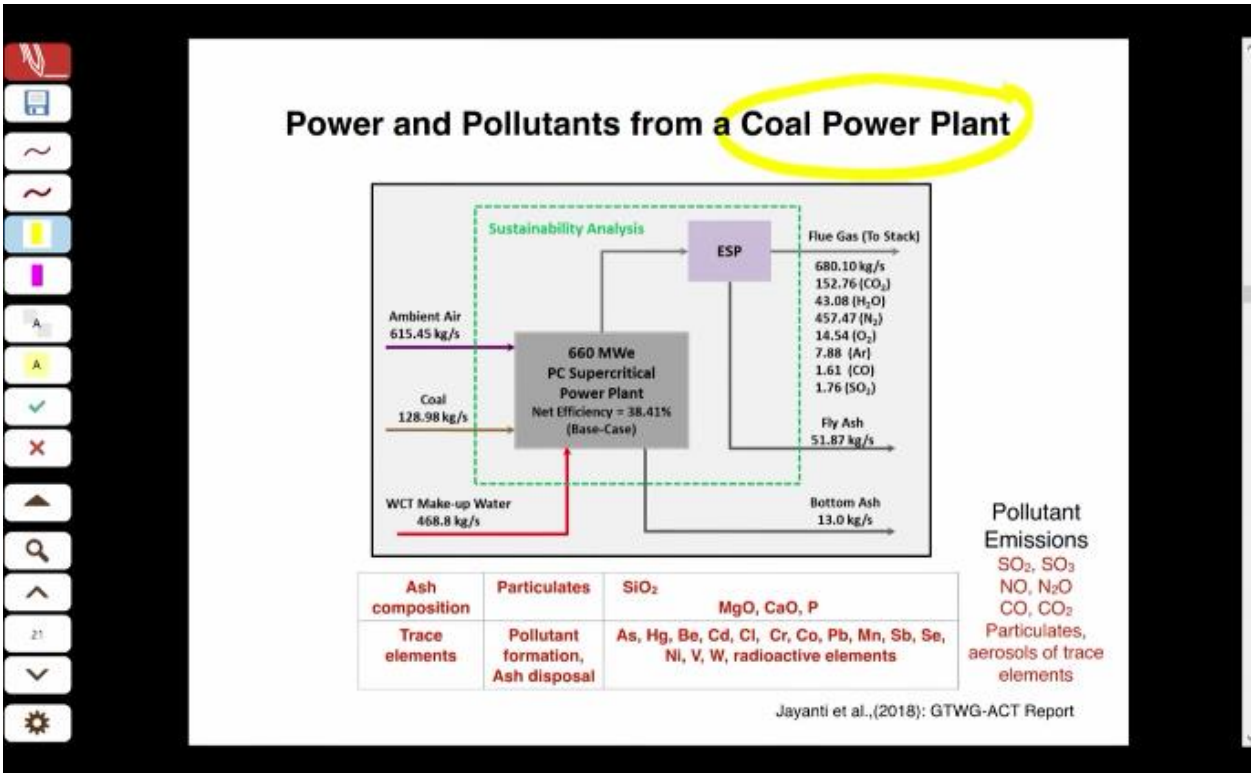
Welcome to the lecture number 4, in the module on Energy and Environment under the Ecology and Environment course. My name is Sreenivas Jayanthi. I am a professor in the Chemical Engineering Department.

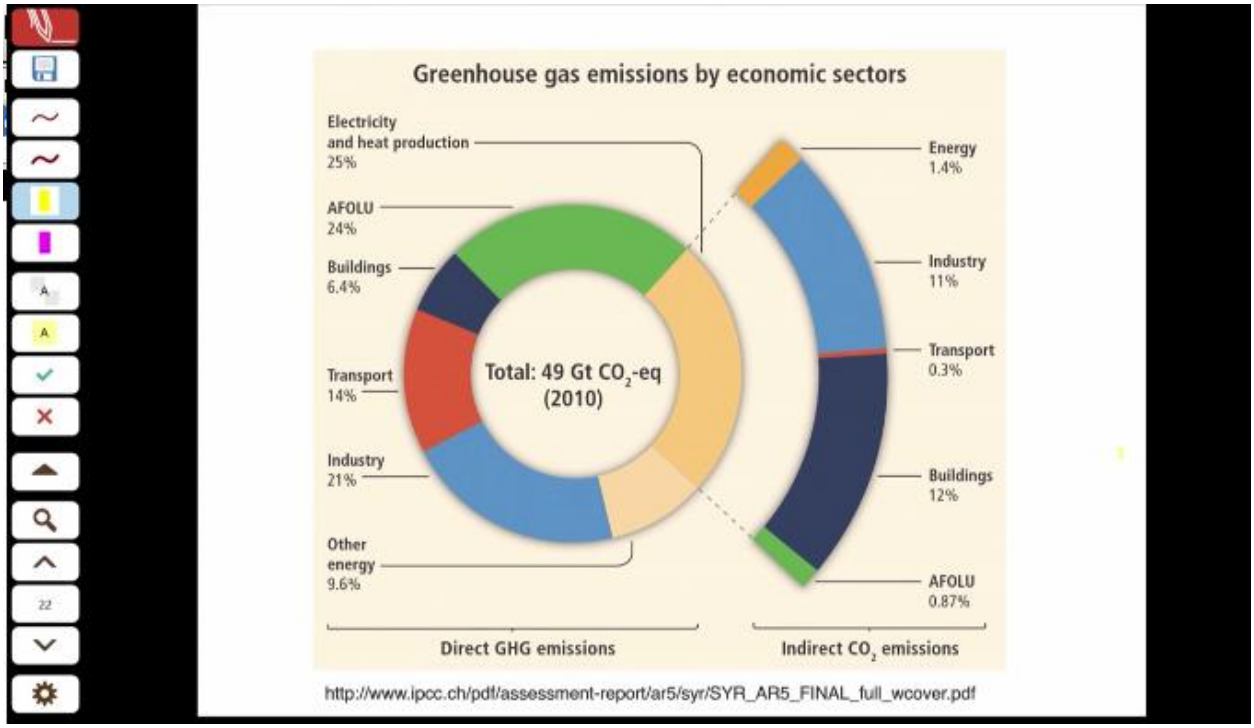
We had already three lectures in this series, in the first lecture we looked at the connection nexus between energy and environment, in the second lecture we looked at in detail about what, where the energy is coming from and what kind of demand is expected from energy in the coming years.

In the third lecture, we looked at the pollutants that emerge from energy harvesting from nature. In this lecture, we are going to continue further and look at the present problem of global warming which is attributed to anthropogenic causes especially to the harnessing of energy from fossil fuels and other sources, other human-related activities.

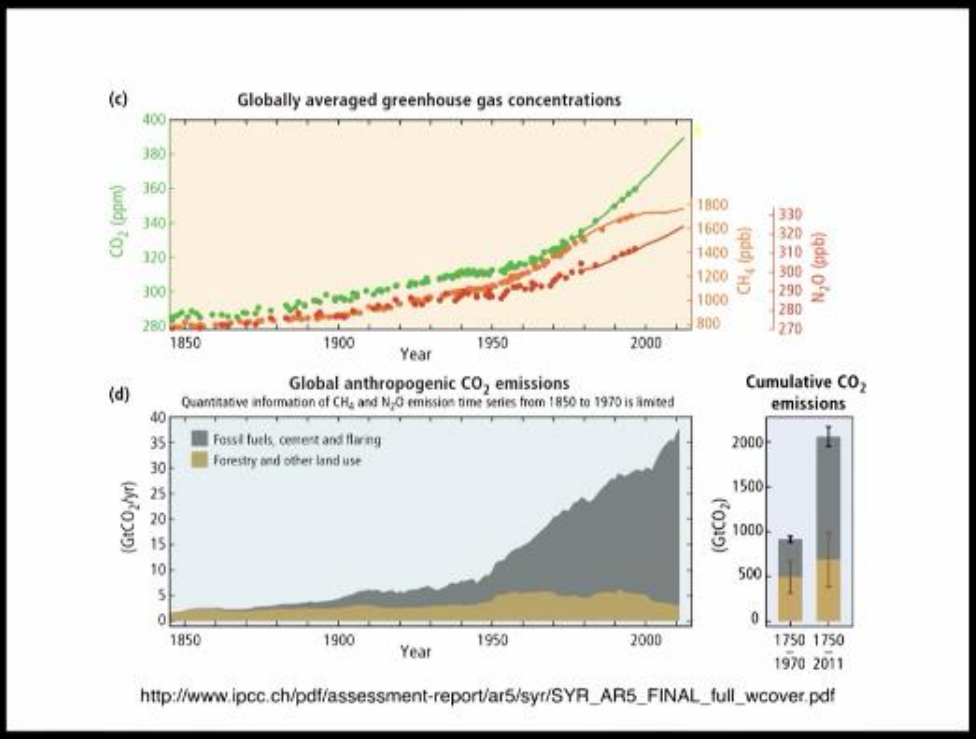


In the first lecture we looked at how the energy demand has been increasing year by year, right from 1970's and how it is expected to increase for the coming several years and also how most of the energy has been coming and is expected to continue to come from fossil fuels, coal, natural gas, and oil. And we also saw that when we draw energy from a coal power plant, we have a number of emissions in terms of sulphur dioxide, nitric oxide, carbon monoxide, carbon dioxide, particulates and aerosols of trace elements, all of which can give rise to a number of immediate health and environmental problems.

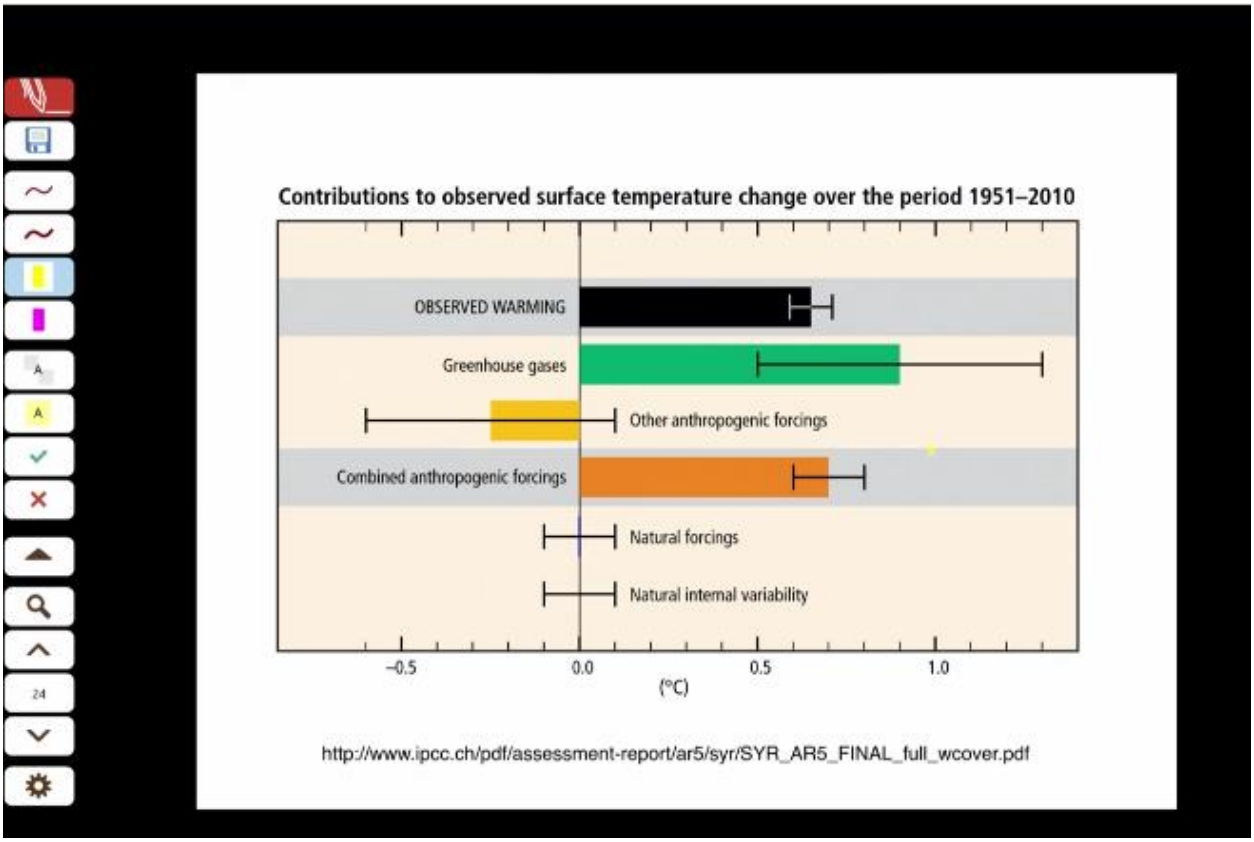




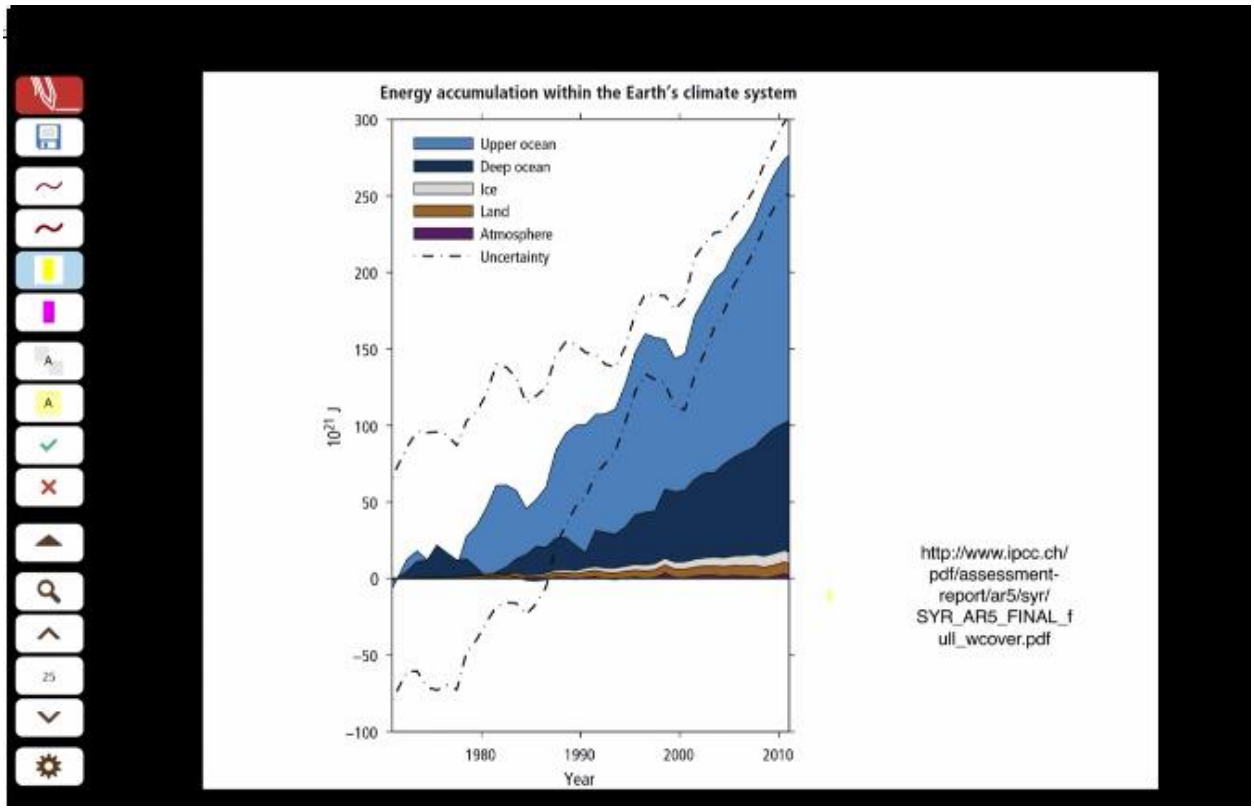
And we also saw that despite this fear about carbon dioxide emissions we have a large increase in, continued increase in carbon dioxide emissions which came up to 49 gigatons of carbon dioxide equivalent in the year 2010.



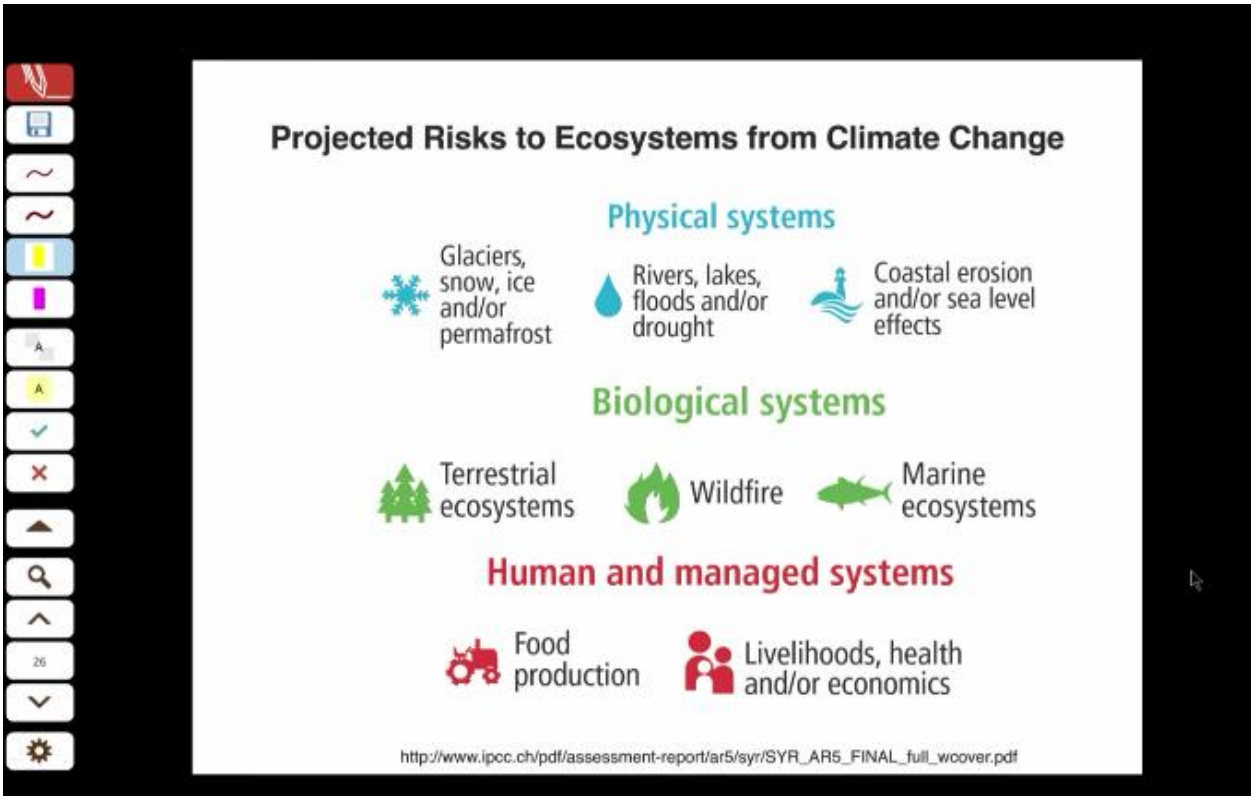
And that these emissions are coming from all sectors of human activity from transport, industry, energy, and buildings and agricultural activities, industrial activities, all these things are contributing to carbon dioxide emission. So, carbon dioxide emission is, has permeated into the human life in a very involved way. But the fact remains that in the modern era, in the past 50 years we see increasing rate of emissions and large increases in carbon dioxide concentration and methane and nitrous oxide concentrations in the atmosphere, these concentrations are still very low. Carbon dioxide concentration is only 0.04% by volume, and these concentrations are so low that they do not pose a direct danger to us in terms of their toxicity, but we have been accumulating carbon dioxide emissions into the atmosphere at such a high rate that it is believed by a number of experts, scientific experts in the scientific community that this is actually caused a net radiative forcing of the order of 2 to 3 watt per meter square compared to about 340 watt per meter square of incident solar energy on to the upper reaches of the atmosphere.



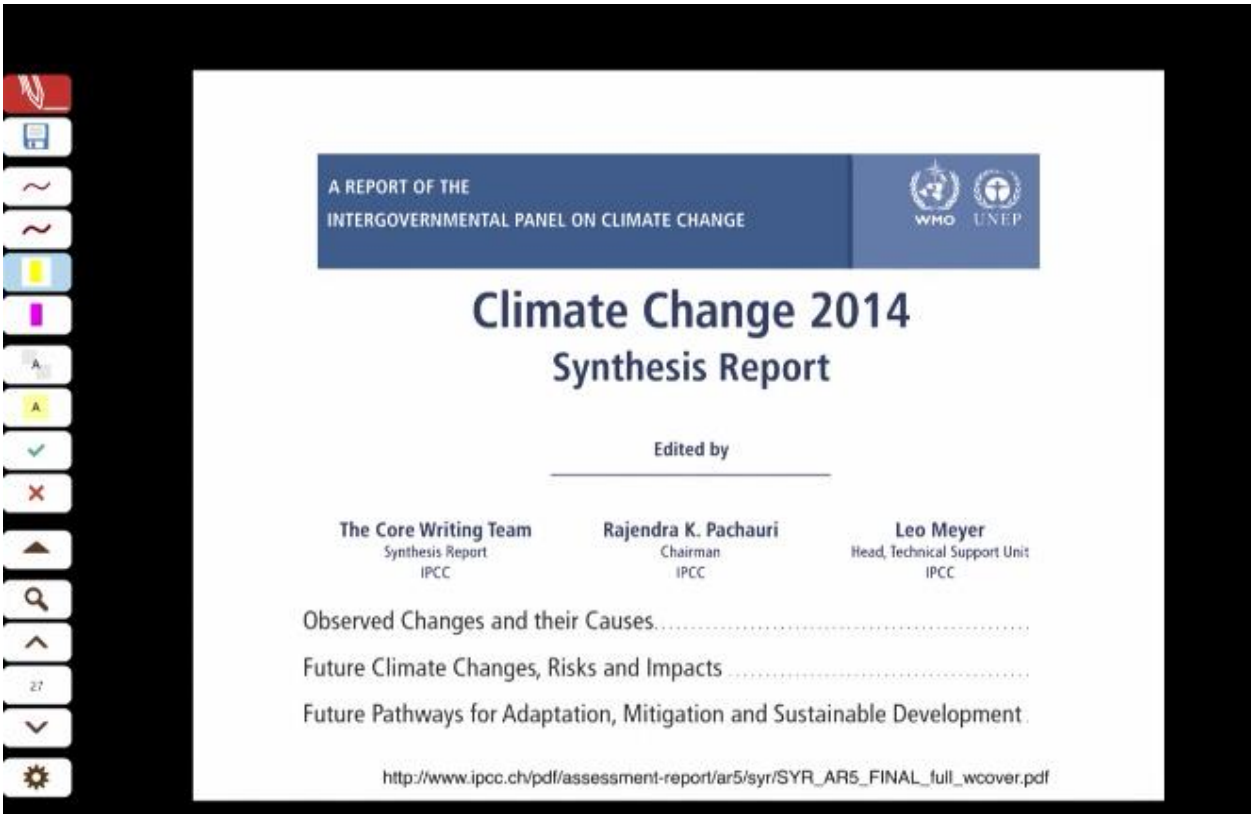
So, it is only about 1% or less, but still, this has given rise to an increase in the atmospheric temperature of the order of 0.5 to 1 degree centigrade.



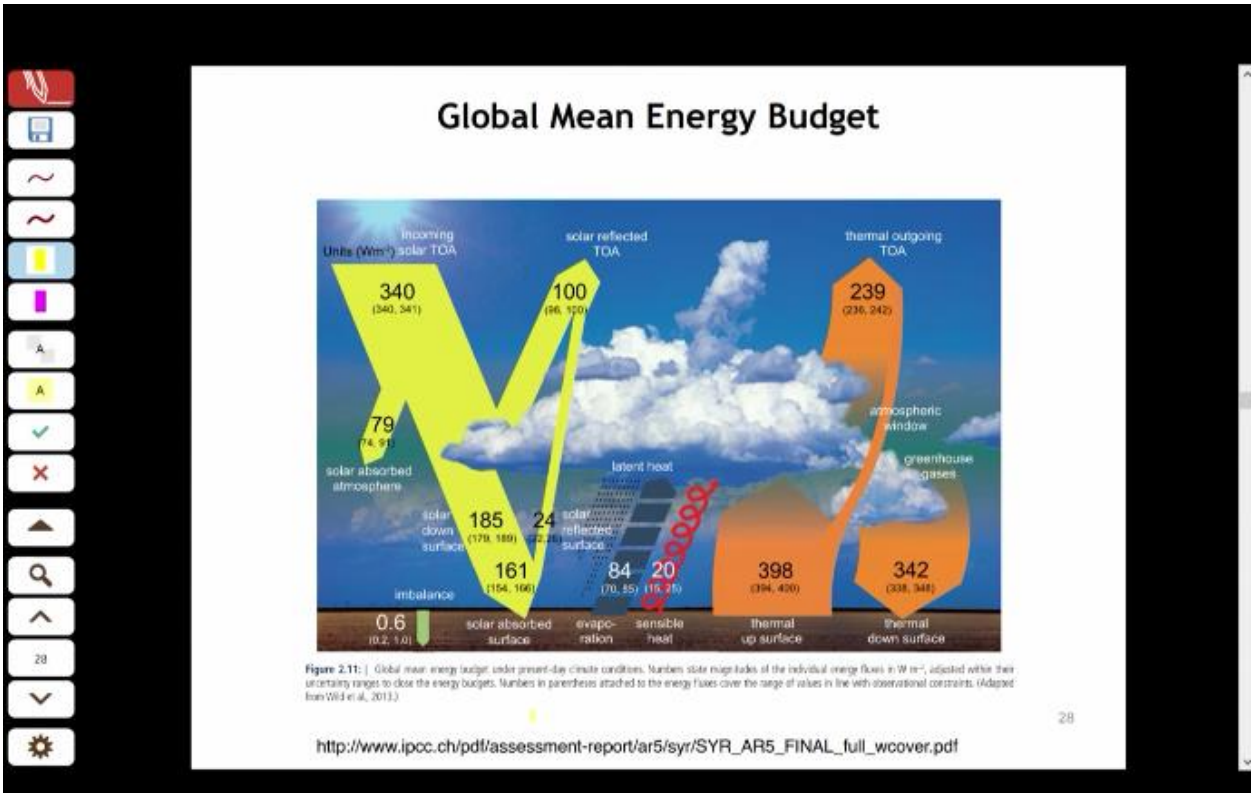
And this has led to huge accumulation of thermal energy in earth's climate system in the upper oceans, deeper oceans, in the ice, land, and also atmosphere. And as a result of this, it is expected to have serious consequences, these small temperature changes are expected to have a serious consequences on the physical systems that are there on the earth like the glaciers, snow, ice, permafrost, rivers, coastal areas, sea level rises, erosion of coastal areas, and also biological systems, terrestrial ecosystems, wildfire, marine ecosystems, and also human and managed systems like food production, livelihoods, health and economics. All these factors are influenced by these sort of changes that have been happening, which are attributed to our continued emissions of carbon dioxide and other greenhouse gases in the process of energy harvesting which is needed for our economic prosperity.



So, there lies the conflict between and energy environment. In order to find a possible midway path between and energy environment, we would like to take a close look at what is this, what this global warming is about, and we would like to understand the scales, the orders of magnitude of the problem and see what kind of solution is possible. So, in this lecture we are going to look specifically at the global warming problem and what is behind it, and what kind of message it has for us, okay.



So, this issue of global warming has been under worldwide study of scientific scientist across the world under the form of IPCC intergovernmental panel on climate change which is celebrating its 30th year, this year and so it is been on the study, continuous study with improvements and improvements and revisions over the past 3 decades and even more. And these have produced report, I think in 2014, latest report which has a very detailed analysis as of climate change 2014, and it has a lot of analysis on observed changes and the causes in the atmosphere climate, future climate changes risk and impacts, and also it suggests certain pathways for adaptation, mitigation and sustainability development. So, all these aspects are important when we deal with global warming. And we would like to look at some of the contents of this report for us to understand the science behind it and the causes behind it and the timescales involved, the magnitudes of effort that is required, that is involved in all these things. We can get, we would like to get an understanding of these issues by looking at some of the evidence that is presented here, and some of the reasoning that is presented in this.



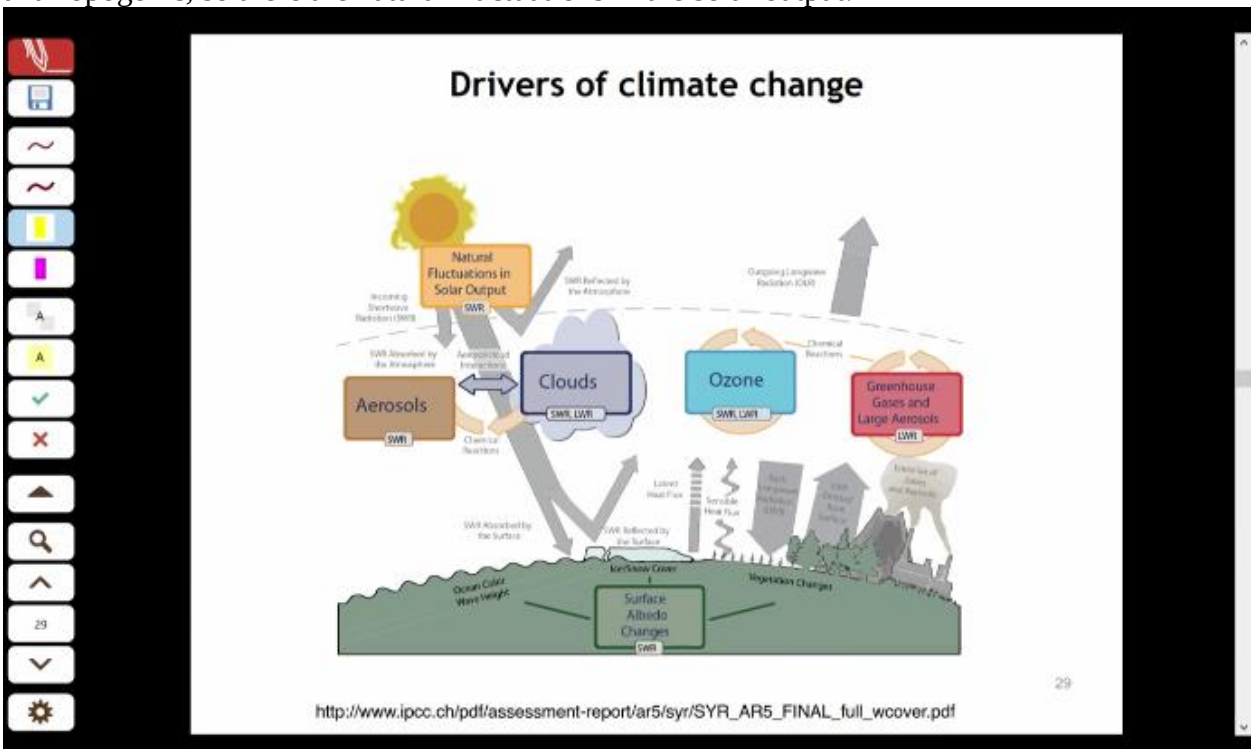
So, we are going to look at a series of pictures extracted from this report, and I would really suggest this 1500 page report as reading material for anybody interested in climate science, and it is multifarious effects on the global warming problem. It is a very detailed report contains lots of analysis and lots of observations, lots of data using many, many substituted techniques and it is a great compilation of current understanding of the global warming problem, okay.

So I would really recommended to all of you, and I hope some of you will be able to go through it in bits and pieces. It is freely downloadable from www.ipcc.ch if you go through many of those options you will be able to get, download the full report completely freely, okay.

So, let us come back to this first picture here where we are talking about the global mean energy budget and here the energy is what we are getting from solar source and more than 99.8% of the total energy that we get is coming from the sun, and a small amount is coming from the heat released by the core, in a core of the earth and even smaller, smaller amount is coming from other radiation than solar energy. So, sun is the main provider and probably the only provider of energy for us in large quantities that is as required by us. So, the sun energy can be considered in terms of watts per meter square, 300 watts per meter square of the surface area of the earth, this varies in a number of ways but on the average, this is what it is, and it is been fairly constant over the several decades at least. And 340 watts per meter square is incident at the upper reaches of the atmosphere, and then as it goes through the atmosphere it gets modulated in a number of ways by our atmosphere, by what is happening on the earth surface, and what is happening, what has happened before also as we will see. So, out of the 340, 79 watts per meter square is absorbed in the atmosphere, and a net of 100 watts per meter square, so that is about 30% is reflected back into the outer space, and 185 so slightly more than half is reaching the ground, and 24 of that is reflected back as shortwave radiation, reflected from the Antarctic ice, Arctic ice

and a number of, from the land, from the ocean, all these things, this known as the albedo. So, all of this contribute to the reflection of the incident light without any modulation. And so we have only less than half 161 watts per meter square coming on to the surface, where it gets transformed in a number of ways it gets absorbed into the surface, it leads to evaporation from the land, from the sea, and then it also contributes to sensible heating of the atmosphere, and then it is also, it maintains a certain temperature of the earth surface because of its temperature, it emits radiation to the extinct of 398 watt per meter square. And this is reflected back into the atmosphere, and a significant portion is emitted back 342 is emitted back into the earth surface, and a net amount of 239 is what is lost into this space.

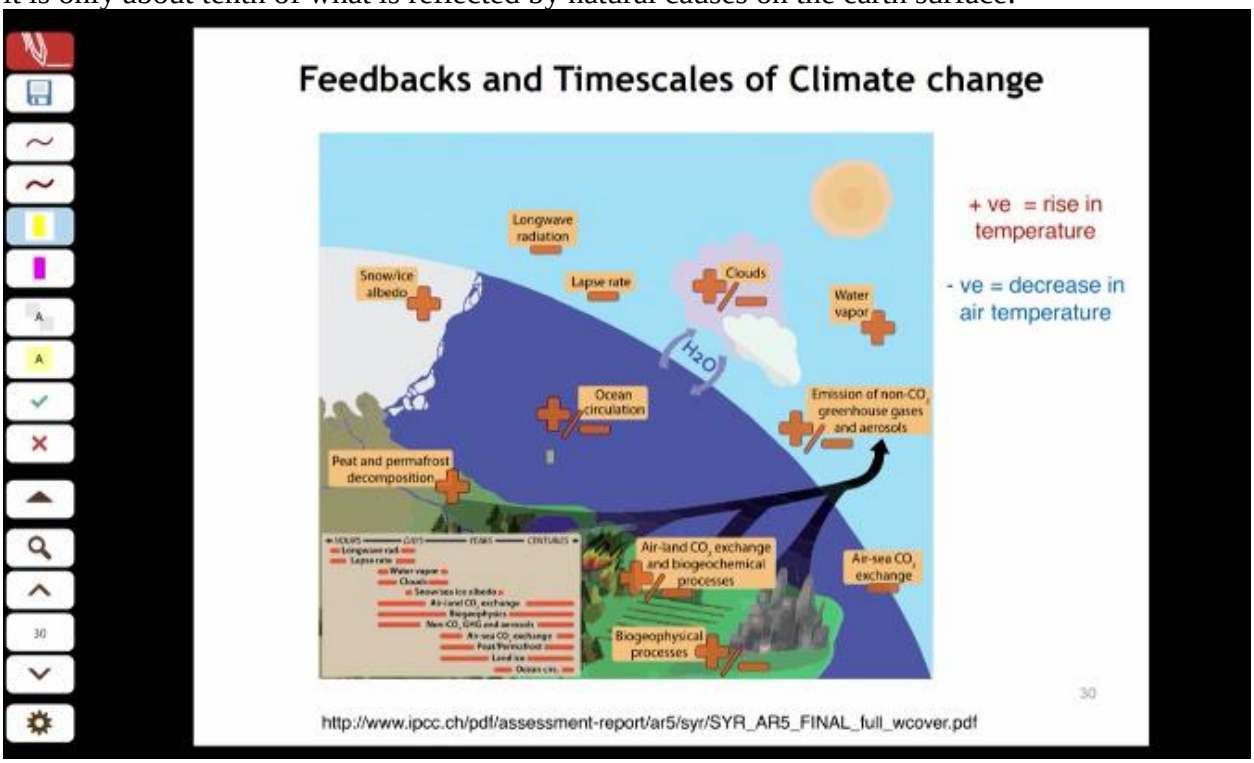
So what is lost into space as thermal radiation, as longwave radiation plus what is reflected shortwave radiation is almost balanced by what is coming here 340. There is a small difference, that is 0.6 watt per meter square is supposed to be the imbalance which is going into the earth surface, this-this has been the way for centuries, but it is not always been like that, there were times, of course, when the oxygen concentration was minuscule, and carbon dioxide concentration was as much as 10%, so this 10,000 ppm. So it is not that life things have been the same way as there are a number of causes for this climate change, natural and also human-related anthropogenic, so there are natural fluctuations in the solar output.



And the aerosols, the minute particles that are present in the atmosphere contribute a significant amount in terms of capturing the solar shortwave radiation and also reflecting it and then also in the long wave range. These aerosols can be generated by us by human activities, they can also be generated by natural activities like volcanic eruptions and then winds, storms, and a number of fires, natural fires, all these things can generate aerosols. And then you can also have clouds, we know clouds are found in many different ways, and then you can have ozone which is a substantial gas which interferes with this process, and we have heard of ozone fluctuations caused by number of factors, and then you have that culprits that we are interested in, the

greenhouse gases and large aerosols, some of which, many of which are contributed to by our human activities.

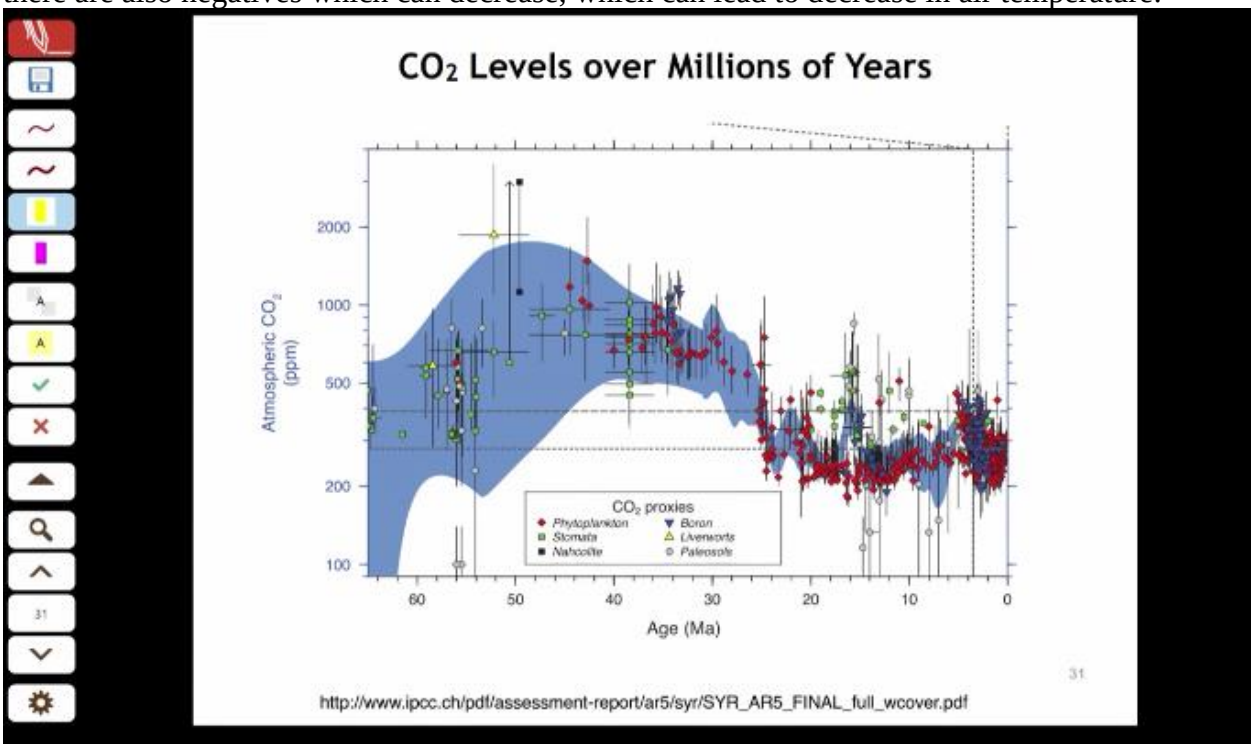
And then you also have vegetation changes on the earth surface, and ice and snow cover during winter time, during summertime, as it changes as the cover changes, then you can have changes. Ocean color wave height are also causes for the surface albedo, that is amount of wave that is reflected, and I would like to point out here that we are looking at 340 watt per meter square as the amount that is coming into the upper reaches, and example what is reflected by the earth surface is 24 watt per meter square and what is attributed to anthropogenic causes, the radiative forcing which can be compared with this is only of the order of 2 to 3 watt per meter square. So, it is only about tenth of what is reflected by natural causes on the earth surface.



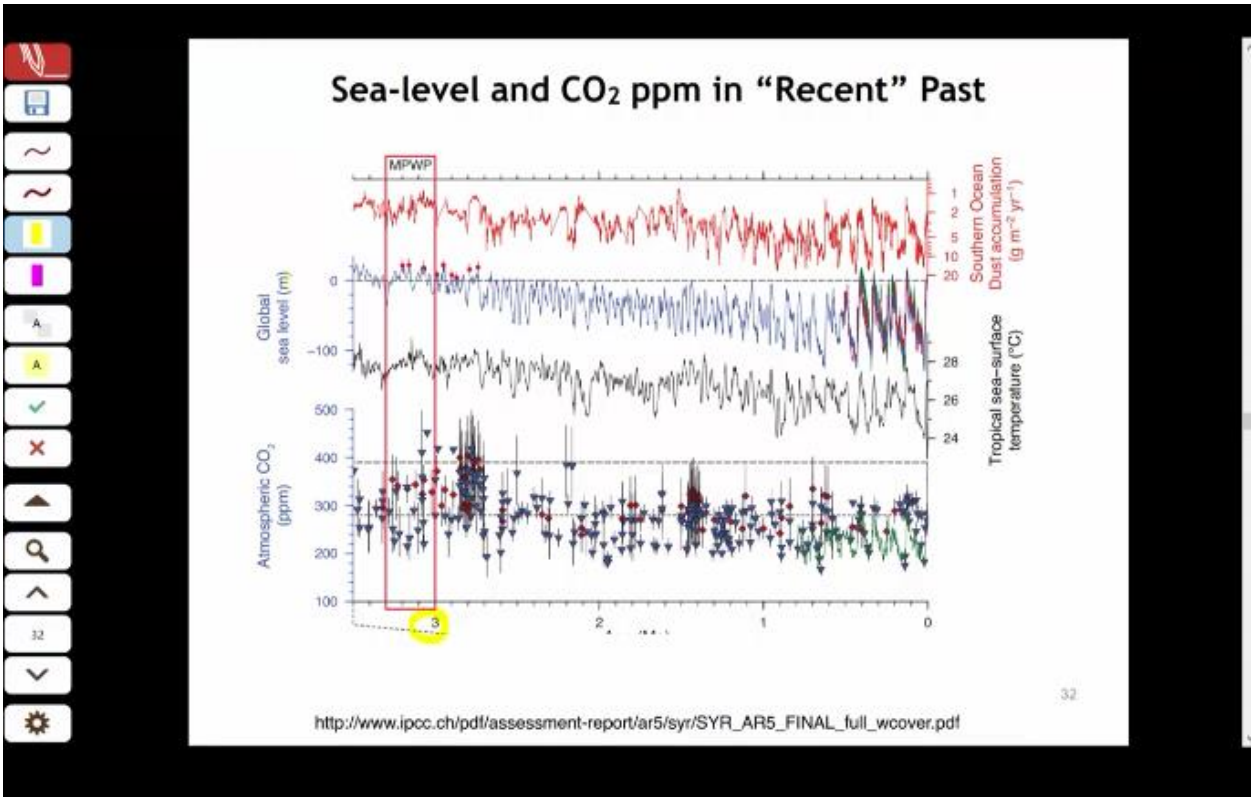
So, in that sense, we are looking at small changes in terms of this, but it is not very simple as it is being too small and things like that, there are other reasons for it, but let us postponed that discussion short time. And complication arising is from a number of physical phenomena that happen, for example you can have snow, ice, albedo effect, longwave radiation, and the lapse rate so that is the rate at which the temperature decreases, clouds, water vapor, emission of non CO_2 greenhouse gas and aerosols, air-sea carbon dioxide exchange, air-land carbon dioxide exchange in the process of vegetation growth and all that, bio geophysical process, and peat and permafrost decomposition as temperature of the air changes, of the atmosphere changes, then these kind of vegetal matter can decompose giving rise to emissions of this GHG gases. So, there are all these factors which contribute to, which are affecting the way the temperature evolves as a result of increase or decrease in concentrations of this GHG gases.

And also as a result of minute changes in the temperature of the atmosphere, temperature of the upper layers of the of the oceans, and the land and so on. So, out of this we can see there are

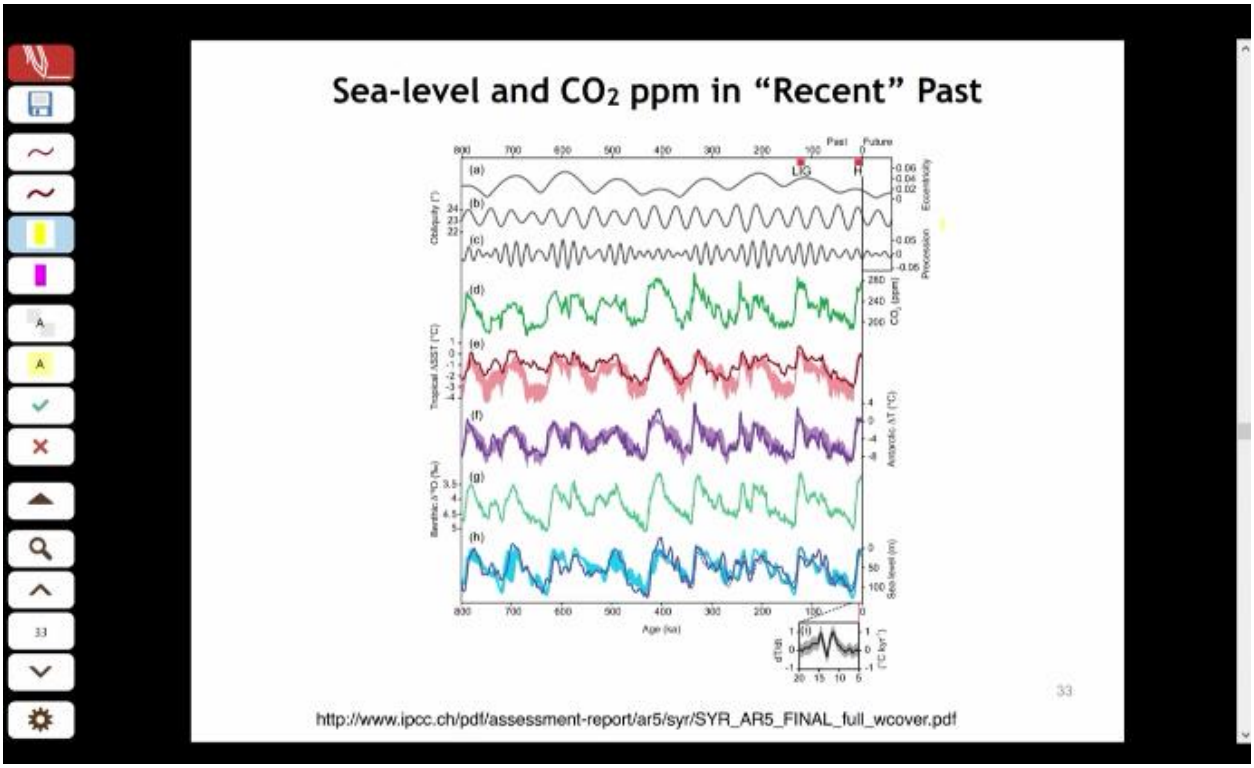
some positives which mean that as a result of this we will have increase in temperature, and then there are also negatives which can decrease, which can lead to decrease in air temperature.



So, as a result of all these things there has been continual change in the atmospheric concentration over millions of years, well, well before man was born. And this is one such part of the data coming from number of sources other than direct evidence, direct measurement, obviously it is so far back into the years, we are looking at 60 million years and you can see that there was a time at which carbon dioxide concentration was in excess of 50 to 500 to 1000 ppm, there are a error bars but there is, there is been a much higher concentration and over the past 40 million years, there has been a steady decrease in this, and a fairly constant variation over the last 10 to 20 million years ago. And here we have, this is where we are really interested in, and this particular reduction is attributed to a natural cause which leads to where we are, which is the collision of India, the Indian subcontinent leading to the formation of the Himalaya mountain range is supposed to have, led to a large absorption of carbon dioxide in the natural weathering process, so as to decrease the atmospheric concentration of carbon dioxide. As a result of which we had cooling here, and this cooling is supposed to be related to the formation of what we now call as India, and of course other neighboring countries.

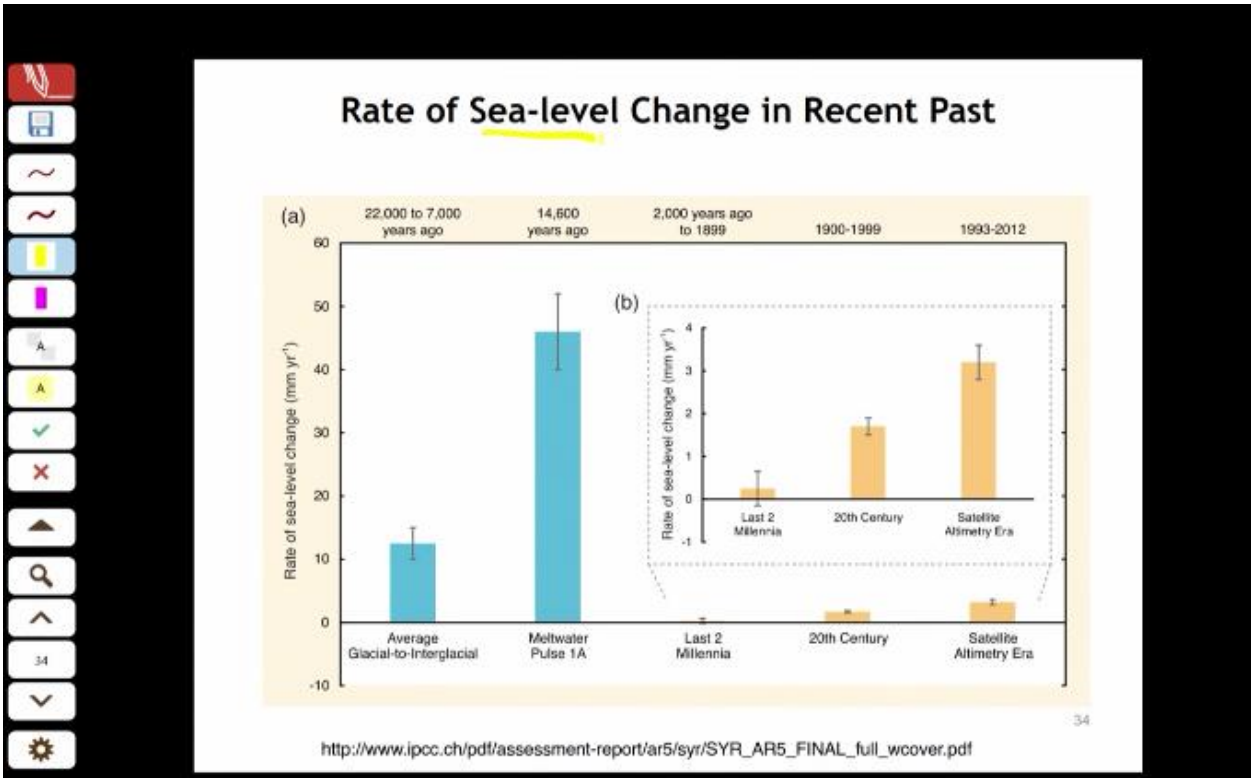


And so they have been natural causes which have led to large-scale changes in carbon dioxide concentration, coming back to a closer range of 0 to 3 million years ago, okay. So, we can see sea level changes, atmospheric concentration changes and you will see variations here of the order of between 200 to 400 ppm, they have been like this, but variations and you can see global sea level variation is given by this compared to present level of zero. They have been significant decreases of the order of -100 meters, so sea level has been rising and falling, rising and falling by tens of meters, naturally, well before man has had his footprint or evil hand into this. And we also see large-scale changes of much larger amplitude almost of the order of 100 meters happening in the last 500 to 1000 years like this here, and we also see large scale fluctuations here of the sea surface temperature, okay.



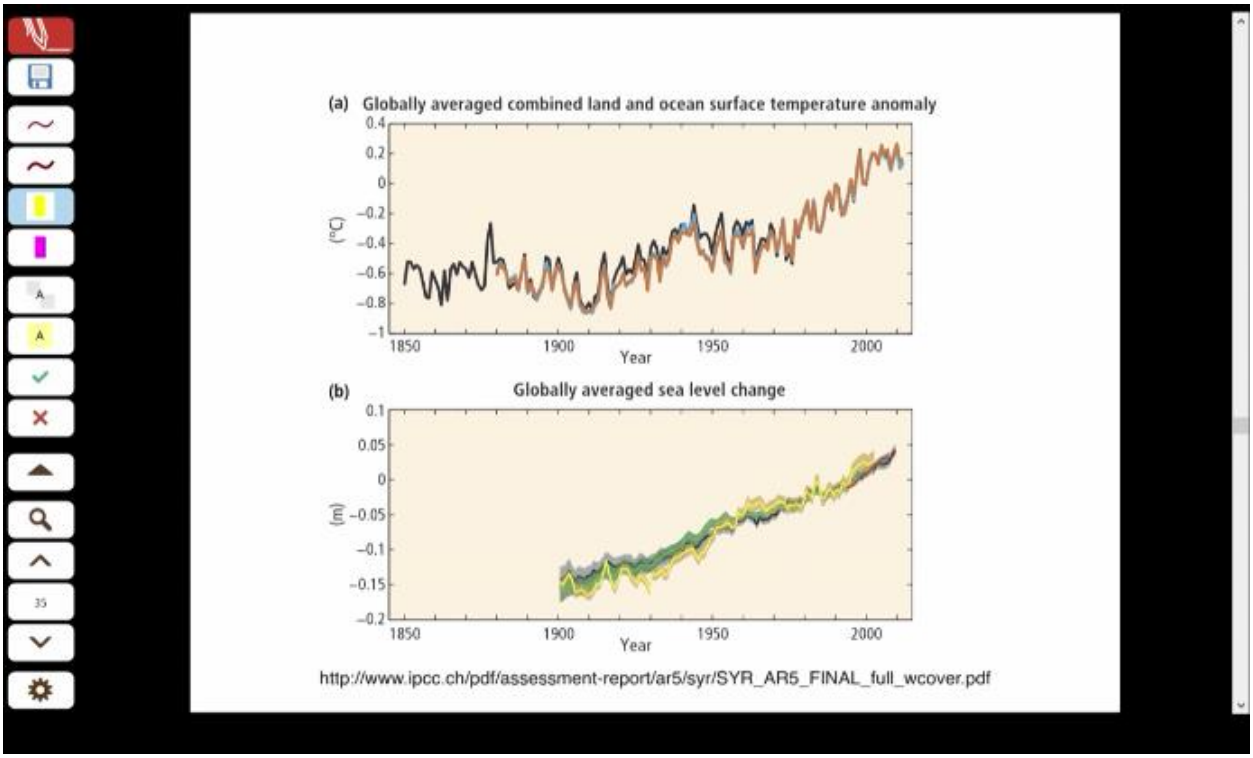
And then other dust accumulation which is actually leading to this kind of observations here, so there have been changes of the things that we have been looking at, and this is more of the recent past where there is more of direct evidence in the form of ice cores that have been dug up in various places, and from these things you can find variation of sea-level, variation of Antarctic temperature with respect to the present and then sea surface temperature in the tropical thing, carbon dioxide concentrations and also what is expected to be one of the causes of this climate changes in the in present times which is the precession of earth around the sun is supposed to cause a small change in terms of the radiation that is received. And there is been some evidence to say that this have had the corresponding changes in these. And these also seem to show that present-day climate of these last million years ago is far more susceptible to this kind of changes, which have led to changes, systematic changes in the carbon dioxide concentration and temperature changes of the order of several degrees, a few degrees at least. Sea-level changes of the order of 100 meters have happened in the recent in the previous 800 to 1000 years, 8 lakh years, 0.8 million years, okay.

So, this is an evidence that is that has stood the scrutiny of a number of scientists, and so this is something that is both a cause for worry and also an assurance that things will not go, so so much out of hand, okay, so there is that kind of thing.



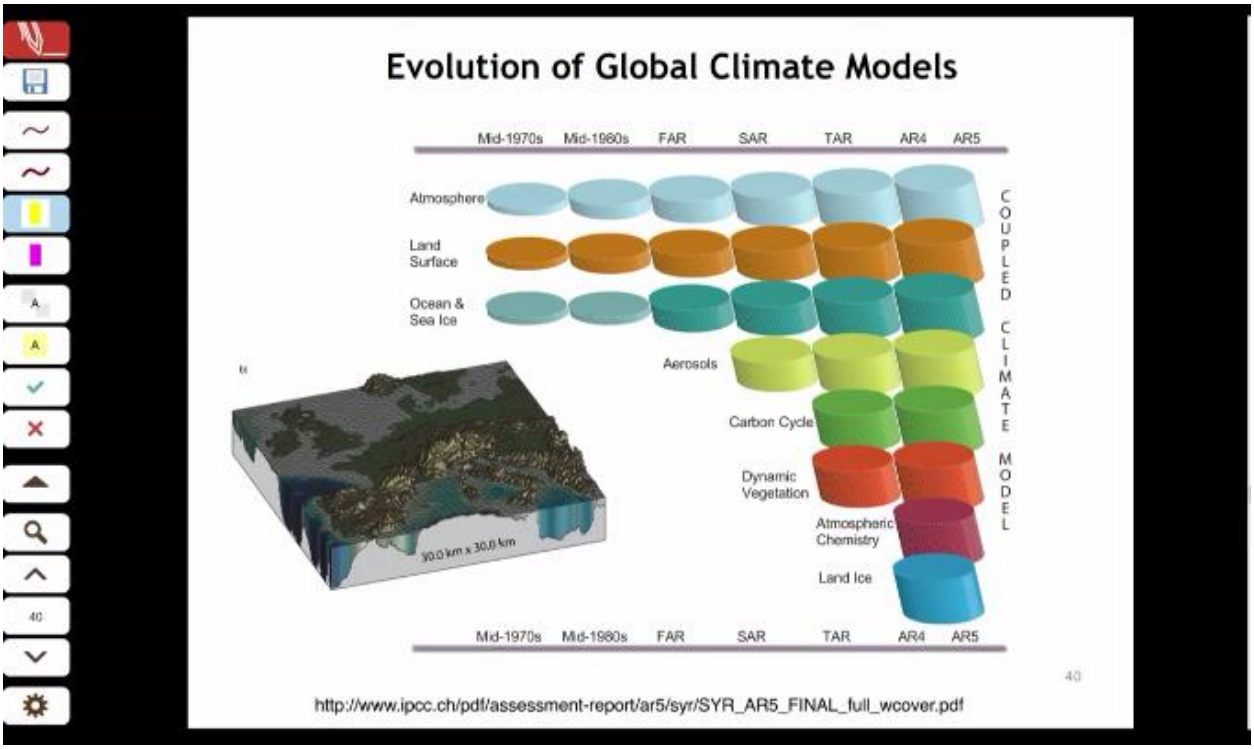
And if you look at one of the headline figures in terms of the sea-level changes in the recent past and what we are looking at is a rate of sea-level changes. So, about 20,000 years ago there is a rate of sea-level change of the order of about 12 millimeters per year, okay, and around 15,000 years ago there is a specific climatic event during which the rate of sea level changes as high as 40 millimeters per year.

And over the last 2000 years, it is minuscule you can see that it is 0.2 millimeters per year and in the 20th century, we have 1.7 millimeters per year. So, this is very small compared to the changes that have taken place about 15,000 years ago. And of course, man was there, but man was not there leading to such a large footprint in terms of carbon dioxide emissions to a 15,000 years ago. So that is why we can say that these are assurances that much larger scale changes have happened in the recent past and man himself have faced them, of course, there is a lot of consequences on the human population, and at one time during one of these events it is said that there has been almost a decimation of the human population at that time. So, that is 90, decimation is coming down to a level of 10% of that, okay.

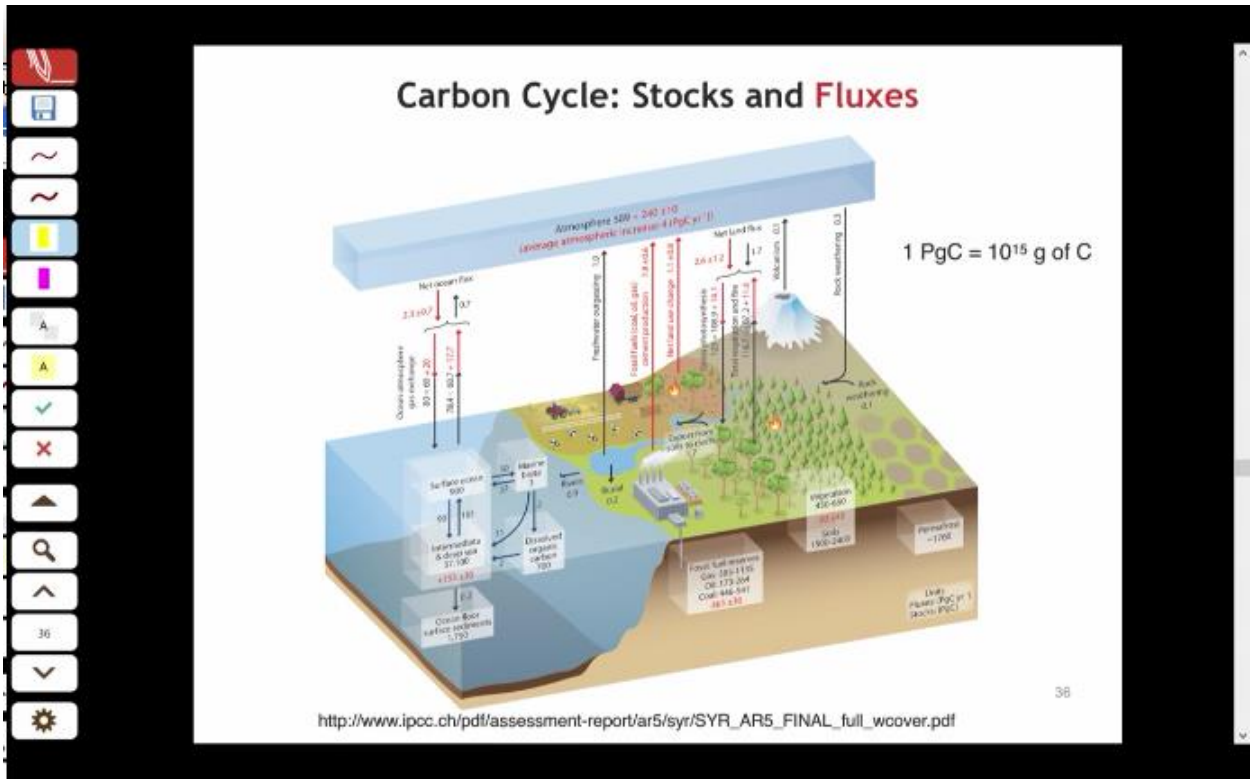


But large-scale almost extension type of event, consequences have happened, and so the consequences of this can be very large for small changes in this, in the atmospheric temperature, and when we say small changes in this, we are talking about changes of the order of 4 degrees in the sea surface temperature. So are these kind of things possible? And is there creditability?

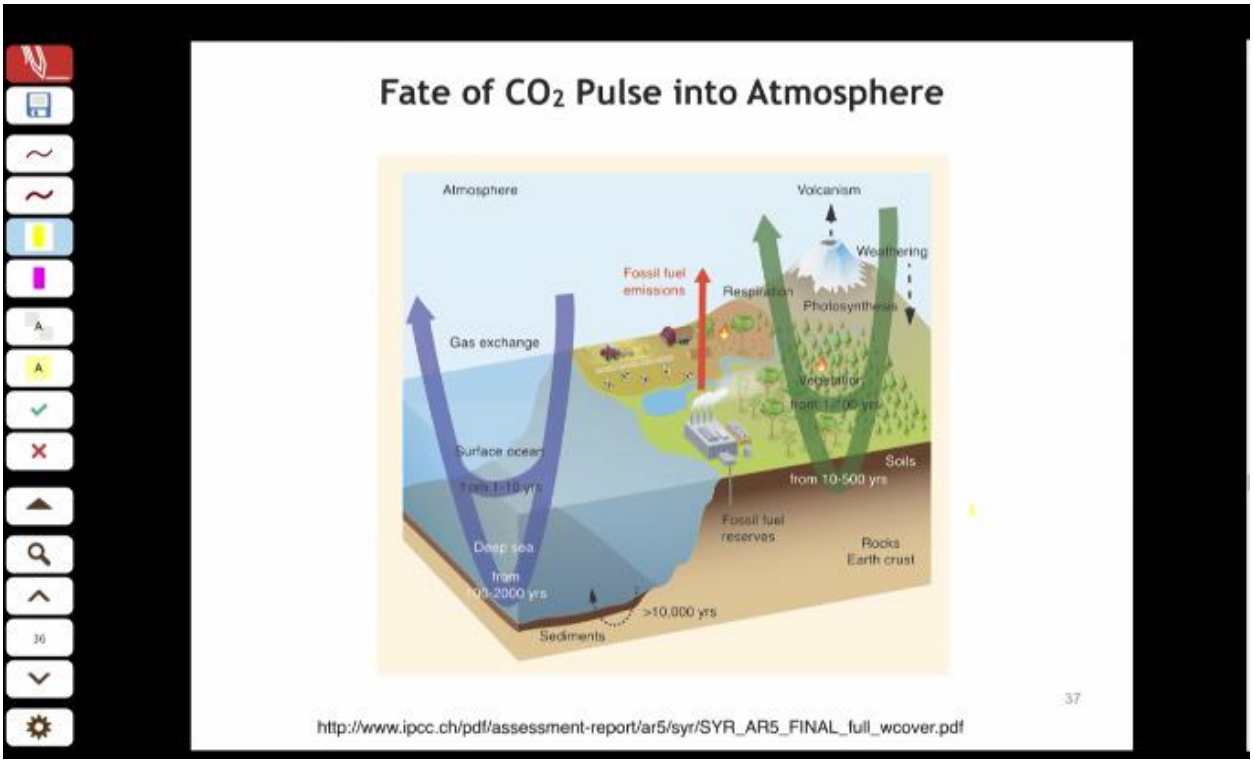
If you look at the changes that are happened in the last 150 years in terms of temperature change it has gone up from -0.6 to about 0.2, so it is about 0.8 degree centigrade over the last 100 years, over the last 150 years, but worrying trend is that over the last 50 years it is been rising at a fairly large rate. And sea level change in the last century has been from -0.15 to about 0.05, so that is about 20 centimeters it has risen. So, on the face of it, okay, when you look at these figures whether it is carbon dioxide concentration or sea-level change, temperature changes, 1, 2 degrees, what is the big deal because there are seasonal changes which are much more rapid and much much higher. And we have sea level change of 0.2 meters, 20 centimeters in 100 years, is hardly anything for us to worry about. This is something that on the face of it, it looks like this, but consequences of this, on the whole, are supposed to be much more much more harmful, and some of these are predicted by the global climate models because of the complexities that are involved in the agents that contribute to change of climate and the number of different factors that come into picture.



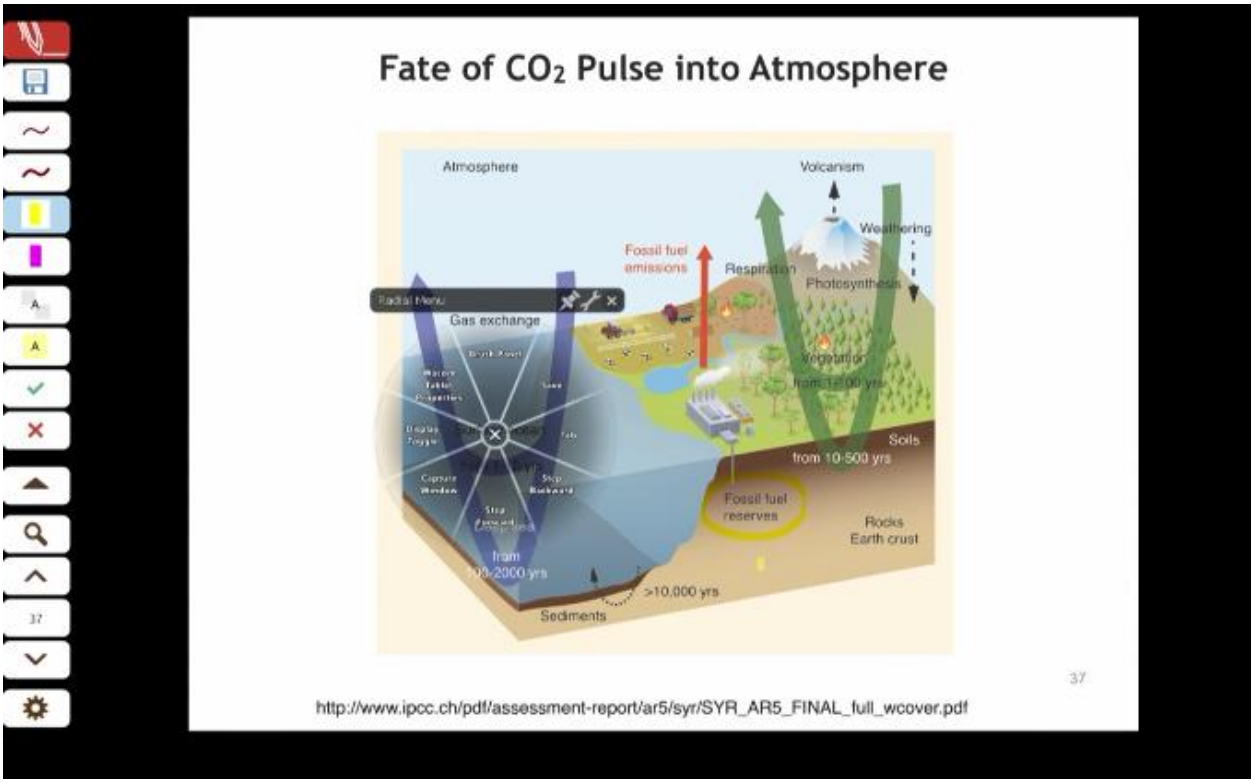
There has been a consorted attempt going back to 40, 50 years towards developing global climate models, and early studies have linked only the atmosphere, land and ocean surface, but gradually we have other factors like aerosols coming into picture, the carbon cycle, vegetation, the dynamic vegetation and some atmospheric chemistry, land ice, all these factors have been gradually included into this.



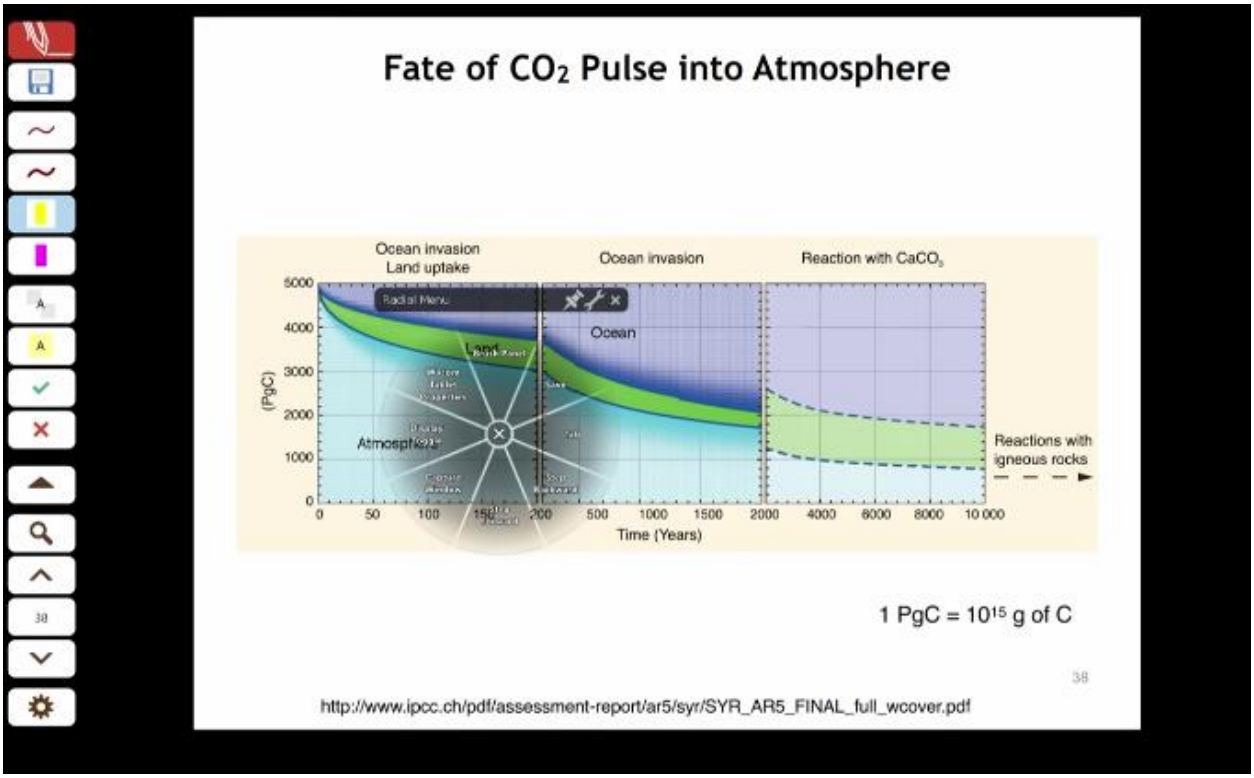
For example, when we look at carbon dioxide concentration we really have to understand how much carbon dioxide there is, how much carbon dioxide, how it changes when you look at this carbon cycle we have here stock of carbon in, so that is amount of carbon stored in different state of the upper parts of the earth surface and the atmosphere. And then we also have fluxes, because amount that is there in any particular reservoir is not constant, it is being continuously exchanged with other reservoirs so that there is a carbon cycle. So, you have atmosphere, and atmosphere and the ocean surface are in constant exchange of carbon dioxide because carbon dioxide can dissolve in the sea water and then go into bicarbonate form, or bicarbonate is getting converted into carbonate forms. And carbon dioxide can also be taken by vegetation on the surface, and when vegetal matter or animal matter decomposes or when you have a wildfire, you can have carbon dioxide generation. And then you can have volcano, volcanic eruptions giving rise to both direct evolution of carbon dioxide, but also, more importantly, some other minerals which come out on to the surface and lead to carbon dioxide absorption, there is a possibility.



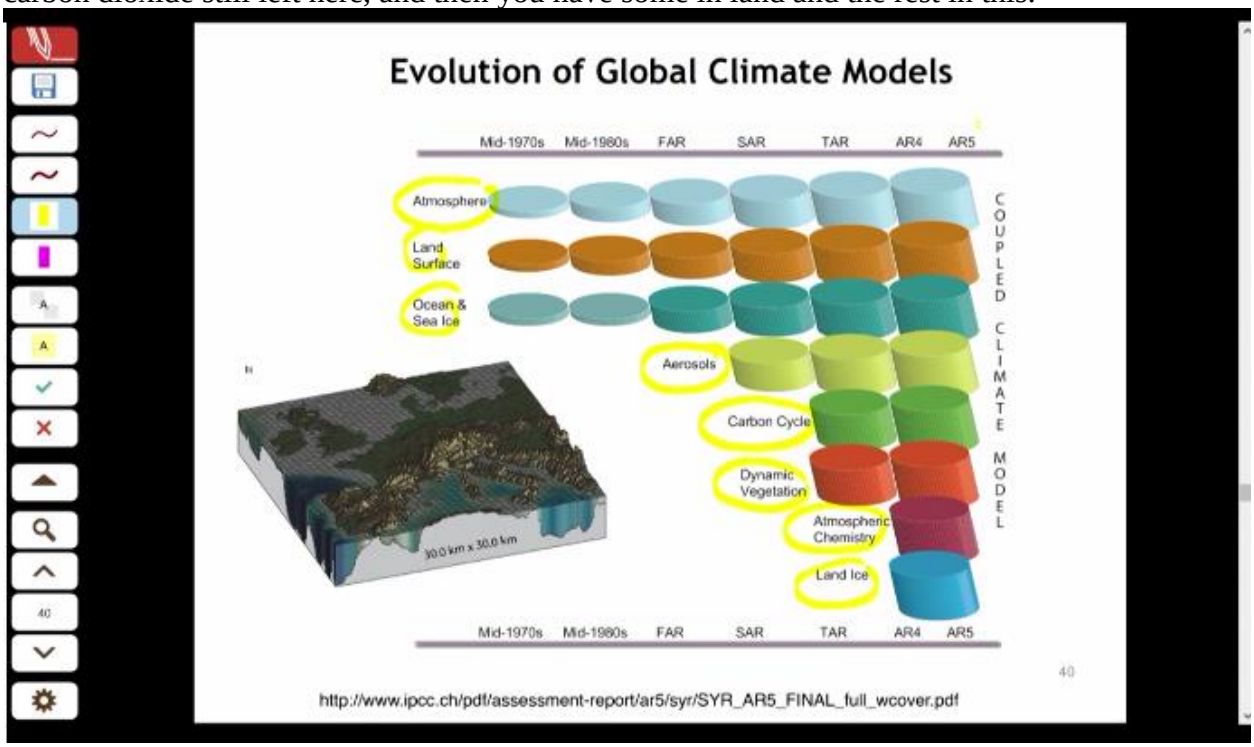
And these volcanic eruptions also cause distribution of very fine scale aerosols into the atmosphere which play which interact with incoming solar radiation from the sun and also outgoing solar radiation from the earth and then lead to accumulation or release of this. And then you have vegetal matter becoming deposits and then forming the earth surface, earth crust, and then all these things, these are all and fossil fuel reserves that are there may be a kilometer, 2 kilometers inside the, from the earth's surface, these are all carbon reserves.



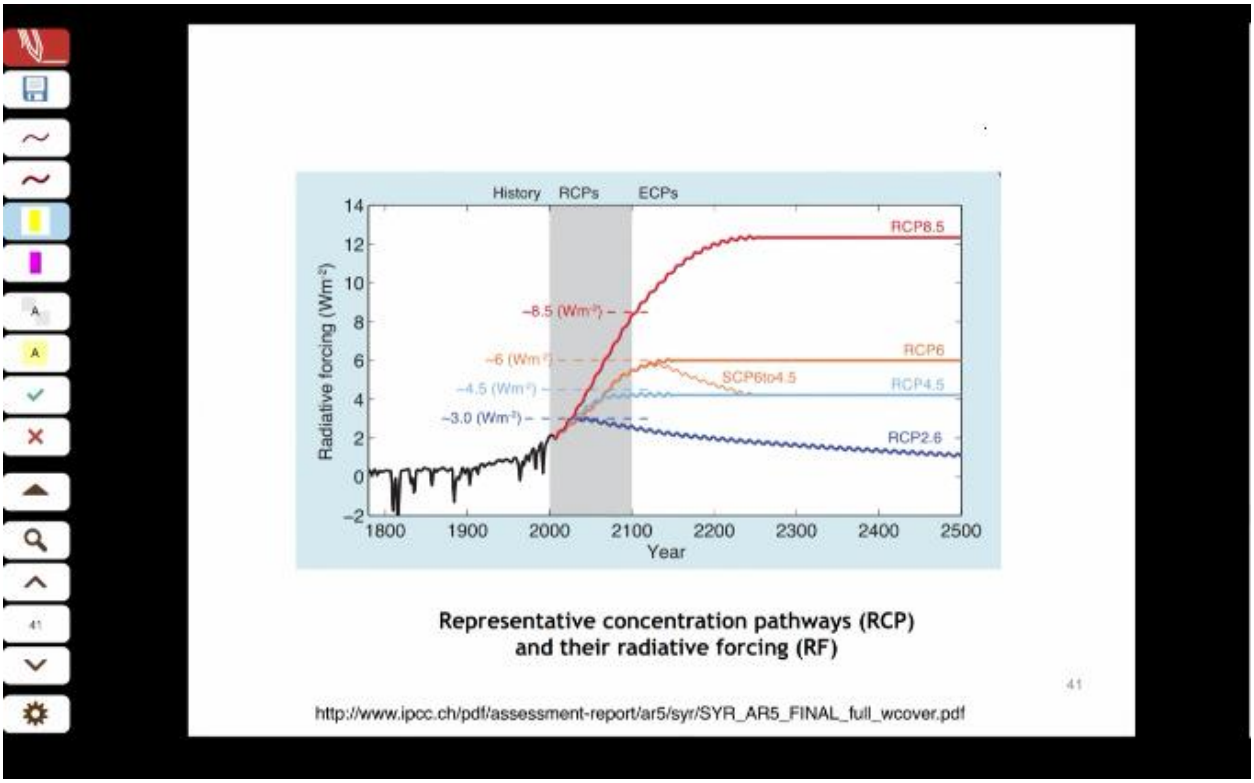
So, carbon is found on the earth crust and in the atmosphere in many, many different forms. In gaseous form, in dissolved form in water, in transformed solids in the form of vegetation, and also in terms of fossils, in terms of carbonates and rocks.



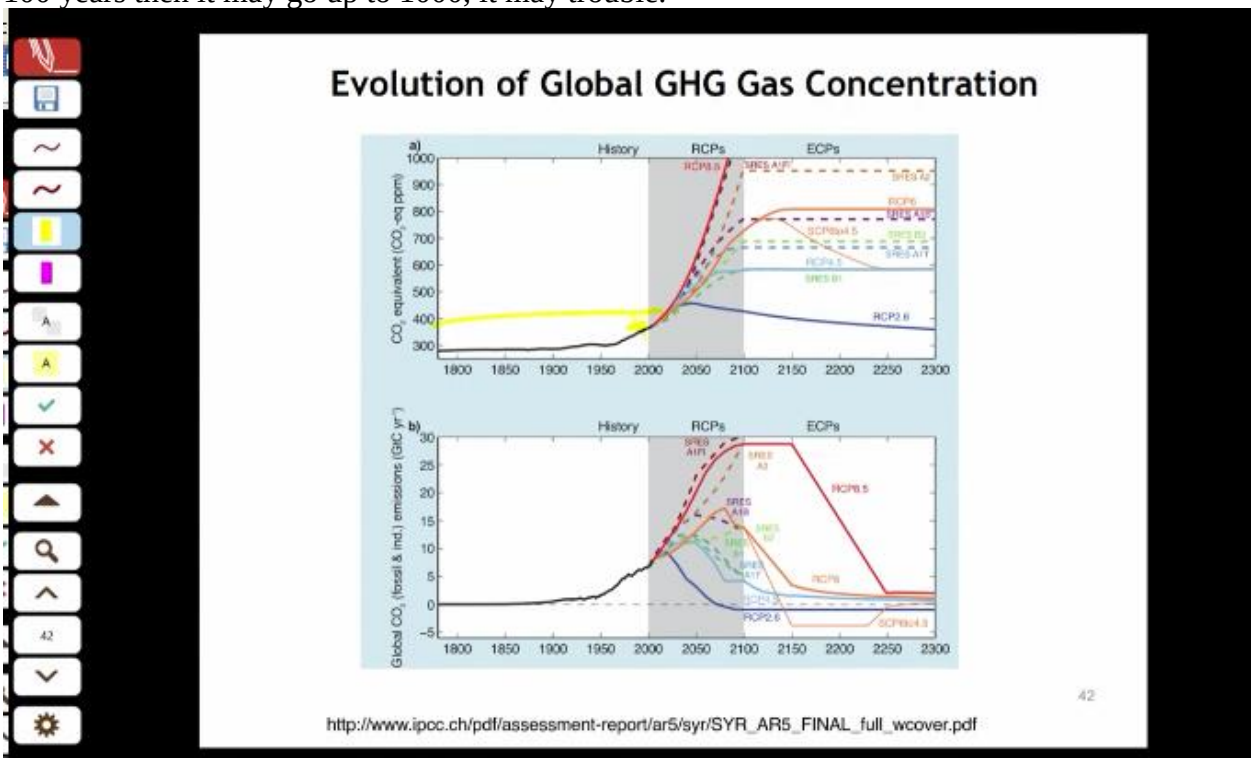
So, there are all these kinds of things, and each of these has a timescale, of interaction so that if you were to release a certain amount of carbon dioxide into the atmosphere now, then it gets slowly, slowly evacuated by this natural processes. For example, you have 5000 into 10 to the power 15 grams of carbon that is released into this, into the atmosphere and a substantial portion about 30% is slowly absorbed into land and into the atmosphere, into the ocean over 200 years, and then over 2000 years some more of that will go and you still have about 30, 40% of the original carbon dioxide still left in the atmosphere here. And some amount has gone into the land, and more amount has gone to the ocean, and after slow reaction with calcium oxide to form calcium carbonates it becomes solidified. So, after 10,000 years you still have about 15% of carbon dioxide still left here, and then you have some in land and the rest in this.



So, you have a slow evacuation of carbon dioxide. So, this causes in our timescales, an accumulation. So, if our rate of release of carbon dioxide is significant, is large then there can be accumulation, and that is what we are seeing here, and this is what is actually the cause of concern for us as shown by climate models.



And these climate models show that there is going to be a continued increase in the carbon dioxide concentration, for example here carbon dioxide concentration from 2000 is of the order of close to 400 ppm, 380 but if a current rate of emission of carbon dioxide continues for the next 100 years then it may go up to 1000, it may trouble.



That is if you do not take any action now, it can go up to 3 times what it is, and more concern showing concern and taking some measures may take it up to double, okay. So, if we retain it at our current levels and not go through the increases that we have seen, then it may lead up to doubling of carbon dioxide concentration, okay.

So, there are other scenarios which say that okay you can, they will continue to grow up, but if you take very strong action in terms of reducing carbon dioxide emissions and going towards near carbon zero emissions then over the next 50 years they continue to grow but gradually decrease like this. So, back into this and bringing it back towards is to 300 to 400 ppm level is a humongous task for which you have to go into almost carbon zero type of emissions.

And we know that that is a very big challenge and that is a challenge that we are faced with. That is, if we continue our conventional 20^{th} century way of life, where we are continuing to extract, consume more and more energy and continue to extract more and more energy from fossil fuels. And if you continue to cater to our economic prosperity goals and needs in the conventional way then by the end of this century we are going to see three times a level of carbon dioxide that is there. And that is expected to increase temperature by almost 5 degrees, 5 to 6 degrees centigrade over the past 1000 year average and that is a huge change because we have seen in some of the past cases that the sea-level changes have been like several tens of meters, okay. So, it is not sea-level is not going to change so rapidly in our current thing, it is a big question mark, but there are other causes like increased heat waves and increased cyclones, distractions and tidal waves and all this kind of things are expected to happen. The climate, the immediate climate and the way the rainfall patterns, precipitation patterns and the way that we are fed with water for agriculture needs, drinking water needs, and these are going to be affected by small changes, fractional degree changes, one or two degree changes in the ocean temperature. So, that is where we have a problem, not in terms of absolute concentration of carbon dioxide or absolute level of the sea-level or the amount of small degrees of 1 or 2 degrees increase in temperature, it is not the direct impact on the human beings, that is of concern to us, but indirect impact on natural process on which we depend for our daily life, so that is the biggest concern.

So, in the next lecture we are going to see what we can do about it, what how we can live with it and how we can try to mitigate the consequences and what we can do to make to, not make them more worse than what they can be, okay.

Thank you.