Course Name: I Think Biology

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W11L56_Biology and Climate Change - Part 2

Hello and welcome to the I-Think Biology NPTEL course. This week we are discussing biology and climate change. In the first lecture on this topic, I introduced the concept of planetary boundaries. Planetary boundaries are nine processes that regulate the stability and resilience of the Earth system. Climate change is just one of these boundaries. As you can see in the figure, from 2009 to 2023, we are now in the position where six of these boundaries have been crossed, which means we are entering a zone of great risk and uncertainty.

And maintaining the planetary boundaries is important because if we remain within these boundaries, then humanity, or life on Earth can continue to develop and prosper for years to come. The other framework I introduced was that of the sustainable development goals. So how are we to remain within these nine planetary boundaries and continue to develop as a human society? So the SDGs provide us with a pathway to do that.

The SDGs are 17 interlinked objectives and they serve as a blueprint for peace and prosperity for people and the planet. And they were adopted during a UN meeting in 2015 and India is also a signatory to the SDGs and achieving the SDGs. This model of the SDGs makes it very clear that the biosphere, maintaining the biosphere, which is life on land or life on Earth, freshwater, maintaining those systems is key for human society to develop and achieve societal goals like an end to hunger or an end to poverty. And from there we can move on to a thriving economy. So this is a good way of looking at the whole picture of the SDGs.

Now let's look at climate change in more detail. But before we do so, let's talk a little bit about terminology. We hear these words like global warming and climate change and they're used pretty interchangeably. But they mean slightly different things. So global warming refers to the rise in global temperatures, which is mainly due to the increasing concentration of greenhouse gases in the atmosphere from the burning of fossil fuels. Climate change is more of an umbrella term and it refers to the increasing changes that we are now observing to climate or measures of climate over a longer period. And these measures are things like increased rainfall or changes to temperature and wind patterns. But because the Earth's temperature tends to be a central determinant of its climate, we talk about climate change and global warming interchangeably.

I'm now going to talk about global warming and then we will come to climate change. So global warming has been known as a problem for over a hundred years. So this is a news report from 1912 and it says the furnaces of the world are now burning about 2 billion tons of coal a year.

When this is burned, it adds about 7 billion tons of carbon dioxide to the atmosphere yearly. This tends to make the air a more effective blanket for the Earth and to raise its temperature. So in a very brief and precise fashion, it has laid out the problem and its causes. So now let's look at some of the data about global warming. And these come from IPCC reports.

The IPCC is the Intergovernmental Panel on Climate Change which is a global scientific body that advises the UN and governments around the world about climate change. So the graph on the left plots the Earth's global surface temperature over the last 2,000 years and you can see that it stays mainly flat or horizontal and starting around the 1500s there's even a small dip which is known as the mini ice age. But then starting around 1850, we started to see an upward trend with an increased spike in the 20th century. And this warming has not been seen over the last 100,000 years. And the warming is on the order of about 1 degree centigrade.

The graph on the right shows us an expanded view of the period between 1850 and 2020. So we can see this warming trend more clearly. And then overlaid on the data are simulations and these are done in two ways. A simulation using just natural factors to account for the warming which is the line shown in green. And a simulation that takes into account human factors along with the natural factors to account for the warming.

We see that only when we take into account human factors does the simulation fit the data indicating that it is indeed human activity that is responsible for the warming trend that is now being seen. This image shows us the same pattern except on a global scale. So here we are plotting global surface temperatures as an average for 2011 to 2021 against a baseline of 1956 to 1976. And over most of the world, we see a warming trend. And a lot of the warming is seen towards the poles in the Arctic which has seen a temperature change of around 2 degrees centigrade which is indeed quite a lot and very worrisome.

So what are the measures that the IPCC uses to track climate change? Shown here are four such measures. So the graph in A is for global surface temperature which I have already spoken about. The graph in B tracks Arctic sea ice change in units of million kilometers squared. The graph in C is for ocean surface pH so this is in units of pH which is a measure of acidity. The graph in D is the mean sea level change in meters.

And the data is plotted from 1950 onwards to 2015. And so the grey lines are the actual data. Then the colored lines are simulations that the IPCC has done taking into account different socioeconomic pathways that the world can use to develop towards 2100. So I will come to what these SSPs are later on in the lecture. But for now, let's just concentrate on the grey lines.

So I have already spoken about the global surface temperature and how we have seen a 1-degree rise as compared to 1850 to 1900. Now coming to the graph in B we see that there is a decrease in the Arctic sea ice area from approximately 6 million kilometer squares starting in 1950 to about 4 million kilometer squares by 2015. Similarly, for pH the graph in C, we can see that there is a decrease in pH and while the decrease may not seem like much when you know in the lab we are doing these titrations and acid-based titrations and we are looking at changes of pH of 2 to 3 units this may not seem like a lot but it is quite drastic for the ocean's ecosystem and all the marine organisms that live in the earth's oceans because increasing acidity can spell disaster for a lot of organisms that use calcium carbonate to create their exoskeleton. Finally, we come to the mean sea level change shown in D and here again, you see an upward trend of about approximately a quarter meter again this may not seem like a lot but if you consider the large amount of humanity that lives on low-lying islands or coral atolls or next to a coastline this change can spell drastic consequences for them. Then coming to the infographic which is shown on the right shows you the kind of data that the IPCC uses to generate its reports.

It relies on paleo records or fossil records so basically these are looking at ice core data or marine fossils to measure the amount of carbon dioxide in them. Then they look at imaging data from satellites to track sea ice changes or they have a global network of floats that can track pH changes or the sea level change finally they also use simulations and theory. So we now have built up an excellent understanding of the earth's climate over the last 100 years and so using known physical laws we can simulate the changes to the climate and try and fit it to the observed data. So the IPCC uses a variety of methods to arrive at its recommendations. So moving on from looking at changes to climate to the causes of global warming global warming is caused by an accumulation of greenhouse gases in the atmosphere the primary greenhouse gas here is carbon dioxide and the graph on the left shows you the concentration of carbon dioxide in the atmosphere and this is a continuous measurement which has been kept at an observatory in Hawaii since 1958.

It was started by a scientist named Charles Keeling and this is now known as the Keeling Curve you can see that there is a continuous upward trend starting at approximately 220 parts per million in 1958 to over 400 parts per million by 2020. So carbon dioxide is now accumulating in the atmosphere at a very rapid rate. One interesting thing about this curve is the sawtooth pattern and I have asked a question there why does this curve have this kind of a pattern? So as students of biology, we should think about that. The graph on the right shows you more historical data so this is tracking carbon dioxide concentrations in the atmosphere over the last thousand years you can see that they remain mainly flat or do not exhibit much change but then starting around 1800 we start to see an upward trend or an increase in the carbon dioxide present in the atmosphere and it starting to spike in the middle of the 20th century.

So what does the accumulation of greenhouse gases in the atmosphere and the associated warming do to the earth's planet? So here we have to consider the earth's energy budget and under normal circumstances you would have a stable climate where you have a certain amount of solar energy coming in, some of it will be absorbed and then most of it will be reflected out. But in today's scenario because you have this blanket over the earth's surface in the form of these greenhouse gases there is less energy going out so it remains trapped and so where is that energy going and looks like most of that excess energy is being absorbed by the earth's oceans leading to their warming. This graph shows us the sources of global warming in greater detail. Radiative forcing refers to this earth's energy balance which I spoke about on the earlier slide radiative forcing is measured in watts per meter square so we can think of it as energy incident upon the unit area and so the different sources that contribute to an increase in radiative forcing which are all the horizontal bars going towards the right and shown in red are greenhouse gases and greenhouse gases are carbon dioxide, methane, nitrous oxides, and halogenated gases.

So they all contribute to the warming. Certain effects can contribute to cooling. So these are the bars shown in blue and these are aerosols so we can think of them as particulate matter in the air or the atmosphere and they have a cooling effect due to blocking of this incoming solar radiation. But if we add up all these sources and their effects we see at the bottom that overall there is a net warming trend in the radiative forcing. And then if you look at the columns to the right you can see that for each source you are given what is the extent of its scale?

So carbon dioxide or greenhouse gases have the effect and then some of these other parameters might have more local or continental effects. For instance, aerosols might be more localized on a continent or even over a country. The last column refers to LOSU which means level of scientific understanding. So for each of these radiative forcing components, the IPCC has given us a subjective parameter of what is the current level of scientific understanding of its contribution to the overall radiative forcing. And we can see for greenhouse gases the level of scientific understanding is high.

This shows us the same data but now it is plotted for temperature instead of radiative forcing so it's in degrees centigrade. So the graph on the left shows us that overall there has been a warming trend of approximately one-degree centigrade and the graph on the right in B and C shows us the various contributors to this warming and you can see that greenhouse gases in the form of carbon dioxide, methane, nitrous oxides and halogenated gases shown in the graph in C are all contributors to warming whereas you can have aerosols which can come from a variety of sources which can contribute to some cooling. So now let's look at the major greenhouse gas which is carbon dioxide and its level of emissions globally here the graph shows us the change in global CO_2 emissions from 1850 to 2021 and you can see that there is a constant upward trend to the amount of CO_2 being emitted into the atmosphere. One thing that you should note here is the numbers shown on the y-axis so the major contributors to CO_2emissions are fossil fuels currently, we are emitting about 40 billion tons of CO_2into the atmosphere per year and so as students of science we need to have certain numbers at our fingertips and this is one number that you should keep in your head. So then moving on to who are the emitters of these greenhouse gases.

So there are two graphs shown here, present-day emitters and the data for 2017, and then historical emitters where the data is clubbed from 1751 to 2017 if you look at the graph on the left the different colors refer to different continents so Asia is shown in red, North America in green, Europe in yellow and so on. And here if you look at Asia under present-day emitters China is a major emitter and it contributes about 27% of global emissions. If you look at the US it contributes about 15% of global emissions and if you look at the EU as a whole so EU28 it contributes approximately 10% of global emissions. And in 2017 India contributed about 6.8% of global emissions. And you will notice that in blue is shown the continent of Africa and the whole continent contributed only 3.7% to global emissions. If you look at the historical graph shown on the right who has contributed most to global CO_2 emissions we can see that North America and especially the USA has contributed about 25% or a quarter of all global cumulative emissions since 1751. China has contributed about 12.7% and India has historically contributed only 3%.

This graph shows us the changes in the share of global CO_2 emissions as a function of time for various countries. So the line in pink or purple is for the United Kingdom and it shows us that it started by contributing a majority of the share to global CO_2 emissions in 1750 because it was an early pioneer in the Industrial Revolution and then you started to see its share decreasing as the years progress and in 1889 you see an inflection point where the US overtakes the UK in a share of CO_2 emissions. So this one graph is a good historical document if you want to look at human development since the Industrial Revolution and then starting say in the 1980s you see a large upward trend for China which is shown by the line in light blue. So just summarizing the historical data, the United States has emitted more CO_2 than any other country to date at around 400 billion tons and is responsible for 25% of historical emissions. The EU28 is also a large historical contributor at 22% and many of the large emitters today such as India or Brazil are not large contributors in a historical context.

So this is a very problematic issue to figure out who is responsible for climate change because once you decide on responsibility then you know who is responsible the most for fixing it. But there are different ways of looking at it. So one is this lens that I showed you of the historical perspective versus the present day. You can also do a sector-wise gradation of the major industries contributing to fossil fuel emissions. They are the fossil fuel industry of which electricity generation is a major cause.

The cement and steel industries are major contributors to CO_2 emissions. You can look at it from the lens of lifestyle. So basically people with high incomes are the major contributors to CO_2 emissions in the present day. And so even within India, there is a very large disparity with people in the top 1% contributing out of proportion to the population to the carbon footprint of India. You can also look at it from the perspective of producers and consumers.

So here is a question for you. If a car is produced in China and driven in the US who is responsible for its emissions? Finally, a good way of looking at it is in the context of what is called CBDR, Common but differentiated responsibilities. This phrase was put into the Rio Declaration during the Rio Earth Summit of 1992 and India played a large role in putting in this language. So what this means is that we acknowledge that global warming and climate change are serious problems and it's a problem common to humanity. But everybody has a different level of responsibility for fixing it. And so again we can look at it using different lenses to figure out what is the level of responsibility of each person or each sector or each producer or consumer.

I will just show you one more graph related to this. This graph looks a bit complicated but it's not. The X axis is plotting the population country and this X axis has now been bent to form a 3-quarter circle around the earth shown in the center. The Y axis shows us the carbon dioxide emissions per capita in terms of tons per year. So basically you take the total CO_2 emissions of a country and you divide it by its population so you get the per capita emissions.

You can see that certain countries in the Middle East are amongst the top in terms of per capita emissions and they are close to 20 tons per year. The US again has a very large per capita footprint at almost 15 tons per year. China is at 7.1 tons per capita. India is relatively low at 7.1 tons per capita. So again if you look at China you might think okay it has a very large footprint but if you divide it by the population of China which corresponds to a very large percentage of humanity, then it is below the global average. So this one graph allows us to look at the problem differently. So this plots CO_2 emissions along a timeline and we can see that it has been divided into two different areas. So CO_2 emissions before 1990 have been added up and CO_2 emissions in the 30 years, approximate 30-year period from 1991 to 2019.

And we can see in the last 30 years we have emitted more than 50% of all the CO_2 which has presently accumulated in the atmosphere. So if there is one piece of data or one piece of information that I would like you to take away from this lecture it is that in the last 30 years, we have emitted more than 50% of all the CO_2 which has now accumulated in the atmosphere. So what are we doing about all this?

The major player in telling us what we should be doing is the UNFCCC which is the United Nations Framework Convention on Climate Change. So this was a historic document to which the countries of the world were signatories. So once you sign on to the UNFCCC you become a party to the conference and starting in 1995 you had a conference of these parties. And then moving on every year since we have had a COP and at every COP different targets are discussed, different things like funding is discussed or fixing responsibilities discussed and the COP always uses the IPCC reports as a basis for making any decisions. The IPCC has so far released six reports which are called Assessment Reports, AR, and the last report was in 2020, which was published in 2021. So the COPs are the global forum on which we decide action for the climate crisis starting in 1992 when the UNFCCC was signed. Since then we have had COPs and each COP has had its flavor this graph shows us some of the highlights where in 1997 there was a pledge to reduce global emissions by half and it was a very encouraging COP to the low of 2009 in Copenhagen when the US was expected to make a very historic announcement which it didn't. And then again to the last big inflection which is in 2015 when we finally have the Paris Agreement where 195 countries and the EU pledged to limit global warming to within 2°C and preferably to less than 1.5°C. So in line with the Paris Agreement if we are to maintain global warming to less than 2°C or preferably to less than 1.5°C then this is the trajectory for CO_2 emissions that we should be following. The Y axis shows us gigatons of CO_2 equivalent which means it is clubbing together all the greenhouse gases and then plotting it as a cumulative CO_2 total. So you can see that currently we are at approximately 50 billion tons of CO_2 equivalent and that needs to be reduced to about 20 billion tons per equivalent by the next 7 years by 2030 for us to meet the target of keeping warming within 1.5°C. India is also a signatory to the Paris Agreement and so if you are a signatory then you have an NDC, the nationally determined contribution which is basically what are you pledging to counter climate change. And so India has made very ambitious targets and this is India's updated NDC. So the first target is we have affirmed to reduce our emissions intensity of its GDP by 45% by 2030 against a baseline of 2005 level. So what this means is that if you are doing any kind of economic activity, say for instance you are producing cars, so what was the level of CO_2 you emitted to produce a thousand cars? And against that level, we are saying we will reduce that level by 45% to produce those same thousand cars by 2030. The second target is that of renewable energy so we are pledging to achieve a 50% cumulative electric power installed capacity from non-fossil fuel-based energy sources by 2030.

The third one is that we will create a carbon sink that uses forests to sequester carbon and the sink will be to the level of 2.5 to 3 billion tons of CO_2 equivalent. This will be through various afforestation and restoration measures. So what is to be done about climate change? There are two actions that one can take. One is that of mitigation and the other one is that of adaptation.

So mitigation is basically what are the actions you can take to avoid or drastically reduce greenhouse gas emissions. Adaptation is assuming that climate change is real, it is affecting us right now. So what are its current or future consequences and what can we do to adjust to these changes in the climate? And so there are a variety of measures that one can think of. For instance, renewable energy is a big mitigation measure that you can take to reduce greenhouse gas emissions. And of course, I should mention that mitigation measures and adaptation measures are not independent of each other and in fact, in many ways can intersect with each other.

So how do you achieve mitigation and adaptation? And that depends on what is your pathway to development. And so we are coming back to these SSPs which I spoke of earlier, the shared socioeconomic pathways. And these are pathways of development that the IPCC has used to simulate what will be the rise in global temperatures. So SSP1 takes the most conservative pathway of development. It's that of assuming sustainability or taking the green road as it says.

And so here you would have the lowest challenge for mitigation which means you would do perhaps a drastic change in your electricity generation or your transportation system to reduce carbon dioxide emissions. You would also have low challenges to adaptation. Things like a heat action plan or finance measures to farmers against drought measures. Whereas SSP5 assumes that you're kind of taking the standard development pathway which is energy intensive and it is fossil-fueled development. So that's called taking the highway which means we will reach a certain level of economic prosperity and then we will make changes which are necessary for mitigation or adaptation.

So what are the major categories where you can do mitigation? This is shown here on this graph. It's a bit complicated but perhaps I can break it down. So the first major category in which we need to do mitigation is that of energy generation. And here we need to do an adoption of renewable energy sources such as wind energy or solar energy. So the horizontal bars tell us what is the potential contribution to a reduction in gigatons of CO_2 equivalent per year.

If we go all out in terms of the adoption of wind energy or solar energy. And so for instance you can expect the potential contribution of a reduction of 4 billion tons of CO_2 emissions if we do a complete adoption of wind energy. The colors of the bar refer to the expected cost of making this change. So going from a net reduction of 2 gigatons per year of CO_2 to 4 there is a large increase in the cost. That's what the graph is telling us.

The second category is called AFOLU which stands for Agriculture, Forestry, and Other Land Use. So basically agriculture can be used for carbon sequestration or you can do things like ecosystem restoration, and afforestation which will again be a carbon sink. So they have a large potential for mitigation but what these graphs are saying is that the cost associated with that might be quite high. But we must remember that this is calculating the cost in economic terms. The cost in social terms or cultural terms might have greater benefits than just the economic cost.

The other category for mitigation is that of building construction. So because we use a huge amount of steel and concrete in building construction and infrastructure development around the world it's a major category in which we need to do climate mitigation. So again there are various categories here. For instance, we can have things like new buildings that are green or we can have new buildings, we can have onsite energy generation so a decentralized model of energy generation. The next category is that of transport followed by industry. So as you can see this graph shows us all the major categories of human activity and what are the areas in which we can do mitigation and what is the level to which we can expect mitigation if we do an adoption of all these various measures.

Then coming to climate adaptation. So adaptation can be done in two ways. One is that we give governments money or people money or certain communities money so that they can take actions that reduce the risk and decrease harm from present climate hazards or future climate hazards. The other one is quite simple. It is called nature-based solutions. So what are the actions you can take to protect, manage, and restore ecosystems this can have multiple benefits not just for climate. And so the adaptation measures you can do is to prevent floods, ensuring that your fresh water supply is protected in many different ways.

You have a heat adaptation plan say for cities in terms of cooling systems. You make changes to your food systems in terms of heat-resistant strains. You have disaster management systems for early warning and quick response and you can do restoration which I already spoke about. And you can see that we can have a variety of adaptation options depending on the context. And there are two major categories here. What are the adaptation measures you will need in rural areas and adaptation measures in urban areas?

And because you're seeing a large urbanization trend, how do you manage your present city so that you have different adaptation measures against climate change and warming? For instance, you can see that different cities around the world have different measures. So sea walls to prevent sea ingress or things like a sponge city in China which will act counter flooding or you can have a heat action plan which the city of Ahmedabad has or you can have postal regulation in Mumbai. So adaptation is a measure against the extreme weather events which are increasingly being seen around the world. And you can use this tracker to figure out what different weather events are being seen around the world and what are the trends being seen for them.

So what is the situation in India? What are the effects of climate change being felt in India? So shown here is a comparison of the temperature changes seen between 2008 to 2018 against a baseline of 1950 to 1980. The grids are a grid of one degree by one degree. This is based on data provided by the Indian Meteorological Department. So you can see that the grids in purple mean there has been a warming trend in those areas. So parts of Rajasthan and Gujarat, parts of South India, and Tamil Nadu have seen a warming trend.

Whereas certain parts of the Ganjetic plains have seen a small cooling trend. This could be due to the presence of aerosols from air pollution in the atmosphere which block solar radiation cooling the land surface. But overall we can see that many parts of the country have experienced a warming trend. Then this map shows you the risk or vulnerability of rural areas to climate change because agriculture is the mainstay of people's livelihoods and our economy. And so this graph, I mean this map shows us a district-wise risk assessment of climate change.

There were three measures used. One is what is the sensitivity of a particular location to changes in the weather. What is its exposure, so what is the level of change? And what is its adaptive capacity? So adaptive capacity could mean things like administration, how good is the administration, what measures are being taken, is there finance available, and things like that. And so as you can see parts of Rajasthan, Gujarat, large parts of Maharashtra, and Karnataka, districts there are at extreme risk of climate change.

Whereas certain coastal areas are less vulnerable to climate change. Finally, this map shows us the vulnerability to flooding. So we are already witnessing severe storms like cyclones and we are seeing sea ingress into low-lying areas. And because India has a very large coastline, what is the risk level certain areas in the country have to these changes? And so the insect on the blue shows us that areas that are marked in blue are particularly vulnerable to things like sea level ingress or exposure to storms.

So indeed India is going to be heavily affected by climate change. So I hope you have had a good introduction to climate change in the third lecture in this series. We will look at what are the effects of climate change on the biosphere and we will do this at three different scales. I will see you in that lecture. Thank you.