Course Name: An Introduction to Climate Dynamics, Variability and Monitoring

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Week- 01

Lecture- 02

INTRODUCTION TO CLIMATE DYNAMICS, VARIABILITY AND MONITORING PART 2

Good morning class and welcome to our second lecture on our climate physics, climate dynamics and monitoring course. We will continue our discussion on introducing the climate and its importance in the world today. In the last class, we ended our lecture on looking at the primary zones that influence the climate of a region which of course includes the atmosphere, the layer of air where weather primarily occurs, the hydrosphere, the zone of liquid water which interacts strongly with the atmosphere through evaporation and condensation processes, the cryosphere, the zone of ice which also impacts the heat budget of the earth by reflecting sunlight into space the zone of biosphere which includes all the living plants animals and humans which interact with the climate primarily to exchange of gases like oxygen CO2 with the atmosphere the zone of lithosphere or rocks of the ground volcanism from these rocks, mountain formation and erosion processes, continental drift. These processes impact the climate over both short scales and geological scales. And finally, astronomical variables, which includes the Earth-Sun distance, the Earth's inclination, solar cycles, etc., which determine how much heat is coming to Earth from the Sun, at what rate and what is its distribution on the planet.

And these processes impact the climate through heat transfer processes of radiation, reflection, transmission, absorption, as well as physical transport of heat through convection forces in the air and in the oceans, as well as mass transfer processes like water cycle, which controls the amount of water vapor in the atmosphere in different regions, as well as the carbon cycle, which controls the amount of CO and CO2 that is present in the atmosphere. Now, the question comes, why is climate important? So in a sense, climate has always been important because it controls how living things have adapted to certain regions of the world. So it controls the distribution of vegetation and soil types that you will find in various geographical regions. For example, an arid region like Rajasthan will have a very different soil type and vegetation compared to extremely wet region like Kerala or Meghalaya or a hot interior region like Delhi or Madhya

Pradesh in India will have a very different climate and hence very different vegetation and soil types in a coastal region like again Kerala or Bombay.

As a result climate also determines the agricultural production that is happening in a particular region because it impacts the soil fertility, the water availability, what type of temperature one expects during a certain growing season etc. It also determines the type and frequencies of weather events, when is the rain supposed to come, when is snow supposed to come, how frequent are droughts and floods etc. For example, Indian climate is controlled by monsoon rains significantly as well as Indian agriculture, whereas if you look in a different region of the world like Europe or USA, there is no monsoons and the weather patterns and rainfall patterns are completely different. And these are determined by the climate of that region. Hence, inevitably, the human adaptations and human productions, the way they are done in different regions of the world, are tied to the climate of that region.

the type of housing that exists in a certain region, the type of clothes that one wears, the type of agriculture that is being done, the type of commercial activities that are happening are all influenced by the climate. For example, in India, the tropical region is primarily a rice-growing region, eastern India and southern India, whereas northern India, which is more of a subtropical, semi-arid climate with colder winters, is ideal for wheat-growing regions. Similarly, mountain climates like eastern Himalayas as well as the western Ghats is ideal for tea and coffee plantations, whereas the plains cannot grow such cash crops. So clearly, agricultural and commercial activities depend strongly on the climate. Climate also determines the existence of Himalayan region perennial snow, that most of the Himalayan mountains are covered with perennial snow, and that is a major source of river water in North India during the summer.

So in case a climate changes and the snow cover decreases, that will have severe impact on the amount of water that is available in summer in northern India. And it is in this context that understanding climate has gained urgency because it has become increasingly clear over the last decades that humans are causing significant change in climate. And how they are causing it? We are causing this through large-scale emission of CO_2 as well as methane and other gases through burning of fossil fuels like coal, oil, natural gas, etc. As a result, the composition of the atmosphere is changing as the concentration of CO_2 has risen from around 280 ppm which was measured in around 1750 to 419 ppm which is the most current global measurement of CO_2 concentration in 2022. Here ppm means parts per million, CO_2 we will discuss concentration and its units, but here the most important thing to see is we have increased CO_2 significantly almost if not two times at least 1.5 to 1.6 times over the last 250 years. And this CO_2 is a strong greenhouse gas. What this means is it acts to trap the heat in the atmosphere. As a result, the increase in CO_2 concentration causes an increase in the atmospheric temperature. As more of the heat coming from the sun gets absorbed by the atmosphere, so the

atmospheric temperature rises and this causes global air temperature to increase and this effect is called global warming.

So, as a result of global warming in most regions of the world and we will see examples and data about this in this class only is experiencing a rise in the mean temperature. This effect is called global warming and the current mean global temperature increase has been 1.2 degree centigrade since 1850 onwards. So since the industrial revolution and the use of fossil fuel based power and work generation began, The corresponding CO2 has increased, has caused an increase in global temperature of around 1.2 degrees from 1850 onwards.

And the rate of rise has in the last few decades has been around 0.15 to 0.2 degree centigrade per decade. So every 10 years, the mean global temperature is rising between 0.15 to 0.2 degree centigrade. So this means that the climate of the world is changing and we are changing it. We are changing it by warming the air. And what is the impact of this? The impact is quite severe already and is expected to become more and more severe as we go along in this route. The first effect is the loss of cryosphere or the snow cover, permanent snow cover in the Arctic and the mountain glaciers, including overall and as well as overall glacial retreats in Greenland and Antarctica.

The Arctic sea ice has been melting. A lot of glaciers in Himalayan regions, alpine regions, regions of other high mountains are retreating. and hence the cryosphere as a whole is shrinking. A corresponding effect which is related to it is the increase in sea level which results in increasing frequency of coastal and island inundation. So sea level is rising because of two reasons.

The oceans are getting warmer and warm water is less dense so it occupies more volume okay so what is happening is as the water warms it expands and hence the sea level naturally rises That's number one. Number two is a lot more water is coming into the hydrosphere from the shrinking cryosphere. Water that was locked in ice in land, in glaciers, in the Himalayan regions or in the Greenland regions are coming and are melting and adding extra water to the oceans. And this is also causing a rise in sea level. Now this creates extreme risks and hazards of coastal and island inundation and note that most of the world's most populous cities even in india like cities like madras kolkata chennai etc are coastal cities new york is a coastal city okay and there the difference the height of the land above the sea is not significant.

So small changes in sea level can create large scale inundations of shallow coasts where a significant part of human population lives. This is also especially risky for island nations in the Pacific or in the Indian Ocean where the sea level rise can inundate entire islands and the people there would be homeless with nowhere else to go. Also increasing in sea level causes increasing chances of inundation due to cyclonic weather. So when cyclones

and typhoons hit the land, the amount of coastal inundation that happens will also increase as the relative altitude difference between the coast and the sea decreases. So you will get more severe coastal flooding.

A third problem is that coasts are becoming more saline. Because the sea level is rising, more of the sea water is entering into the rivers at the point where the river is meeting the sea. So the river water near the coasts are becoming more saline and the salinity of the coastline is increasing. This is causing significant problems like in Sundarban region where the mangrove habitat and corresponding ecosystem is in danger of getting extinct because the rising salinity and the invasion of seawater into the Gangetic Delta. And this is true in many other coastal regions as well.

The third problem is the rising frequency of extreme weather events like heat waves. Obviously, if the temperature is rising, the mean is rising, the extremes will also become more and more extreme. So the hottest day will be significantly hotter today than what it was 100 years back. heat wave will be more significantly intense than what would have been the case hundred years back when the earth's temperature was colder and what we find here is when the mean moves to a some extent the extremes can move significantly more okay so and the reason is there is a statistical structure of how the extremes react to changes in the mean and so a small change in mean can cause a large change in the magnitude of an extreme event. So we have a rising frequency of extreme weather events like heat waves, more intense storms like hurricanes and cyclones.

So let's take a step back and understand intuitively of why this is happening. When the earth's atmosphere is trapping more heat, what it means is there is more energy in the atmosphere. And that energy is being dissipated through more intense cyclonic circulations. So cyclones are getting more energy because the atmosphere is getting more heat and hence more energy from the sun. Hence, you are getting more intense storms like hurricanes and cyclones, catastrophic precipitation events creating catastrophic flooding.

You have extreme droughts in arid regions and destructive forest fires. Because of the rising heat, the chance of fire events in forests and vegetations during hot, dry, hotter, drier summers is becoming more and more frequent and you can get extremely destructive out of control forest fires, especially in the regions which are becoming hotter and drier because of the global warming impact. Especially this is true in California, Southern California region in US, Australian regions which has been hit by severe droughts and wildfires. All of this contributes to loss of critical ecosystems that support biodiversity. As we see, marshes are in danger, alpine regions, glacial regions and corresponding alpine forests in the Himalayas are in danger.

As the weather becomes warmer, those forests are severely affected. Coral reefs in oceans due to increasing acidification of the ocean, so what is happening is as you lot of the CO2 that we are emitting is being absorbed by the oceans to create carbonic acid which is making oceans more acidic that is the pH of the oceans are decreasing and this is impacting coral reefs whose structure is made of limestone kind of structure and these limestones or calcium carbonate systems are dissolving due to the presence of acids and hence coral reefs are dying off Alpine ecosystems due to glacial retreat as we discussed. Loss of forests in semi-arid regions due to forest fires and droughts. Coastal mangroves due to rising salinity. These are only a few of the examples where global warming is directly contributing to loss of critical ecosystems.

Rising crop failures due to climatic instability. Extreme weather events like strong storms, large precipitation events, heavy flooding, extreme droughts, extreme heat waves are not conducive to crop production. So crop production is becoming more and more unreliable, which is causing an increasing chance of famine, crop failures, and food shortages. And the last case is increasing virulence and spread of viral and bacterial pathogens that thrive on warm, humid climates, which are becoming more and more common throughout the world. As climate becomes warm, the bacteria and the viruses that usually thrive on these warm, humid climates become more and more widespread and stay active for longer and longer periods in the year, creating greater virulence and greater chance of disease and death.

So these six impacts have been cataloged as impacts that are likely to get more and more severe as global warming and corresponding climate change goes on throughout this century. This is why we need to understand not only how climate interacts, all its parts interact to understand the true magnitude of what type of climate change we expect so that we can develop technologies to mitigate the worst impacts of climate as well as to stop climate change by shifting increasingly to non-fossil fuel based energy sources. So there are two aspects. We have to prevent further climate change from occurring by shifting our energy systems.

That's one part. And the second part is we have to understand what are the impacts global warming is happening throughout the world so that we can create more resilient infrastructure and adaptations to prevent the loss of life and property in the future. And all of that requires a thorough understanding of the climate system and its variabilities over the long as well as short terms. And we also have to understand how we can best monitor these climate variables as they change during the next century or so. So this course is aimed at giving you a brief overview of these ideas. And hopefully that will help you in developing technologies or interact developing climate models or using climate technologies and climate models to understand climate change and adapt to it or mitigate to it.

So I will start a little bit on some of the data that has been collected from the IPCC Sixth Assessment Report that is currently being published sequentially from the last two years onwards. So this is data from the International Panel for Climate Change, IPCC. And it's a large multidisciplinary effort of which where the scientists, thousands of scientists from all disciplines come together and prepare an extensive and exhaustive report for the global policymakers to explain to them what is the current status of climate? How is it expected to change in the future depending on the various emission scenarios? What are the vulnerabilities and how best to adapt to it? We will discuss a little bit of high precision report as we go along in the class. This is just a primer on some of the things that I told you right now. So here is for example a figure of the observed.

So the black line is the observed global mean temperature. So here when we say mean temperature, it's the mean temperature of air near the surface of the planet. We will discuss later that air temperature changes with altitude as well. This is the mean of the average planetary air temperature near the surface and how that has changed from 1850 to 2020. And if we take 1850 as the baseline, so the baseline at that time was around 14 degree centigrade.

So, the average mean temperature of the world around 1850 was around 14 degree centigrade. We see the measurements, this black line going up and down, but showing no clear trend till around 1910 or 1920 onwards. And after that, we are beginning to see a significant and accelerating increase in the global mean temperature from 1930, 1940 to 2020, so that the mean temperature is increased by around 1.2 degrees up to 2020. So, the current global mean temperature will be around 15.1, 15.2 degree centigrade. So, we have seen an increase of around 1.2 degrees due to human caused global warming over the last 170 years. The question is, how do we know that this is caused by human activity? So, there are a lot of sophisticated models modeling this. We will not go into much details in this course of how large-scale climate models work, but here is the ensemble average. So, all the global climate models and their predictions is this brown area and the mean of this models.

So, what is the average model prediction of this model climate models? That is this brown line and you can see the observed mean temperature and the model predicted mean temperature are quite close to each other. And this model predicted mean temperature is close to each other only when we take into account both human activity and natural causes into those models. However, if we neglect human activity and only look at natural, solar activity and volcanic activity primarily, then we see that there is no significant impact on the mean temperature if we eliminate the contribution of human activity. Yes, there is some changes, ups and downs, especially in 1930 etc, there is, till then, it's working reasonably well. After that, it starts to diverge significantly from 1920, 1930 onwards.

So this kind of shows, that human activity is the primary driver of climate change in today's world, primary driver of the increasing surface temperature in today's world. And so we can see that the global surface temperatures has increased by around 1.2 degrees over 1850 values and the entirety of this increase may be attributed to human activity based on our best understanding of climate models. So I will stop here today. We will continue this discussion on other aspects of what has been observed so far and their impacts in the next class.

And thank you for listening and see you in the next class. Thankyou.