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

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Lecture- 01

INTRODUCTION TO CLIMATE DYNAMICS, VARIABILITY AND MONITORING PART 1

Good morning class and welcome to our first lecture on our new course on the introduction to climate dynamics, variability and monitoring. I am Dr. Sayak Banerjee and I am a professor at IIT Hyderabad in the Department of Climate Change as well as in the Department of Mechanical and Aerospace Engineering. As you may have seen in our introductory video to this lecture, I will be covering the various aspects of climate physics and how climate variability, variability of climates happen and how we can monitor climatic variability through instrumentation. So today we will start with an introduction to the ideas and the concepts that we will be covering in this course. The first part of the course will be mostly focused on climate dynamics and climate variability.

And the second part of the course will be looking at the principles and the instruments used in climate variables monitoring. The picture you can see on the screen is a snapshot that represents our Earth's climate, our Earth's atmosphere, which is the main theater in which climate and weather operates. Atmosphere is primarily a relatively thin shell of gas that covers the solid and liquid surface of our planet. And it is vital for maintaining our life, our ecosystem, our planetary ecosystem.

The various properties of this atmosphere is the primary variables that are the study of both weather and climate. So we will start our discussion in trying to understand what is the difference between weather which you may have heard many times in weather forecasting and other aspects and climate which you may have heard but you may not have a very good understanding of what climate it is and how is it different from weather. Now, in news channel broadcasts or any weather prediction websites, when they are talking about weather prediction, what they're primarily saying is how certain atmospheric variables will be over the next day, over the next hour or over the next three or four days at max. So in a sense, weather is defined as the overall instantaneous condition of the atmosphere at a certain location and at a certain time. So for example, we can talk about the weather of Delhi.

Delhi is a geographically limited location on the planet. and when we are talking about the weather there say on on a Monday or on a Tuesday of say March 14th or March 15th what we are talking about is certain what are the values that certain weather variables are likely to take on that specific time period in the location delhi what are those variables usually these variables are things like temperature pressure Precipitation, which is the amount of rainfall you are getting likely to get, the wind velocity, the humidity, cloud cover, etc. So these set of atmospheric property variables, what is the temperature of air around Delhi on March 15th? What is the atmospheric pressure on March 15th either as an average or hour to hour variation? How much total rainfall can we expect in Delhi in March 15th of 2024? What is the prevailing wind direction and average wind velocity over the day? Or how it varies from one hour to the next over that specific day? What is the humidity of that location? How much cloud cover we will be expecting? Is it a sunny day? It's a cloudy day? It's a foggy day? What? So these, the instantaneous, so here when we are saying instantaneous, we are talking about order of a few days to hours or even minutes. So depending on what your interests are, the period can be stretched to up to four or five days or maybe hour to hour or even minute to minute. So the instantaneous condition of the atmosphere is defined through the instantaneous values of atmospheric property variables.

And these property variables include temperature, pressure, precipitation, wind velocity, humidity, cloud cover, etc. And the overall instantaneous condition of the atmosphere at a certain location at a certain time is the subject matter of weather science. And what is weather science? It's meteorology, the study of weather. The key tasks of meteorology include the recording of weather-related property data. How did the temperature actually change over a certain period of time? of time over a given day, how much rainfall occurred on a specific day of July for example in 2023 in Chennai for example.

So recording of weather related property data at various locations. And the second important task is forecasting of weather events over short durations into the future. Here, short durations means weather forecasts usually are 1 day to 7 day long. As our forecasting technology has improved, we are able to give better and more accurate weather forecasts over longer periods of time. But still, weather forecasts are limited to 7 to 14 day periods even with our best technology today.

So tracking the, for example, the expected path of a cyclone as it makes landfall in a coast, in the eastern coast or western coast, will be an important task of a weather forecaster. And the cyclone's duration is usually 10 to 14 days and you will see that the uncertainty bands increase a lot if you go to the IMD website, Indian Meteorological website, as the forecast period moves further and further into the future. Weather is about the instantaneous condition of the atmosphere over a certain location, certain limited geographical location. The instantaneous condition is defined by the atmospheric

property variables which include air temperature, air pressure, precipitation, wind velocity, humidity, cloud, etc. The science of weather is called meteorology.

and meteorology is about recording the weather related property data as they happen as well as forecasting them over a relatively short period of time in the future. So that's about weather. What is climate then? How is it different from weather? So climate is defined as the state of the atmosphere over a given geographic region but over long periods of time. So, here there are certain differences and we will flesh out differences as we discuss this. Firstly, it is no longer the instantaneous property, it is the state of the atmosphere over a given geographical region and this geographical region can be limited but can be extremely large as well.

So there is no longer a constraint of it being a local property. It can be as large as an entire continent like Asia, Europe. It can be global climate as well. The climate of the entire world as a whole. It can also be microclimates.

The climate of Bombay can also be a topic of climatology. Climatology is the science of climate. So the geographical region can be small or can encompass the entire world. It's about the state of the atmosphere over long periods of time. So we are no longer considering periods which are minutes, hours or days.

Here long durations involve things like 30 year periods. So typically in climatology 30 year periods are considered the proper unit of time. So a 30 year averaging of the state of air atmosphere over a certain geographical region will be the climate of that region. And we are discussing here the statistical properties of this atmosphere. Because clearly if you look at weather, the properties are varying from one time to another time.

There will be diurnal variations, there will be hourly variations, there will be seasonal variations, there will be minute to minute variations. So when we are looking at long period things, we are doing a statistical analysis of this weather data. Statistical analysis may include long term means, long term variabilities, standard deviations, extremes, etc. So the statistical information of weather when taken over a long period of time and analysis of this statistical information is the science of climate. So climatology is the study of long duration statistical properties of atmospheric weather data.

Such statistical properties of weather data sets include things like normals. So these are the mean or the expected values of weather variables over long times. Like 30 year moving averages of yearly precipitation. What is the average annual precipitation of India? You take a 30 year moving average of how much precipitation has actually been recorded Take the mean and that will be the average precipitation. What is the mean

temperature? Again over India.It can be done. Now here it can be annual or it can be seasonal. So what is the mean summer temperature? So here we may define summer as April to June for example. The mean April to June temperature of India will be the statistical 30 year average of the temperature data of these four months over the entire last 30 years. And that average will be the mean summer temperature for example.

Okay. Over a certain geographic region. It can be a city, a whole continent or an entire planet. It can be a nation also obviously. So that is the mean. Then you have like the variability range.

So from weather data, one can extract the usual range of variation in the value of property variables. like variance, range, standard deviation etc. over long periods of time. What is the deviation from this mean? So there are many ways and statistics to analyze these deviations. You can have a standard deviation, you can have a variance, you can have a range, you can have 5 sigma deviations, 2 sigma deviations, 3 sigma deviations.

So these variabilities from the mean are basically what is the variability range. One example would be the temperature difference between mean summer and mean winter temperature values or between mean daytime and mean nighttime temperature values. It can also be variability within a certain variable as well. How much is the standard deviation of mean summer temperature over the 30-year period? That also becomes a variability range. So there can be very hot summers, relatively cool summers.

What is the average standard deviation of the mean temperature in the summer? Those will also be included in the variability range. The range or variance of expected annual precipitation will fall in this category as well. How much is the variability in say monsoon rainfall over Indian sub-combatant? Is it a normal monsoon or is it above normal monsoon or below normal monsoon? You will hear that in newspapers a lot. They understand this by looking at the variability of usual monsoons over the 30-40 year period and then see whether it falls far away from the expected standard deviations or within the standard deviation range. If it's within the standard deviation, it's a normal monsoon, it's beyond one or two sigma, it's a below average or above average monsoon, something like that.

Then beyond this, we are looking at extremes. Extremes of weather events and statistical analysis of extremes become climate extremes. So extremes of weather property variables over a period of time. For example, maximum temperature over a 30 year period or maximum hourly precipitation rate over a 30 year period. What is the maximum temperature Delhi has ever witnessed over a 30-year period is an extreme temperature, so hottest day.

So for example, when you are looking at heat waves, what is the maximum temperature Delhi has reached when one of those heat wave events happened? So that's one of the extreme analysis. Similarly, what is the maximum hourly precipitation that has happened in a region say Bombay over the last 30 years? Okay, so extreme flooding events. What are the trends? Are those maxima increasing or decreasing with time? Are extremes more frequent or less frequent? For example, are what is the most intense cyclonic circulation that has hit the eastern coast over the last 30 years. Those are the analysis of extreme weather events. And the frequencies of these extremes.

So rate of incidence of a particular usually extreme weather phenomena in a geographical location over a period of time. How many heat waves have hit during a summer? How many cyclones have hit the coast during the fall or the autumn period? How many drought events have happened in Rajasthan over the last 30 years? What are the frequencies say over a period of five years is one year drought prone or two years drought prone? Is the frequency increasing with time? So those kinds of statistical analysis of extremes, their magnitudes and their frequencies is also a part of climate science. And this is very important because extreme weather events are harmful because we are not adapted to it, our civilization is not adapted to it. So understanding how frequent those extremes are and what is their intensities and whether they are increasing or decreasing helps us to plan for disaster management in the future. So these five aspects become the topic of climate.

What are the normals, the mean weather? What is the variability range of this weather over long periods of time? What are the extreme weather events? What are the frequencies of this weather events? So these become the topic of climatology. So now we have understood that climate is the long term state of the atmosphere over a particular geographical location or over the entire planet or whatever geographical location we are discussing. What are the zones that influence the climate? What are the influencing factors of climate? What influences it? First is of course the atmosphere. We are discussing after all the state of the atmosphere itself. So clearly the atmosphere is the primary zone that influences climate.

So the zone of air especially the lower layer of air called the troposphere is where all the weather related phenomena occur. So that zone is the primary influencer of climate of a region. The zone of air which is called the troposphere. This is where all the weather related phenomena occur within the atmosphere. We will discuss troposphere and the other layers of the atmosphere as well in detail in a class that is coming very soon.

But basically, first zone that influences the climate is the atmospheric zone, especially the lower atmospheric zone, which we call the troposphere. Then we have the hydrosphere, which is the zone of liquid water on Earth's surface. How does it influence this climate? The liquid water and the air interacts very strongly. The oceanic system and

atmospheric system, we call in technical terms, are strongly coupled. Much later in the class, we will see the atmosphere ocean interactions and how they create variabilities in the climate system.

So some of the ways this happens is it supplies water vapor into the atmosphere. Evaporation process is the main way by which water vapor goes into the atmosphere and this water vapor eventually becomes clouds and cause precipitation. So you need the hydrosphere for this precipitation event to occur. It absorbs and releases heat. The oceans, the lakes and the rivers absorb a lot of heat coming from the sun and it also releases the heat during the absorption, evaporation and the condensation process.

So the hydrosphere acts as a heat sink and a heat source to the atmosphere as well. Further, transportation of heat through oceanic circulation systems impact the climate of many significant geographical locations. So oceanic circulation systems, ocean currents transport heat by transporting hot water from the equator towards the poles. And many geographical locations are warmer than what we would expect them to be because of this oceanic transport that influences the climate of those regions. So the oceanic heat circulation system is very important in determining the climate of many regions of the planet.

The third zone of importance is the cryosphere. This is the zone of solid water, that is ice, on the Earth's surface. This includes the Himalayan glaciers, the Arctic sea ice the antarctic and the greenland land ice as well as the seasonal ice cover that happens in the high latitudes like canada russia etc during the winter times this zone of solid ice also influences the climate because it reflects sunlight changing the net energy absorbed by the earth we will discuss this again in detail later but white surface is a good reflector of light and hence a surface is covered with glaciers reflects a lot of the sunlight back into space hence the earth does not absorb that light okay so there is a feedback loop here that you have ice the planet warms less and if you don't have ice the planet warms more then we have the biosphere which is the zone of living systems in which we fall and this affects the atmospheric composition through respiration, photosynthesis, forest fire, anthropogenic greenhouse gas emissions etc So for example, the respiration process of living beings like us, we absorb oxygen and release CO2. So there is a gas exchange between the biosphere and the atmosphere. Photosynthesis is similar, it releases oxygen and it releases water vapor as well. So photosynthesis process also is a source of oxygen into the atmosphere.

Then the transpiration process, which I forgot to mention here, I should have said, is the release of water by the green plants. This is also an important source of water vapor in the atmosphere, especially in the heavily forested regions of the world. Then you have other things like forest fires, which inject a lot of smoke and CO2 into the atmosphere. And of course, human activity that is causing greenhouse gas emissions like CO2 and methane,

which is causing the modern climate to change. So that is also, if you look at it globally, an influence of biosphere on the atmosphere.

Important fact to note that the current composition of the atmosphere which contains 21% oxygen would not have been possible without the living sphere or the biosphere. If green plants were not generating oxygen continuously by breaking down water through photosynthetic process, oxygen as a free gas would not have existed in the atmosphere. It does not exist in any other planet in the solar system. Fourthly, the lithosphere, the region of rocks, basically our ground primarily, constituting the upper region of the solid earth. This is the zone of volcanism, mountain formation and mountain erosion, continental drift, etc.

Volcanism, of course, influences the climate over short periods of time. Large volcanic eruptions can inject a lot of particles, CO2 and other gases into the atmosphere, temporarily perturbing the atmospheric system. Others processes in the lithosphere create slow changes that have become apparent over longer or geological periods of time. These are mountain building and erosion events, continental drift where the continents are moving across the oceanic beds from one region to other over millions of years.

So these impact the climate over geological timescales. Traditionally, the lithosphere-atmosphere interaction has been the prime driver of climatic changes in the world. Climate changes have been slow. The modern climate change caused by human is of course much faster and is of much different scale. But traditional climatic changes have been driven by the lithosphere-atmosphere interactions.

Then you have the astronomical aspects. What do you mean by astronomical aspects? The Earth's climate is what it is today because of its relation with the sun around which it rotates. The sun is giving it the heat, the light, the warmth, which is maintaining the temperature and the heat in the atmosphere and in the oceans. And Earth's inclination, Earth's distance from the sun, as well as the sun's own internal cycles, like the sunspot cycle, which is an 11-year cycle, for example, there are other cycles as well, affect the heat flux and the distribution of this heat flux on Earth. and hence affect the weather on a diurnal monthly and annual scale as you can see the winter versus summer variation it is entirely due to how the earth is inclined with respect to the sun the diurnal variation how the earth is rotating the day and night climates are obviously very different and monthly is obviously the same thing as the annual or the seasonal variation and it also affects the climate on a decadal scale like the sunspot cycles affect the climate on a decadal scale and there are other small changes that of earth's inclination with respect to the sun or distance with respect to the sun that have a slower impact that is that becomes apparent over the scales of hundreds of thousands or millions of years which are decadal and geological time scales okay so these six are the global zones that influence our climate.

The atmosphere, the hydrosphere, the cryosphere, the biosphere, the lithosphere, and the astronomical variables.

And how do they influence the climate? By two processes. A heat transfer process, the transfer of thermal energy from one zone to another, and a mass transfer process, the transfer of mass from one zone to another. For example, heat transfer process, transport of thermal energy between and within the zones that are driven by thermal radiation. For example, solar radiation hitting the earth, earth radiating heat back to space, atmosphere absorbing part of that heat that is earth is radiating back, reflection, reflection of sunlight by the snow, for example. Then phase change processes, water evaporating, and absorbing heat, water condensing as clouds and releasing heat. Physical transport of heat carrying material, for example warm ocean currents from the equator traveling towards the poles or warm air currents moving from one region of the world to another region of the world.

Thus air currents, ocean currents, convection, evaporation, precipitation are ways in which thermal energy is being transported between the zones. And then you have the mass transport processes. Transport of water from liquid to vapor to solid back to liquid. This entire water cycle between the atmosphere, the hydrosphere, the cryosphere, the biosphere and lithosphere. water is present in all of them when you are evaporating water water is going from the hydrosphere into the atmosphere when water is condensing in the clouds and precipitation is happening it is going back down and heating going back into the hydrosphere when water is freezing and snowfall is happening you are going the water is going into your cryosphere The oceanic continents also absorb and release water.

So there is lithosphere, groundwater is coming in some places. So lithosphere, hydrosphere interactions are also critical. All of this creates a water cycle which is very important in determining the state of the planet. Then you have the carbon cycle, which is the most important elemental cycle for biosphere and climate science. It involves the movement of elemental carbon in its various forms from atmosphere, for example, CO_2, which we are releasing during the respiration process or hydrosphere where CO_2 is being dissolved and producing carbonic acid or green plants, which is absorbing CO_2 and releasing oxygen during the photosynthetic process. Lithosphere, which is sequestering carbon, organic carbon, creating almost rock-like substances like coal, peat, limestone, etc.

Volcanic outgassing, which is releasing these organic substances back into the world through release of CO and CO_2. So this carbon cycle becomes a very important part of determining the state of the atmosphere as well. Okay. So we have, so today I will stop here in this first section of the class. We have looked into climate, we have looked into weather, we have looked into the various zones that influences the climate and the interaction processes between these zones and how those interaction processes occur.

We will go into detail into several of these aspects as we go into the class and we will meet you in the next class. Thank you and see you in the next class.