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

**Professor Name: Dr. Sayak Banerjee**

**Department Name: Climate Change Department**

**Institute Name: Indian Institute of Technology Hyderabad (IITH)**

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# CLIMATIC VARIABLES OF THE ATMOSPHERE

Good morning class and welcome to our continuing lectures on climate physics, climate dynamics and climate variability and monitoring. So in the last class, we were discussing the observed changes in global temperatures from 1850 onwards. And we saw that the global temperatures have increased by around 1.2 degrees from 1850 to 2020. And most of this change can be attributed to human activities like the emission of greenhouse gases like CO2, methane, etc. So what is the impact of these changes to our atmosphere? The impact according to the scientists of the IPCC are significant and is going to be increasing severe in the coming decades.

In this table, the left-hand column gives a set of climate extreme conditions that have been observed to increase either in intensity or in frequency in the last decade or a century. For example, the frequency and intensity of warm or hot extremes like heat waves. The frequency or intensity of cold extremes or cold waves have declined significantly, while the heat waves have increased in frequency and intensity significantly since 1950. This is to be expected when the world is warming on average.

That you will have more heat extremes and less cold extremes. And this is a significant problem for tropical and subtropical countries like India which are far more susceptible to heat waves than cold waves. As you know, heat waves in summer have increased in severity and frequency over the last several decades and are causing significant mortality during the periods of May, June and July in northern India. Along with this, several other climate extremes have also increased in frequency and intensity. For example, heavy precipitation events have increased in frequency, intensity or amount over majority of the land regions since 1950.

We will see why this is the case as we discuss our understanding of climate physics in the future. But very briefly, the idea is this. The hotter the air, greater is its capacity to hold water vapor. Hence, when the air moves upwards through convection in the upper atmosphere, greater is the amount of water vapor that is condensing out of this humid air.

Therefore, more significant and severe precipitation events are occurring more frequently.

And we can see that the main driver, and from modeling we can see this very clearly, is the main driver of this heavy precipitation events is anthropogenic climate change. Another climate extreme that we have discussed is agricultural and ecological droughts. Their intensity and frequency have also increased in some regions, particularly in the regions which are prone to aridity. So while there are some regions which are becoming more hot and humid with more intense precipitation events, other regions like arid regions like sub-Saharan Africa, Rajasthan, Western Asia are becoming hot and dry. And here agricultural and ecological droughts are increasing in intensity.

And it is expected as the world continues to increase, continue to warm, the number of regions where this kind of droughts will be occurring is going to increase over the next few decades. Precipitation associated with tropical cyclones have increased, observably increased since 1950s and we expect that the increase will be up to 11 to 28 percent depending on how much the world warms in the future. If we can control the warming to below 1.5 degree centigrade from 1850 average, remember it's already 1.2, so this is an extremely optimistic estimate, the increase will be around 11%.

However, if the final temperature increase by the end of the century is more than 4 degrees, tropical cyclones will increase in their precipitation intensity by around 28% according to most climate models. Similarly, proportion of intense cyclones are also going to increase to up to 20% with a 4 degree centigrade rise, 13% with a 2 degree centigrade rise and 10% which is almost now is currently around 1.5 with a 1.5 degree centigrade rise. There are certain other extreme events that are also occurring.

For example, marine heat waves in its intensity and frequency where the ocean water in a certain region warms much more than what is usual. This is extremely damaging to the marine species as well as the fish stocks on which a lot of our food supply depends. And this has also increased significantly in many parts of the world since 1950 and is strongest in the tropical oceans and the Arctic Ocean. Again India is abutting the tropical Indian Ocean and hence increase of marine heat waves in the tropical Indian Ocean is a significant threat to the fish supply of India. Sea level increase we have already discussed.

It's increasing in sea levels. So this also is going to become more and more prominent as we go along in this century. The color coding has been shown here. The red is virtually certain. The dark orange is extremely likely.

The orange is very likely. The light orange is likely with high confidence. So all of these are above 50% confidence according to projected climate models. And the red and the orange are almost certainly to occur. So we can see that there is a significant number of climatic extremes that we are currently suffering from and are going to become more and more prominent if this global warming continues.

The question of course comes, how do we know which type of extremes are going to happen, in which part of the world it's going to happen, and how to adapt to it or how to measure it? All these questions  are partly will be covered the fundamentals at least will be partly covered in this course we will try to understand how the different parts of the climate work together so if one part is changing how it is affecting other parts how variability is occurred and what happens when you perturb one system how does the variability impact other variability So these kinds of questions we will be answering and we will be also trying to answer questions regarding how to measure the important climatic parameters like temperature, humidity, cloud cover, etc. which are important to understand the magnitude and the frequency of this climate extreme events. Now, here we can see already a significant regional variance. In some parts, it's becoming hot, humid and wetter. In other parts, it's becoming hot and dry.

Heat waves are occurring in some parts with more intensity. Cold waves are becoming less frequent in some other parts. So the impact of global warming is not uniformly distributed throughout the world. And we can see this by looking at the change in temperature that has occurred  with geography in these maps so remember the climate has increased the global mean surface temperature is increased by 1.2 degree centigrade over the last 150 170 years okay this is a more shorter period where you have a global coverage of data from 1981 to 2020 now if you go back to our So, 1980 is this one 1980 and 2020.

So, 1980 we have a mean temperature of around plus 0.6 degrees from the 1950 mean and it is 1.2 degrees. So, you are getting around 0.7 degrees rise from 1980 to 2020 period. And here is the trend of degree centigrade increase per decade. So if you remember here, in total, if you see here, it has moved from around 0.5, 0.6 degrees in 1980s  here 0.5, 0.4, 0.5 degrees to 1.2 degrees. So, you have 0.7 degrees in a period of 40 years. So, it will be around for per decade, it will be around 0.2 degrees, 0.15 degrees like that over the world in total. So the degree centigrade rise per decade has been between 0.1 to 0.2 degrees. And this I have also noted before if I remember.

Yes, 0.15 to 0.2 degrees in the recent decades. Correct. So this is the mean decadal increase in global temperature. But how is this global temperature increase if you see it region wise? So this is what this map is telling us. Here you see a color code of global temperature increase which is per decade which spans from 0.8 degrees, 0.6 to 0.8 degrees to minus 0.8 minus 0.6 degrees. So a large span.

The mean is here, 0.1 to 0.2, the light orange. And you can see significant region of the world in the tropics and the subtropics falls within this range, particularly the subtropical and subtropical oceans, Indian Ocean, tropical and subtropical Atlantic Ocean, the eastern region of the subtropical and subtropical Pacific Ocean, which covers the main surface area of the world, and hence that is where the average is. However, if you look in the northern hemisphere in the high latitudes, you see much more significant decadal increase in mean temperature. So if you go up to say Europe, you are getting in Eastern Europe and Central Europe, you are getting 0.2 to 0.4 degree rise. to 0.4 to 0.6 degree rise so throughout the eurasian landmass african landmass north america and the landmass of south america so most of the land areas have seen a much greater rise in temperature of 0.2 to 0.4 degree centigrade per decade and particularly in certain regions like west asia eastern europe and central europe regions you are seeing temperature rises of 0.4 to 0.6 degrees per decade so very rapid increase in temperature and if you go in the high arctic regions so greenland arctic northern northern coast of russia so siberian region the northern coast of canada these regions have seen an increase of 0.6 to 0.8 degree centigrade per decade so very so where most of the world has increased by say 0.7 degrees in total here the increase has been more than 4 times that. So it has increased by say 0.7 to 2.8 or 3 degrees. So this region here in the high Arctic has seen a 3 degree increase in temperature over the last 40 years. Eastern Europe and these regions have seen 1.5 to 2 degrees increase in temperature. Most of Asia has seen also, Asia and Africa and most of landmass has seen at least 1 to 1.5 degree increase in temperature. In contrast, the southern oceans, especially the oceans around the Antarctic continent has seen a drop in temperature of minus 0.2 to minus 0.1 degree centigrade. So we will see much later in class why is it that the Antarctic Ocean is bucking the trend. Why is it that this is called the Southern Ocean, the ocean that surrounds the Antarctic continent.

Why the Southern Ocean is bucking the trend and is actually have cooled over time in the last few decades. Similarly there are certain other regions of the west coast of Brazil where also significant cooling has occurred. So these regions have not have seen an anomalous cooling trend and we will see the reasons why much later in the class. But because of this uneven distribution certain regions have been very strongly affected by the global temperature increase so there has been significant loss of arctic sea ice as well as greenland glacial ice which have these regions have seen more than three degree rise in temperature in the last 40 years similarly west asia regions have heated up creating significant crop failures heat waves and food insecurities eastern europe has been hit by significant droughts that have also caused significant economic hardship in the Eastern European regions. And most of land masses have heated up significantly more than what you would expect from global mean temperature analysis alone.

So we need to be, need to clearly understand the regional disparities in the warming trends and how what their impact and consequences are both the ecosystem and the people in that region. And these trends can be seen here as region-wide. So this is the North America region here. Here the temperature has risen from 1850 to 2020 by around, you can see around 1.8, around two degrees. So it has seen a two degree. The landmass of North America has seen a two degree rise in temperature. The landmass of Asia similarly has seen a two degree rise in temperature overall. The land of Central and South America, in contrast, have seen a 1 degree rise in temperature, significantly lower. The landmass of Australia have also seen a 1 degree rise in temperature, so close to the mean, more close to the mean.Landmark of Europe and North Africa has seen a 2 degree rise in temperature, much higher than the mean. Arctic, lower than the mean because of the cold Arctic Ocean, Antarctic Ocean surrounding it. Antarctic, so lower than the mean, about 0.8 degrees rise in temperature.Africa, around the mean, 1.2, 1.3 degrees. Arctic, more than around 3 degree rise in temperature from 1950 alone. So you can see that there is significant and these black lines are the actual observed and brown is the model from current climate change models which include both human action and natural causes. And you can see the current climate models are good enough to predict these regional disparities as well. So this kind of shows the idea that we only do not need to understand the mean climate, but the variability is in climate as well. And the importance of having observations that can test our models. So with that kind of an introduction portion of our discussion comes to an end. So now we will discuss more about the main climatic variables, what they are and how they vary across altitude and latitude and with seasons. So the most important climatic variables of the atmosphere. include things like atmospheric temperature, atmospheric humidity etc and we will start with atmospheric temperature but before that let's just look at the atmosphere in the context of other layers of earth so as we know atmosphere is the layer of gas that surrounds the earth and the mass of the atmosphere is around 5 into 10 to the power 18 kgs which seems like a lot but is significantly less than the mass of liquid oceans which is around 1.4 x 10 to the power 21 kgs. So the atmosphere, the total mass of air surrounding the earth is about thousand times less massive than the total mass of the oceans which are surrounding the continents. And the ocean mass itself is significantly lower than the mass of the solid earth, which seems more intuitive. This is around 5 into 10 to the power 24. So again, this is 1000 times more than the mass of liquid oceans. So in general, if you see the mass of atmosphere is around 1 million. So 10 to the power 6 times less than the mass of solid earth and around 1000 times less than the mass of liquid oceans. Despite its low mass and it's the thinnest and the lightest part of the earth, this is the primary region where climatic systems operate. So atmosphere is the primary component of the climate system and we are looking at the major property variables of the atmosphere that impact the climate. So these include the atmospheric temperature, the atmospheric composition, what gases are present in the climate, in the atmosphere, sorry. The atmospheric pressure, so you have thought, you have heard about high pressure systems, low pressure systems in weather broadcasts.

So atmospheric pressure is an important climatic variable. Hydrostatic balance relations, this many of you may not have heard if you haven't taken a climatology course or meteorology course before. Then atmospheric humidity, it is the how much water vapor is present in the atmosphere. And also atmospheric vertical stability relations. This basically tells us about whether there is possibility of there being precipitation events happening soon or not.

So we will discuss that as well. So these primary variables we will discuss first and then we will look into the astronomical variables which are the next most important in determining the climate of the world. So first we look at the atmospheric temperature and in this lecture we will just start it and we will continue in the next lecture. So atmospheric temperature is obviously the most important and widely known climate variable. Global warming, the mean temperature of atmosphere is increasing, right? So here again we have to be very careful when we say that the temperature is increased by 1.2 degree centigrade, it is the temperature of the surface air. So air just above the surface of the ground or the oceans. That temperature is what we are measuring and averaging over the entire globe and seeing the increment from 1850 onwards. So, the global mean atmospheric temperature at the surface of the earth and this is currently around 288 Kelvin, 15 degree centigrade, around 15.2 if you take the exact values and it is the rise of this mean surface temperature over its pre-industrial levels that is the measure of global warming.

So, current temperature is around 15 degrees. It was around 14 degrees in 1850. So, it is currently 15.2 to be precise. So, that is the mean temperature throughout the world. Of course, you immediately understand that the mean surface temperature is not the temperature of a certain place or a certain time at a given time location right so in winter many places will have surface temp surface air temperature significantly lower than this mean and in summer it will have surface temp air temperature significantly higher than this mean but the mean is 15 degree centigrade  So apart from the mean magnitude, the surface air temperature shows a wide variability with geographical locations throughout the earth as well as variability with the seasons. So this is what we call spatio-temporal variability. Temperature is a function of both the space, the geographic location and the time, at what time of the year we are measuring. Correct? The coldest recorded surface temperature is minus 89 degree centigrade, which is 184 Kelvin.

So, Kelvin is another measure of temperature. It is degree centigrade plus 273.15. So, 0 degree centigrade is 273.15 Kelvin. 10 degrees is 283, 20 degrees is 293, etc. So, that is how it is measured in Kelvin. Usually, when we are looking at radiation relations, and we will discuss these things later, we usually use the unit of Kelvin instead of degree centigrade, which is an absolute temperature scale. So the surface temperature is 184 kelvins, the minimum, which is minus 89 degrees in Antarctica. And the hottest recorded temperature is around 330 kelvins, which is 56.7 degrees in Death Valley, California. This is a somewhat older data. Maybe the hottest temperature record has been broken with the global warming trends going on. But I am not aware of it right now. So, the variability here is quite a lot. So, it is more than 130 degree centigrade or 130 Kelvin. So, the surface temperature depends on the seasons, hotter in summer in general, altitude, colder at high altitudes. That is why in the mountainous regions you have colder temperatures and we will see why. Latitude, lower latitudes are hotter. So tropics, subtropics are usually significantly hotter on average than the higher latitudes like Arctic and Antarctic. And again, we will see why when we discuss the astronomical variables.

And the presence of landmass. So continental interiors have extremes of summer and winter compared to oceans, which usually remain at the same temperature throughout the year. So we have seasonal impacts, altitudinal impacts, latitudinal impacts, presence and absence of landmass based impacts. And we can see these impacts here. So this is January. So remember earth being divided into northern hemisphere and southern hemisphere.

January is winter in north and summer in the south. So, here we can see this impact that in January most of the high latitudes in the northern hemisphere are quite cold. Temperatures of 252 kelvins are often present. So, let us just go down here.

This is the color code. So, this is 240 kelvins, this is 312 kelvins. Just convert this into degree centigrade. So, 273 is degree centigrade is Kelvins plus 273. So, degree centigrade is Kelvins minus 273. So, this is more than around minus 30 degree centigrade something like that and this is around  Around 40-50 degree centigrade.

So this is more than minus 30 degree and this is more than plus 50 degrees. Okay. So if you see in the January, the upper hemisphere, especially near the poles as well as in the continents, you are seeing significantly cold temperatures by these deep blue contours. The tropics, however, remain quite hot and especially you see the red regions extend southwards significantly. So much of Australia, southern Africa, all of these regions are also quite hot because it's summer in those regions. So you see that in the January, upper latitudes of northern hemisphere are quite cold, often below freezing, below zero degrees on average, whereas the tropics, subtropics and the latitudes of southern hemisphere remain quite hot, but Antarctica still is quite cold, which is because it's in the high latitude still. Whereas if you look in the July, which is summer in the northern hemisphere, you see a significant difference.

So what was quite cold here, that cold region have kind of declined. So this is 272 to 280 degree centigrade. So this is zero degree centigrade, right? So this is zero degrees, this is around eight degrees, something like that. So you see even at the high latitudes in summer, the temperatures are above freezing, except in Greenland, okay? And much of the continental interiors in northern hemisphere are quite hot. You are getting 40-50 degree centigrade in Sahara, West Asia, especially near the subtropical zone. Whereas the cold region in the southern hemisphere expanded outwards and you are getting nearly zero or close to zero degree centigrade in the southern tips of Australia, South America and much of the Antarctic Peninsula.

So you can see this large seasonal differences between summer and winter depending on where you are. So these things we will discuss far more, but this kind of makes this clear. And finally, this is the temperature difference between July and January for a certain region. So you can see temperature difference is up to plus 50 and up to minus 50.

So July temperature minus January temperature. This will be negative in the southern hemisphere which is January is hotter in southern hemisphere and July is colder. It will be positive in the northern hemisphere where January is colder and July is hotter. but you see the continental interiors there is large temperature fluctuations between July and January by plus 50 or more interiors of North America interiors of Asia as well as interiors of Australia which are also minus 30 minus minus 30 minus 40 degrees okay interiors of Africa etc even interiors of Antarctica because it's a continent has this trend So you can see continental interiors have much greater fluctuations. Whereas the oceans, the temperature fluctuations are between 0 and 10 at the most.

So this also shows the trend as we discuss it. So we will continue these discussions in the next lecture. So this is enough for today and we will discuss further in the next class. Thank you.