Climate Change Science
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Lecture 01

Introduction

Welcome to this course on Climate Change Science. I am Professor Srinivasan, and I have been talking about climate change for the last 40 years. I find that many people are climate change skeptics. They do not believe that climate change caused by human action can actually occur. So, this course is meant to help you understand the complexities involved in climate change science and to provide a clear understanding. Climate change will be the most challenging problem faced by humanity in this century.

The objective of this course is to enable students to understand the various components of the Earth's climate system that contribute to changes in the Earth's climate. The main focus will be on a quantitative understanding of the factors that contribute to global climate change. You can convince others about climate change only if you make a quantitative statement. So, what will you learn in this course? First, how do we know that human beings are contributing to global climate change? Many people have doubts about whether human beings can change the global climate.

The next important issue is whether the Earth's climate is stable, as there are concerns that climate change may push it to a state that is not favorable. Now, one of the doubts that many people have is why gases whose concentrations are in parts per million can have such a large impact on Earth's climate. So, this will also be clarified in this course. The other important thing to understand is the role of water vapor. Water vapor plays a very important role in Earth's climate, and it is essential for you to understand its role.

Now, there are many positive feedback mechanisms in the Earth system that cause the climate to change rapidly. You need to understand them and also know what is known as tipping points. We suddenly change the climate from one state to another. You should also learn why the Earth experienced ice ages every 100,000 years in the past. This is what we call natural climate change.

Climate change occurred in the past due to natural causes. And you also know that once upon a time, Earth was completely covered with ice, which was called Snowball Earth. These are some of the topics that we will cover. Now, you must remember that when you talk to other people, they may have various excuses to deny climate change. For example, for a long time, people said there was no global warming because we have not accurately measured the climate over the entire Earth.

When it was shown that global warming is occurring, people said that maybe it is natural and that maybe humans are not responsible for global warming. When it was shown that human beings do indeed cause global warming, people said that global warming is occurring, but that its impacts will not be large. Then, when it was shown that global warming is causing large impacts, people said it is too costly to mitigate climate change. Many people today believe that climate change will occur, but we cannot do much about it because it is too costly.

So, to respond to these excuses, you need a good understanding about what controls climate change and how can we mitigate climate change in the future. Now, there are many books that you can find through a Google search that claim global warming is a hoax. One of the well-known books is by Michael Crichton, who is a well-known author. He wrote a book titled "State of Fear." He claimed that the fear of global warming is not real. It is a hoax. Earth will somehow manage to maintain its climate in a constant state. There are people like Donald Trump, a well-known politician. Whenever there is a record cold wave, he says it disproves global warming. This is based on a misunderstanding of the difference between weather and climate.

Weather changes every day; it can be a cold day or a hot day. That does not mean global warming is not occurring. So, it is important for you to understand and also to explain to others the difference between weather and climate.

In the year 2023, the temperature of the Earth was 1.5^0C above the average temperature recorded between 1850 and 1900. It was thought that this would only happen with a 10% chance. Now, during this period, it has increased to 50%. So, we already crossed the 1.5^0C threshold last year (2023). We have to be cautious about further global warming.

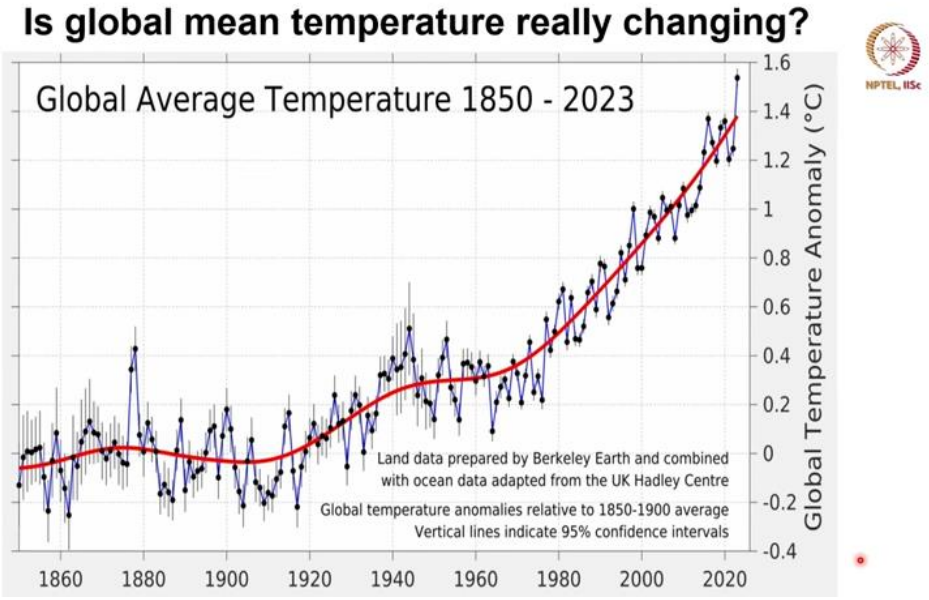
What one must realize is that the Earth's climate can change rapidly. A cascade of tipping points can trigger rapid climate change. We will discuss this in more detail in the course. Rapid climate change is a low-probability event, but if it occurs, it can have a high impact on your life. So, you have to worry about it.

We have already exceeded the 1.5^0C limit that was proposed in the Paris Agreement in 2015. We thought this would happen 10 years from now, but it has happened last year (2023). So, this is a warning to all of us that we must take climate change very seriously.

Now, when you hear various debates about climate change, you will hear two opposing viewpoints expressed with equal intensity. Both sides will make strong claims about what they believe is right. Many journalists feel that the truth is somewhat in between. That is not true. The truth does not necessarily lie exactly halfway between two extreme views. It is possible that one side is entirely wrong. This is a comment by the well-known scientist Richard Dawkins, who argues that we must examine all arguments very carefully. Do not

assume that if there are two opposite views, the truth is exactly in between. That need not be true.

Now, we will start looking at the global mean temperature. The global mean temperature has been evaluated for the last 150 years, starting from 1850. You can see that since 1850, the temperature of the Earth has increased by almost 1.5^0C. And note that this change is not uniform. It was almost constant between 1850 and 1920; then it started to increase gradually. In the last 60 years, it has increased more rapidly.



Now, when people look at this data, they ask the question, "How do you know that this is accurate?" because remember that most temperature measurements occur over land. There are meteorological stations where these measurements are taken. Over the ocean, the measurements were previously taken by ships. They would throw a bucket into the ocean and measure the ocean's temperature. But today, we obtain most of the ocean data from satellites.

Satellites measure the emissions from the ocean surface and convert them into temperature. So, today we have a lot more data from satellites than was possible before 1960. So, we have greater confidence in the data after 1960. Even then, note that the temperature varies significantly from year to year. This is a natural variation because energy is exchanged between the ocean and the atmosphere.

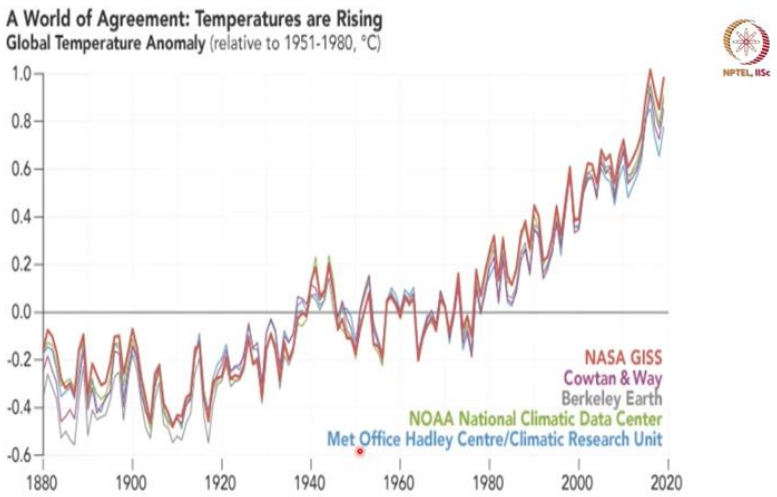
Some years are hotter, some years are colder. A change of about 0.1^0C to 0.2^0C is a part of natural variation. Now, before we try to know how accurate this data is, let us look at why do we consider the increase in global mean temperature as a metric for climate change.

None of us live in the global mean. You live in either a city or a village. You would like to know how the temperature changes in that village. However, we are using the global mean temperature as a metric because it indicates that there is an imbalance between the energy absorbed by the Earth from the Sun and the energy emitted by the Earth. That imbalance causes the global mean temperature to rise.

This imbalance can be due to human actions as well as natural changes. If the temperature was increasing in only one part of the world, then you can look for solutions in that part of the world. However, we now know that the temperature of the entire world is increasing, and if we want to control that, all the governments of the world must come to an agreement. For that agreement to exist, we need a global metric, and that global metric is the global mean temperature. If the global mean temperature is rising, then all the countries in the world must realize that we are all contributing to that change.

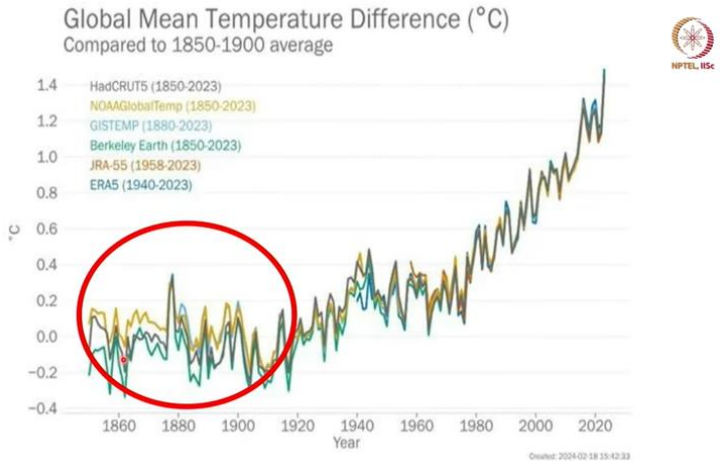
All of us have to take action to control the increase in temperature. That is why this is a metric used by the United Nations. They have an Intergovernmental Panel on Climate Change (IPCC), which monitors this temperature. In the Paris Agreement signed in 2015, the goal was to limit the increase in temperature to 1.5^0C compared to the temperature recorded between 1850 and 1900.

Now, you might still have a doubt about how accurate the measurement is. So, here I have shown you five different groups in the world: NASA and NOAA, both in the USA; the Met Office in the United Kingdom; and a group called Berkeley Earth. All these groups are determining the global mean temperature from thousands of data points over land and ocean, and they have computed the temperature change compared to the values from 1951 to 1980. Now, you can see that the world was colder before 1940s, and it has become warmer in the last 60 years.



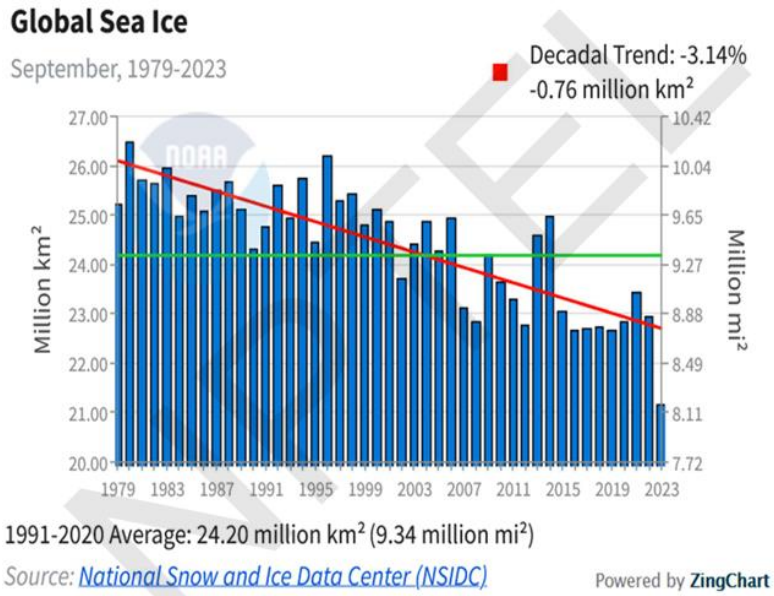
Now, notice that the five different groups do not agree entirely. There is a difference of around 0.1^0C, which is not surprising because when you collect data from thousands of sources and calculate an average, there are various ways to do so, including different methods of taking the mean. So, there are some differences in methodology. But the key message is that they all agree that the temperature today is about 1.5^0C above the temperature between 1880 and 1900. So, although there are small differences between different groups, they all agree that the Earth's climate is changing and that temperatures are rising. If any of you have doubts about whether the climate is truly changing, this should allay your concerns.

Below is another graph computed by six other groups. Now, the reason this graph is shown is that I want you to focus on the period from 1860 to 1920.

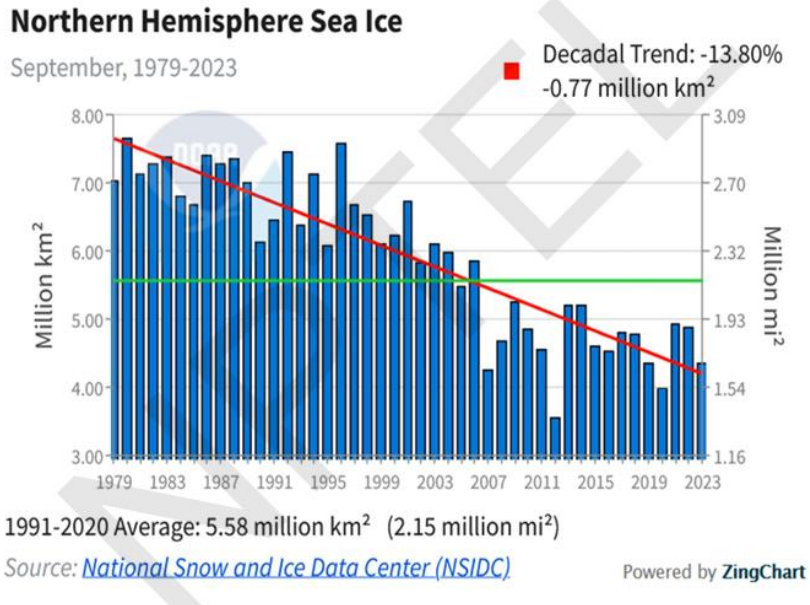


Here, you can see that there are larger differences compared to the last 10 years. Why? Because from 1860 to 1920, there was no satellite data and there were only a few ships in the ocean. So, there are large gaps in the data collection. When the different groups compute averages, they get somewhat larger differences. But as you look at the last 60 years, you can see they are almost in perfect agreement. You can see that we have more trust in the data from the last 60 years compared to the data from 150 years ago.

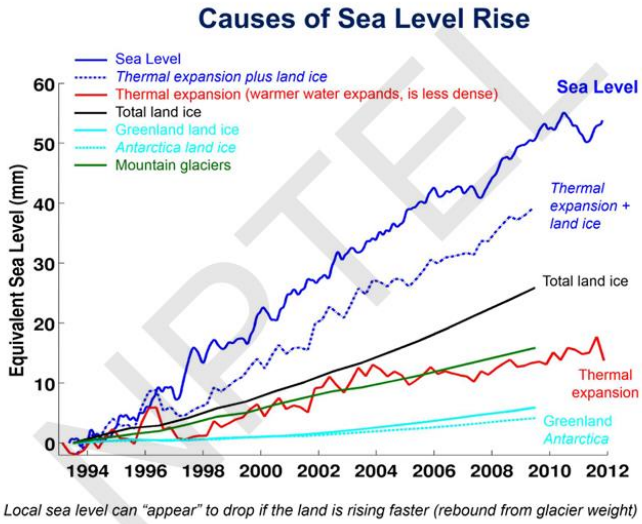
Now, if you do not believe in global mean temperature, you can look at the consequences of global warming. When global warming occurs, the sea ice starts melting rapidly. Now, sea ice has been measured from satellites over the last 40 years, and you can see that global sea ice cover has been decreasing quite rapidly since 1979, when we had the first satellite data, to today. It declined from around 26 million square kilometers in 1979 to 21 million square kilometers at present in 2023. So, we have lost 5 million square kilometers of sea ice in the last 45 years. This is a clear indication that global temperature is rising and sea ice is melting.



Now, there is one more example below from just the northern hemisphere's sea ice, which is measured more accurately because more people live there. And there, you can see that the sea ice has declined from around 7 million square kilometers in 1979 to just above 4 million square kilometers in 2023. So, it declined by approximately 3 million square kilometers in the Northern Hemisphere. Both of these indicate that global warming has reduced sea ice cover.

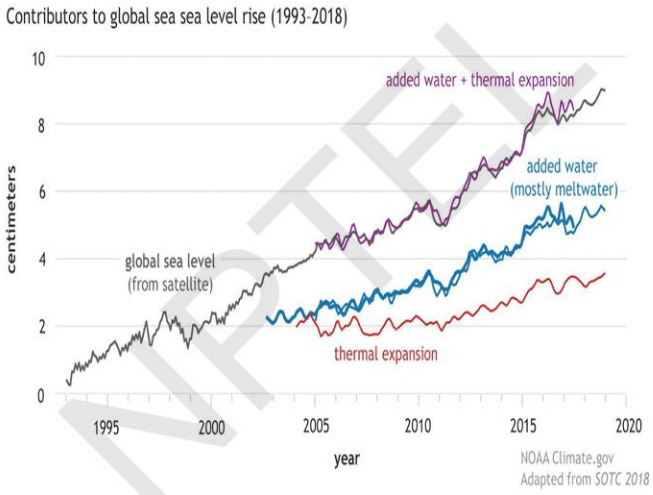


Now, what are the consequences of global warming? One major consequence is increase in sea level. When the global temperature rises, the ocean temperature rises, and then the water expands. So, you can see that due to the rise in temperature, thermal expansion has contributed to about 12 mm of sea level rise, while land ice melting and water reaching the ocean have contributed around 25 mm, and the melting of Greenland and Antarctic ice, as well as mountain glaciers, has contributed around 13 mm. All put together, the sea level has increased by around 50 mm in just 18 years (since 1994). So, if this continues the sea level will rise by almost 1 meter by the end of century.

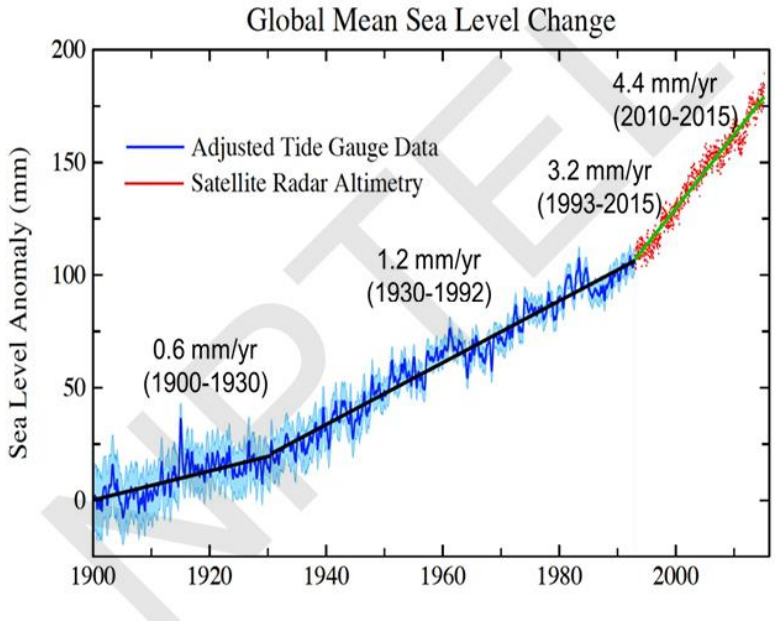


Local sea level can "appear" to drop if the land is rising faster (rebound from glacier weight)

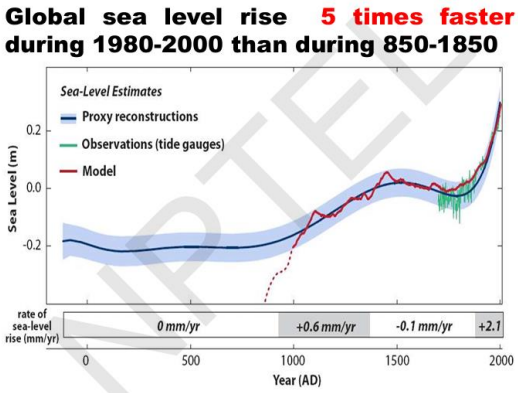
Now, if the sea level rises, it has important consequences for people living along the coastline. A large number of people live along the coastline, and they will face serious consequences from this sea level rise.



Above is a comparison of the roles of the expansion of seawater and the addition of water from the melting of land ice, including both Antarctic and Arctic land ice. So, in total, as you can see, compared to 1993, it has almost increased by 9 cm.

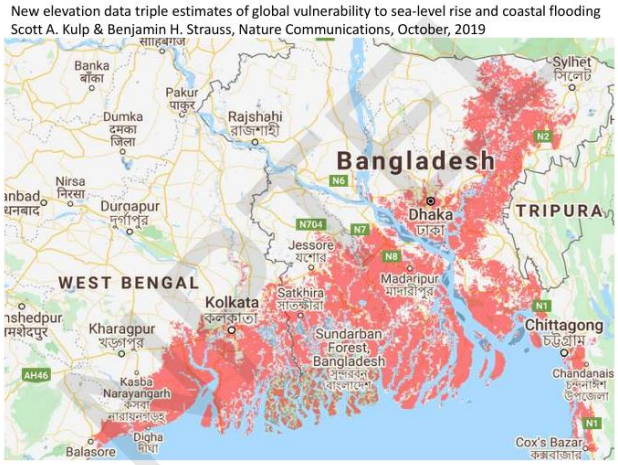


Now, if you look at a longer period, going from 1900 to 2015, you can see that the sea level has risen by about 160 mm, or 16 cm. You can see that the rise in sea level was gradual in the early part of the 20th century. It then accelerated to 1.2 mm per year and now it is increasing at 4.4 mm per year. So, the sea level rise is accelerating. This is also a warning for the future.



Now, if you compare the sea level rise over the last 2,000 years, some of the data are what is called proxy reconstructions based on sources other than direct measurements. You can see that sea level rise in the last 120 years has been five times faster than in the previous 1,000 years. All this is a warning that climate change is occurring more rapidly

now than in the past and also points to the human impact. Human impact has occurred in the last 100 years.



Now, why should you worry about it? You can see that the consequence of rapid sea level rise is that many coastal areas will be inundated. There will be flooding in many coastal areas. Here is an example of what can happen to West Bengal and Bangladesh in the Indian region, which will be underwater in the future due to sea level rise, a consequence of the increase in global mean temperature. So, this is one of the serious consequences of global temperature change.

Now, there is a common misconception that carbon dioxide, which is a very minor constituent of the atmosphere, cannot influence climate change. The purpose of this course is to help you understand how a very minor gas, like carbon dioxide, methane, or ozone, can have such a major impact on Earth's climate. This is an unusual feature of the Earth that the major gases like nitrogen and oxygen do not directly contribute to climate change. It is the minor gases that are contributing.

Now, before you get into that issue, I want you to understand the difference between weather, natural climate variability, and human induced climate change. These are three different things, and there is a lot of confusion among politicians and the public because they cannot understand the difference between weather, natural climate variation, and anthropogenic climate change. These are completely different things.

Now, weather is something all of you understand well, because every morning when you get up, you want to know whether it is going to be clear or whether it is going to rain, so that you can wear the right kind of clothes. And then, you want to know whether you want to get an umbrella. Weather is the state of the Earth's atmosphere (temperature, humidity, cloudiness, rainfall, and other variables) which changes on a timescale of hours to days. It is a regional feature. For example, the weather in Bengaluru is not the same as the weather in Chennai or Delhi. The main component that affects weather is the

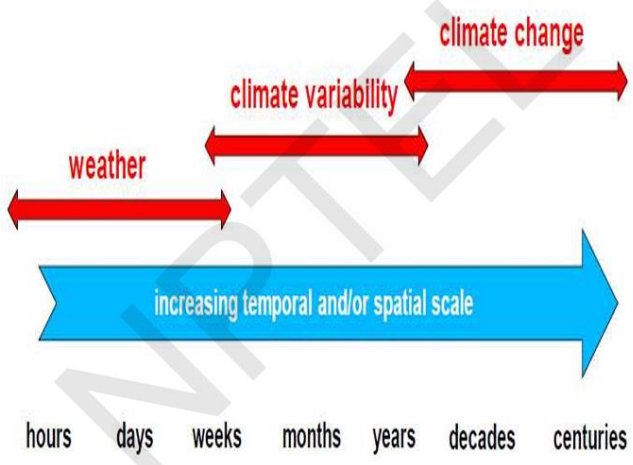
atmosphere. If I know the state of the atmosphere today, I can accurately predict what the weather will be tomorrow.

Today, computer models are accurately predicting the weather a few days in advance. You can look up the weather on your mobile or on television. They will tell you what the weather will be like tomorrow, and they will be fairly accurate. So, the weather is something that changes from day to day, and all of us have to get used to those changes and be prepared for them.

Climate is the statistics of the weather, that is the mean distribution of climate variables (temperature, rainfall, humidity, cloudiness), and how it is distributed in a given area. When we talk about climate, we do not talk about today. We talk about averages over months, years, decades and longer periods. Climate is influenced not just by the local atmosphere. It is also influenced by global changes. Suppose, I want to know what will be the climate of Bengaluru next month, let us say in August or September, then I have to know what is going on in the Pacific Ocean. Because the climate of the Pacific Ocean, for example, sea surface temperature will have an influence on the weather in Bengaluru one month from now.

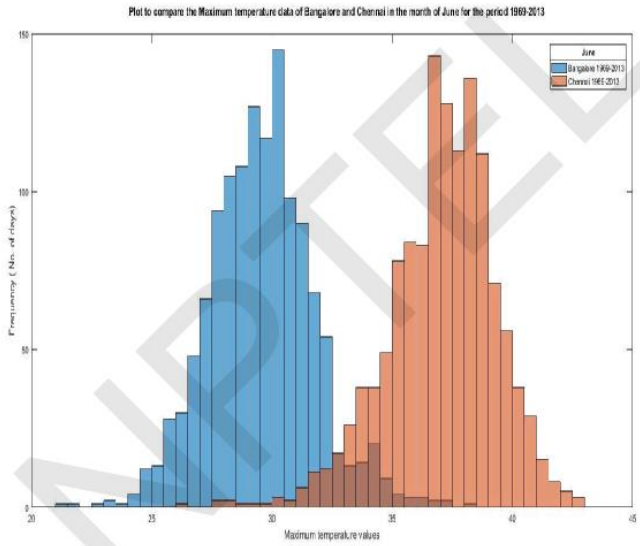
So, what you must know is that climate is influenced not only by the local atmosphere, but it is also influenced by ocean all over the world, land, and also by human beings. That is what makes climate different from weather. I will give examples for you to understand the difference between climate and weather. So, climate is average of the weather over a certain time period of years or longer, and it is not the same as weather.

The below image shows the difference between weather, which occurs over hours, days, and weeks; climate variability, which refers to changes in climate from year to year due to natural causes; and climate change, which involves long-term changes in climate (over 10 years, 30 years, or 100 years) that are influenced by human activities.



So, as you go from left to right, the temporal scale as well as the spatial scale (in many scenarios) are going up. For weather, we are talking about days and weeks. For climate variability, we are talking about months and a few years. For climate change, we are talking about decades to centuries.

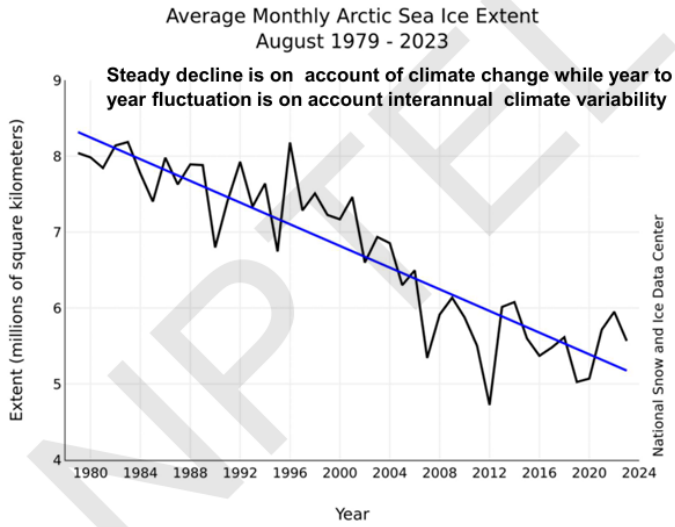
Look at the scale ranging from hours to centuries. So, the major concern in this course is about changes from decade to century, not what is happening tomorrow or the day after.



To illustrate the difference between climate and weather, I have taken the temperature distribution in Bengaluru and Chennai, two different cities in India, during the month of June, a summer month, averaged over a fairly long period. In this case, it is around 45 years. Now, you can see that the temperature distribution in Bengaluru shows a lower temperature than that of Chennai.

Generally, Bengaluru is cooler than Chennai by around 6^0C. So, Bengaluru has a colder climate than Chennai. But on a given day, you can see this overlap here, temperature (weather) of Bengaluru and Chennai can be same. For example, in the month of March, Bengaluru sometimes is hotter than Chennai, but on an average Bengaluru is about 6^0C cooler than Chennai. Bengaluru climate is cooler than Chennai on an average, but on a given day the weather in Bengaluru can be hotter than Chennai. That tells you the difference between weather and climate.

Now, the below graph shows how the Arctic Sea ice has come down rapidly in the last 40 years obtained from climate data. And in this, we show the difference between long term climate change, the blue line and the year-to-year climate, which is the black line. The black line is an indication of climate variability.



Year to year climate is changing. Every year arctic sea is not decreasing. There were years when arctic sea ice went up. So, that it should not cause any concern for you because that is natural variation. You should look at the long-term change. In the long term, the sea ice is declining. Some years more rapidly, some years less rapidly, some years it is going up. So, you should not let year-to-year variation bother you and make you think that climate is not warming.

To summarize this lecture, there is natural climate change occurring due to energy exchange between ocean and atmosphere, which is due to natural causes, which controls year-to-year changes. Then, human induced climate change, which is changing climate over a long-time scale from decades to centuries. And then, you have local climate change, which is different from global climate change.

In local climate change, there can be many reasons. For example, local climate can change due to urbanization. If you build more and more concrete jungles, then local climate will change even when global climate does not change. So, the focus of this course will be only on global climate change because that is much simpler to understand than local climate change. Local climate change is caused by many factors which I will discuss briefly in the next lecture. You must remember that the focus of this course is on global climate change because it is easy to understand and you should master that first before you start looking at local climate change.

So, with this, I will conclude this lecture. In the next lecture, we will continue this discussion about local versus global climate change.