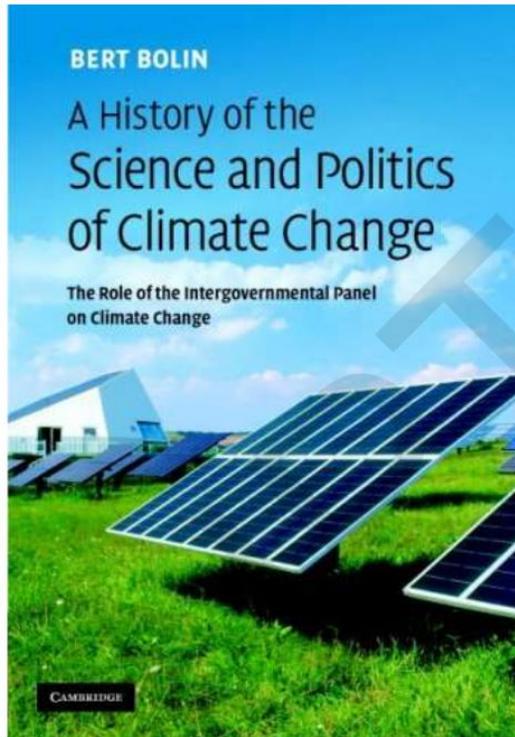


Climate Change Science
Prof. J. Srinivasan
Department of Environmental Science
Indian Institute of Science, Bangalore

Lecture – 59
Denial of global warming



Today, we will talk about the science and politics of climate change. So far, the focus has been only on the science of climate change because that was the main goal of this course. But you cannot avoid talking about politics because science and politics get mixed up in this issue. You may wonder why—many people think science and politics are two distinct areas and they should never be together—but it is important to remember that science is never partisan. It is always objective, but science is always political. Why is that? It is political because new knowledge either confirms or challenges vested interests.

**Science is never
partisan, but science is
always political.**

**It is political because
new knowledge either
confirms or challenges
vested interests**

Shawn Lawrence Otto

The best example of this is the story of Galileo. When Galileo announced that Earth goes around the Sun and not vice versa, he was condemned, and the authorities at that time forced him to admit that he was wrong. Why did they do that? Because it challenged the paradigm that existed at that time. So, this clash between science and politics will occur now and then in the history of our civilization, because sometimes science does bring knowledge that makes many people uncomfortable.

The changing excuses of Climate Change deniers

- There is **no global warming**
- **Humans are not responsible** for global warming
- Global warming is occurring but **impacts will be minimal**
- Although impacts be large , it will **cost too much to mitigate climate change**

To respond to these excuses you need a good understanding about what controls earth's climate

Climate change caused by human beings poses a threat to the fossil fuel industry and the countries whose major revenue comes from the export of fossil fuels. More than 40 years ago, these countries got worried that if human-induced climate change were accepted as a reality, then there would have to be a reduction in fossil fuel burning. That would mean almost ten countries in the world, whose economies depend on the export of fossil fuels, would be in deep trouble. So, they encouraged climate change deniers to make statements—such as that there is no global warming; humans are not responsible, and even if it occurs, the impacts are minimal. And even if impacts are large, it will be too costly to mitigate climate change.

The purpose of this course is to give you the scientific background about climate change so that you can respond to these excuses. To do that, you need a good understanding of what controls Earth's climate. That was the purpose of this course. Today, I will review some of these things and the politics that resulted from them.

WALL STREET JOURNAL
2 January 2013 Indian Edition

No Need to Panic About Global Warming

There's no compelling scientific argument for drastic action to 'decarbonize' the world's economy

For example, more than 10 years ago, the first Indian edition of the Wall Street Journal said, “No need to panic about global warming. There is no compelling scientific argument for drastic action to decarbonize the world economy.” This was an effort by the fossil fuel lobby to create the impression that global warming is not a serious issue. And they were not the only people.

Secret funding helped build vast network of **climate denial think tanks**

Anonymous billionaires donated \$120m to more than 100 anti-climate groups working to **discredit climate change science**

[The Guardian](#), Thursday 14 February 2013

Secret funding helped build a vast network of climate denial think tanks and billionaires who gained from the sale of fossil fuels. They donated more than 120 million dollars to 100 anti-climate groups to discredit climate change science. This was shown by The Guardian more than 10 years ago. That is why, if you do a Google search for climate change, you will get many websites that pretend climate change is not a serious issue. These are fake websites paid for by somebody.

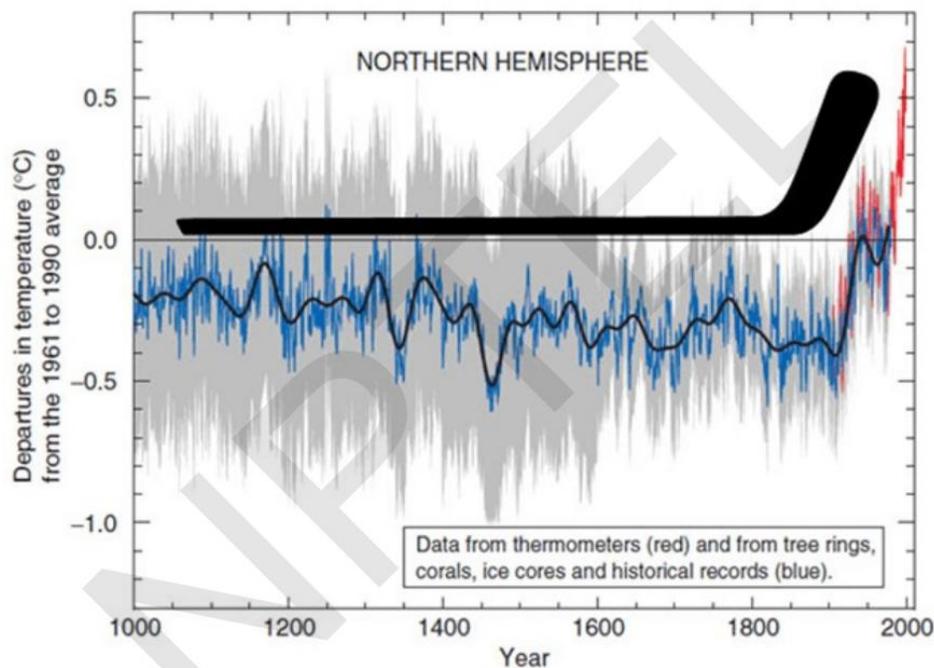
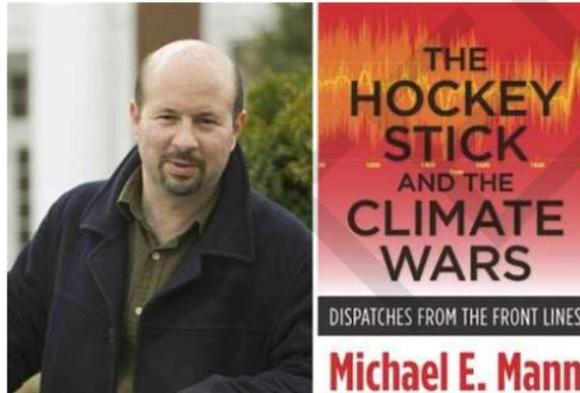


Figure: Hockey Stick Curve

Now, the best example of this controversy is the so-called hockey stick controversy. That is the work done by Professor Michael Mann at Pennsylvania State University. He used proxy data,

which we discussed in this course—mainly tree rings—to show that temperature was below the 20th-century temperature for a long period, from 1000 AD to almost 1850 AD, and then it began to rise rapidly. This was a very important paper that showed clearly that climate change occurring in the 20th century is not due to natural causes. This variation is due to natural causes from 1000 AD to 1800 AD.

IPCC scientists who were harassed



In the late 1990s, Michael Mann, author of the famous “hockey stick” diagram of global temperatures, and was a key part of the third assessment report, came under fire from right-wing thinktanks and even the Attorney General of Virginia.

When this paper appeared, the entire fossil fuel lobby attacked Michael Mann. He had to face many challenges. He lost his job at one of the universities. He has written about his experience in a very interesting book called *The Hockey Stick and the Climate Wars*. The word “hockey stick” comes from the shape of this curve. The curve is shaped like a hockey stick. That is why it is called the hockey stick curve.

THE NEW CLIMATE WAR

M I C H A E L E . M A N N

“A consortium of fossil fuel interests known as the Global Climate Coalition, which included ExxonMobil, Shell, British Petroleum, Chevron, the American Petroleum Institute, and others, came together in 1989.... to challenge the basic science of climate change”

Michael Mann has written many books showing how the fossil fuel lobby is creating confusion about the climate change issue. I strongly recommend that all of you read the book *The New Climate War* by Michael Mann, published about two years ago, in which he says a consortium of fossil fuel interests known as the Global Climate Coalition—which included ExxonMobil, Shell, British Petroleum, Chevron, the American Petroleum Institute, and others—came together in 1989 to challenge the basic science of climate change. So, this book gives in great detail how they went about creating confusion and doubts about climate change occurring due to the burning of fossil fuels.

The fossil fuel industry has been granted the greatest market subsidy ever: the privilege to dump its waste products into the atmosphere at no charge
Michael Mann

Michael Mann says the fossil fuel industry has been granted the greatest market subsidy ever—the privilege to dump its waste product, carbon dioxide, into the atmosphere at no charge. So, this industry, worth more than a trillion dollars, has benefited from this market subsidy and is not willing to permit the reduction of fossil fuel burning, which is necessary to control climate change.

We should learn a lesson from the ozone hole, which we discussed in this course in one of the early lectures. In the 1970s, scientists showed that ozone would decline steadily on account of chlorofluorocarbons. But what actually happened was a catastrophic decline in Antarctica, called the ozone hole.

Lessons from the “Ozone Hole”

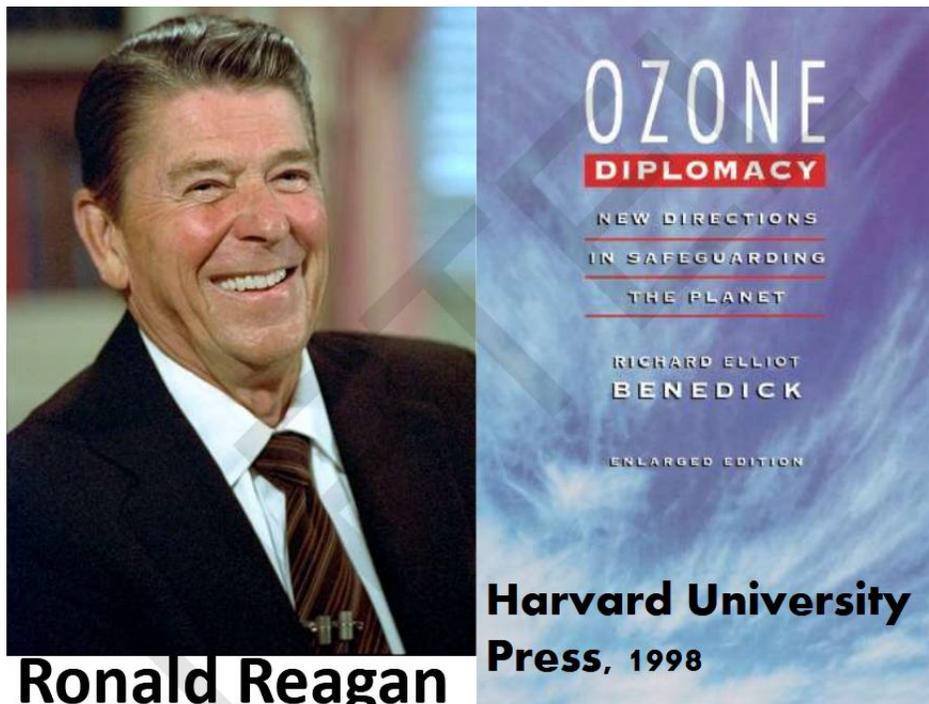
Although a steady decline in the Ozone layer was predicted by many scientists no one predicted the catastrophic decline in Ozone that led to the Ozone hole in Antarctica

So, what you should realize is that, in spite of our very good understanding of Earth's climate system, our predictions can be too optimistic. The real situation can be much worse because the Earth's climate system is very complex, and we are not able to model all the complexity. So, there is always a surprise, like the ozone hole, that can happen when it comes to global warming.

Now, because the ozone hole appeared suddenly out of nowhere, it created a big concern. Very soon, the Montreal Protocol on Substances That Deplete the Ozone Layer was agreed upon on 16 September 1987 at the headquarters of the International Civil Aviation Organization in Montreal.

The Montreal Protocol on Substances that Deplete the Ozone Layer was agreed upon on 16th September 1987 at the Headquarters of the International Civil Aviation Organization in Montreal

This is a very famous protocol that resulted in the phasing out of chlorofluorocarbons and other chemicals that cause ozone depletion. This was possible because at that time, the President of the USA, Ronald Reagan, decided that he would support this protocol. This whole interesting story is mentioned in a book written by Richard Benedick, who was involved in the negotiation, and he showed how the leadership provided by the USA resulted in this protocol. But you must remember that the success of this Montreal Protocol does not mean a similar success will occur in the case of climate change, because it is a different problem. Now, this can be compared.



In the table below, ozone depletion is in the left column, and climate change is in the right column. When ozone depletion occurred, only 20 countries were involved because they were the ones contributing most to the ozone depletion. There was clear scientific evidence from the ozone hole. We have not found clear-cut evidence of disastrous climate change yet.

Table 2. Differences between the stratospheric ozone and climate change problems

Stratospheric ozone depletion	Climate change
20 countries were involved in the original negotiations	~180 countries participate in climate negotiations
Clinching scientific evidence in the form of 'Antarctic ozone hole'	No smoking gun; evidence is incremental and cumulative
Term 'ozone hole' is evocative	Term 'climate change' is neutral
All countries expect to lose	Both losers and (at least initially) winners
Three scientific assessment panels inside the formal Montreal Protocol process for advice	Three IPCC Working Groups outside the formal Convention Process provide advice
US (and UNEP) leadership	EU leadership
US Senate ratified Montreal Protocol 87-0	US Senate opposed Kyoto Protocol 95-0
Costs of developing substitutes reasonable	Substitutes to fossil fuels for electricity and transport currently expensive
Developing countries were perceived by northern countries to be aid recipients	Developing countries perceived to be competitive threats
Northern legislatures willing to transfer technology and resources to developing countries	Northern legislatures unwilling to transfer technology and resources to developing countries

The ozone hole would have affected all countries in the world. While in the case of global warming, some countries like Russia will benefit somewhat from the warming, but most countries in the tropics will lose. In both cases, the United Nations had scientific assessment panels that made it clear that both the depletion of ozone and global warming are serious issues. In the case of the ozone hole, the United States provided the leadership, and, being the largest contributor to ozone depletion, it helped. In the case of climate change, the European Union is providing leadership. Unfortunately, the United States is not helping.

The United States opposed the Kyoto Protocol 95 to 0 in a vote in the Senate, while in the case of the Montreal Protocol, it was approved 87 to 0. In the case of the ozone hole, the cost of developing substitutes was not very high, so the switch was easy. But this is more costly. Replacing fossil fuels with solar, wind, and other renewable sources is happening, but it will take much more time. In the case of the ozone hole, developing countries were considered not the major contributors, so they were provided with aid to reduce ozone depletion. But here, in the 1990s, developing countries like China were considered competitors to Europe and the USA.

So, this big difference meant that although the Montreal Protocol was successfully adopted, the Kyoto Protocol, which is equivalent to the Montreal Protocol for global warming, is still

struggling. Now, the problem is that the Earth's climate is always changing. You have to distinguish between natural climate fluctuation, which changes from year to year due to energy exchange between the ocean and the atmosphere, called internal variability, from the outside effect caused by human beings, which is over and above the natural climate variation.

The Earth's climate is always changing, and that can occur for many reasons. To determine the principal causes of observed changes, we must first ascertain whether an observed change in climate is different from other fluctuations that occur without any forcing at all.

Climate variability without forcing—called internal variability—is the consequence of processes within the climate system. Large-scale oceanic variability, such as El Niño-Southern Oscillation (ENSO) fluctuations in the Pacific Ocean, is the dominant source of internal climate variability on decadal to centennial time scales.

The natural climate variation includes the well-known El Niño Southern Oscillation phenomenon, which occurs every four to five years and is a natural climate fluctuation. Global warming is on top of that. So, one has to differentiate between the signal of human-induced climate change from the natural fluctuation that is occurring.

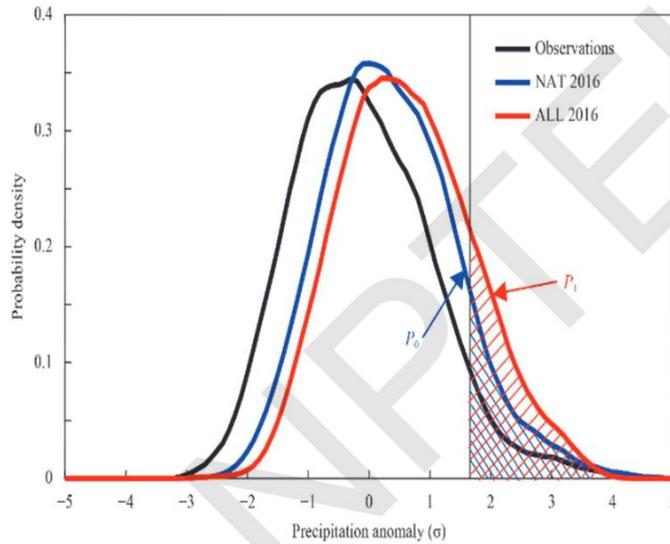
A related question concerns ascribing blame for causing an extreme event. For example, if a damaging hurricane or typhoon strikes an area and causes much damage, affected residents may ask whether human-caused climate change was at least partially to blame for the event.

In this case, climate scientists sometimes use the "Fraction of Attributable Risk" framework, where they examine whether the odds of some threshold event occurring have been increased due to anthropogenic climate change.

Knutson, T., 2017:Fourth National Climate Assessment, Volume U.S. Global Change Research Program, Washington, DC,USA

How do you do that? To show the impact of global warming, you have to show how much additional risk is caused by global warming. This is called the fraction of attributable risk. This was defined more than seven years ago.

It is based on this kind of figure shown below.



Fraction of attributable risk (FAR)

$$FAR = 1 - \frac{p_0}{p_1} = 1 - \frac{1}{PR}$$

Imagine rainfall distribution. Black (in the figure above) is the observed value of rainfall distribution in a given region, and blue is a variation in a model which does not have increasing CO₂—it is called "natural." It is not identical to the observation because models are not perfect, but in that model, if we increase CO₂, the distribution shifts, which we discussed earlier in this course. Because of the shift due to increased CO₂ in the rainfall distribution, the chances of very high rainfall—which we can define by a vertical line above which the heavy rainfall will cause serious damage—has a certain area under the curve for the natural variation (shown crosshatched), and a different, larger area for the case with CO₂ increase (shown as the area covered with red lines).

You take the ratio of these two probabilities—that is called the fraction of attributable risk. How much attributable risk is increased due to global warming? And you can now compute this for every extreme event like heat waves, extreme rainfall, droughts, and landslides.

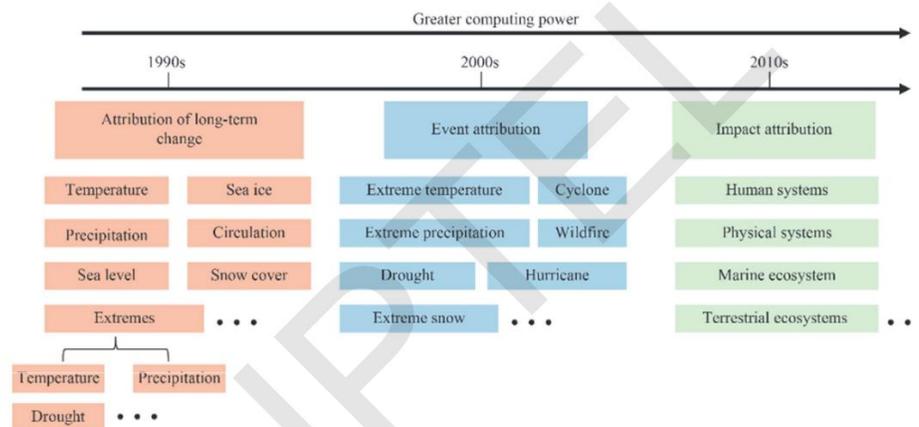


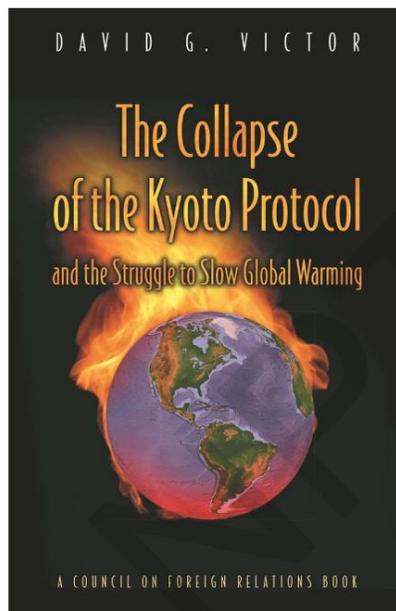
Fig. 1. The three main types of climate attribution studies along with their respective subjects and emergence times.

Zhai, P. M., B. Q. Zhou, and Y. Chen, 2018: A review of climate change attribution studies. *J. Meteor. Res.*, 32(5), 671–692, doi: 10.1007/s13351-018-8041-6.

So, you can quantify the additional risk we have to face on account of global warming. When you do that, you can do it for global mean temperature, decreasing sea ice, or event attribution—that is, extreme events occurring in, say, Europe, like heat waves, or more extreme cyclones, extreme rainfall, or wildfires—which we saw are some of the impacts of global warming. These have been discussed. Attribution is a very important issue because in order to pay for the damages of global warming, we must be able to show that an event probably increased dramatically on account of global warming.

On 11 December 1997, representatives from 160 nations gathered in Kyoto, Japan, for the Third Conference of the Parties (COP) to sign the **Kyoto Protocol. The Protocol agreed to address global warming by cutting greenhouse gas (GHG) emissions in **38 industrialized** countries by 5.2% between 2008 and 2012 compared to the levels registered in 1990.**

So, in December 1997, we had the Kyoto Protocol, which was similar to the Montreal Protocol, which was agreed upon in 1987. There, 38 industrialized countries agreed to reduce their greenhouse gas emissions by 5 percent between 2008 and 2012, compared to 1990. Unfortunately, this protocol was never actually implemented because there was a collapse of the protocol. The United States decided, as I pointed out earlier, that they would not agree to the Kyoto Protocol. Although they signed it, they did not ratify it. This was a major breakdown in the climate negotiation process that has been ongoing since 1987.



“I oppose the Kyoto Protocol because it . . . would cause serious harm to the U.S. economy. The Senate's vote, 95-0, shows that there is a clear consensus that the Kyoto Protocol is an unfair and ineffective means of addressing global climate change concerns.”

**George Bush,
President of United States**

Finally, the Kyoto Protocol was diluted substantially, and we had the Paris Agreement in 2015, signed in 2016, which has no binding provisions like those in the Montreal Protocol for ozone-depleting substances. Now, we only have voluntary provisions, and we do not know whether they will actually be implemented. So, that is the background for the politics of climate change.



Paris agreement, in contrast to Kyoto Protocol, had no binding provisions for reducing Carbon dioxide emissions

Now, let us review what are the major issues that we discussed in this course. First, we said it is important to differentiate between fluctuating weather, which all of us understand on a daily basis, from natural climate variation, which changes from year to year, and human-induced climate change due to increase in carbon dioxide. So, among many people, there is a lot of confusion. I hope those of you who have taken this course have a better understanding of this difference.

- **Fluctuations in weather**
- **Natural climate Variability**
- **Anthropogenic Climate change**

Another thing that is important to understand is the difference between natural climate change due to changes in solar input or volcanic eruption and human-induced climate change, which is either

due to an increase in carbon dioxide or an increase in air pollution. Then we have to differentiate between local and global. There are a lot of local climate changes going on for which there is no global cause. So, it is important to understand that also.



Global change is caused by changes in ice cover, clouds, gases that absorb Earth's radiation, and changes in incoming solar radiation or volcanic eruptions. All those are global causes. There are many local causes. Local causes can be due to a change in wind direction, which can be natural or human-induced, or a change in land use pattern when you convert a forest into an urban area—that is a huge change—or it can be local air pollution.

Global climate changes are caused by changes in ice cover and clouds, changes gases that absorbs earth's radiation, changes in incoming solar radiation and volcanic eruptions

Local climate changes are influenced by global climate changes as well as local factors such as

1. **Change in wind direction**
2. **Changes in land-use pattern(e.g., urbanization or deforestation)**
3. **Air pollution**

Now, the anthropogenic climate change has three scales. There is a small-scale urban heat island, where we convert green areas into urban land with lots of concrete, and the area heats up substantially. That is a purely local factor, which can be addressed by local laws. Then, there is a large-scale conversion of forest to agricultural land, which has occurred over the last 10,000 years in Earth's history. That is a land cover change, and that is larger in scale than the urban heat island. Then, there is the global scale, which is the greenhouse effect, where we have released CO₂ all over the world, and now it is there everywhere on the planet.

Anthropogenic Climate Change

- **Small Scale -- Urban Heat Island**
- **Larger Scale -- Land cover change**
- **Global Scale- Greenhouse Effect**

Now, the process of establishing climate change without assigning any specific reason is known as detection. We detect climate change as being a signal above the noise of natural climate variability. After that comes attribution. Once you detect climate change, you have to decide what is causing the climate change. That is the attribution. These two are two different things.

The process of establishing climate without assigning any specific reason is known as **detection and the process which assesses the relative contributions of multiple potential causal factors for the detected changes is defined as **attribution****

So, because of the presence of natural climate variability, you have a signal-in-noise problem. The natural climate variability is the noise that we have to live with. On top of that, there is a signal caused by human-induced climate change. So, we have to use statistical techniques to differentiate between signal and noise, and that has been done. We have not discussed that a lot in this course. But to understand that, you need a good background in statistics.

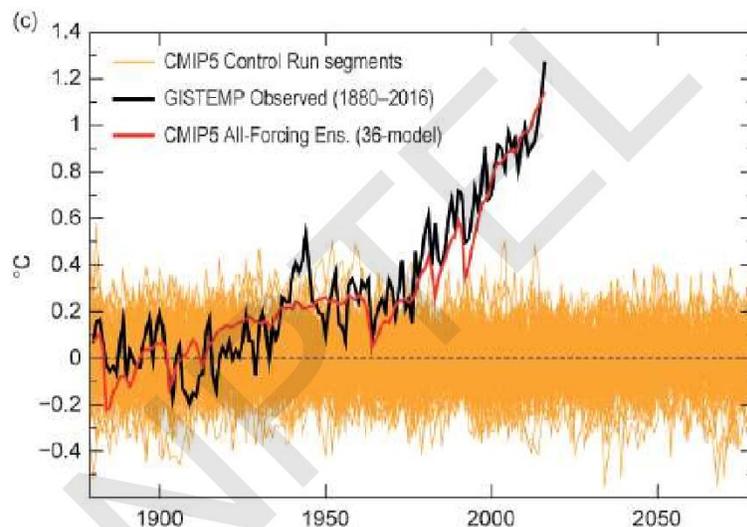
The presence of natural climate variability means that the detection and attribution of anthropogenic climate change is a statistical “signal-in-noise” problem. Detection is the process of demonstrating that an observed change is significantly different (in a statistical sense) than can be explained by natural internal variability

This is addressed in great detail in the IPCC Third Assessment Report (TAR), Chapter 12, about how to detect climate change and how to attribute the causes.

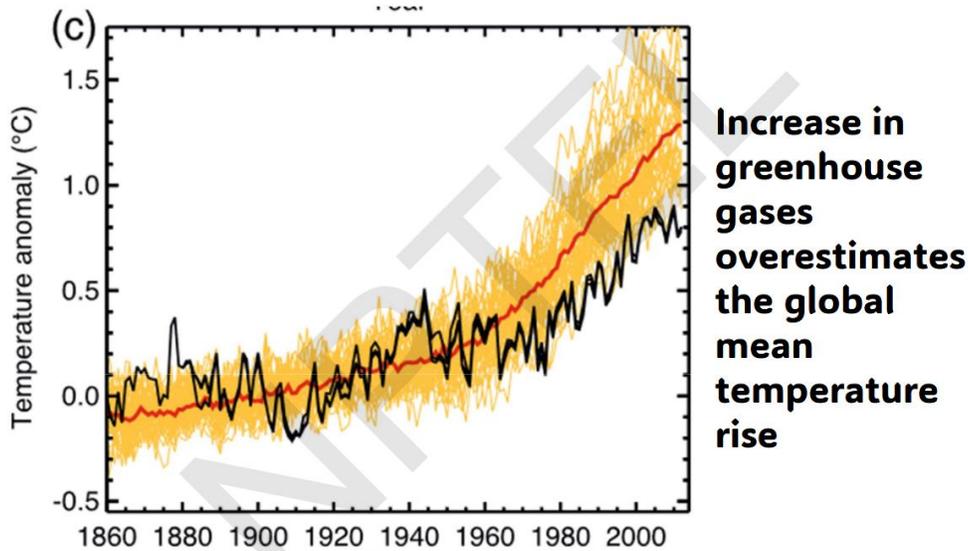
**Detection of Climate Change and Attribution of Causes
By J.F.B. Mitchell and D.J. Karoly (IPCC TAR Chapter 12)**

Assessments based on physical principles and model simulations indicate that natural forcing alone is unlikely to explain the increased rate of global mean temperature or changes in vertical temperature structure since the middle of the 20th century

One example we saw in this course was that the observed global mean temperature—that is, the black line (in the figure below)—can only be explained with the climate model if we allow CO₂ to increase as per observation. If the model is run without CO₂ increase, we get this almost steady state fluctuation (dotted line in the plot shown below), which is natural climate variation. So, this was a good use of a climate model to demonstrate the impact of CO₂ on climate change.

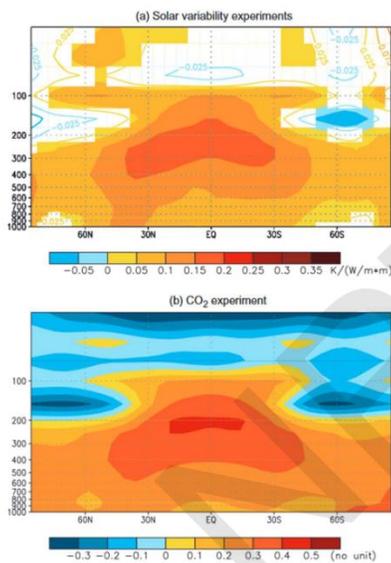


Knutson et al., Bulletin of the American Meteorological Society, December 2017



Now, after that comes attribution. Why did the global mean temperature increase? That was done by comparing the observed increase in temperature (black line in the plot shown above) with the model-predicted climate change due to an increase in CO₂ (red line). There are a lot of simulations, and we average them. So, the ensemble mean shows a clear difference between the simulation with higher CO₂ and the simulation and observation. Simulation with no CO₂ increase, we saw already, was a horizontal line. So, this is the attribution problem, which shows clearly that CO₂ is the cause of the increase in global mean temperature that we observe.

Now, one more thing is called fingerprinting. When CO₂ is increased, it causes warming in the troposphere, but cooling in the stratosphere. This is a unique fingerprint of increasing greenhouse gases, which we have discussed in this course. I am comparing that with what will happen if solar radiation increases. If solar radiation increases, we will see only warming in the troposphere. You will not see much change in the stratosphere.



Zonal mean of the greenhouse gas-induced temperature change simulated by ECHAM3/LSG model (from Cubasch et al., 1997). This indicates that for ECHAM3/LSG, the zonal mean temperature response to greenhouse gas and solar forcing are quite different in the stratosphere but similar in the troposphere

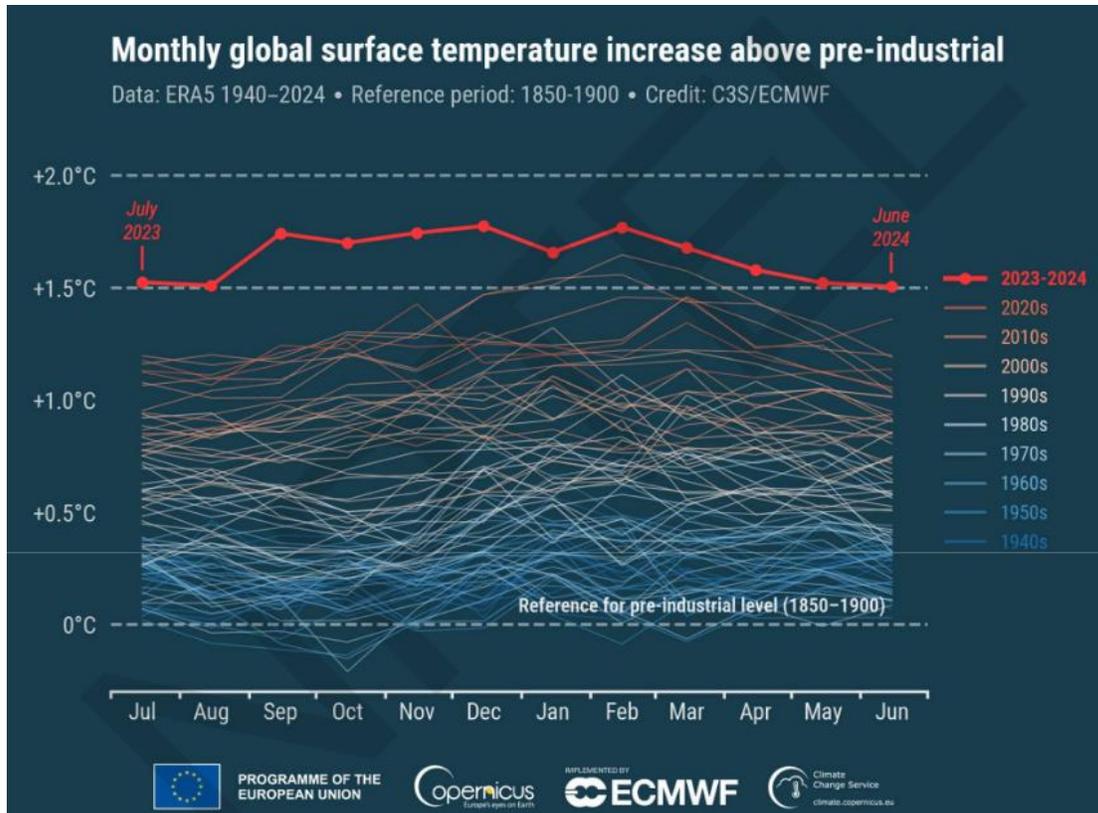
We saw that this is due to the fact that in the troposphere, temperature is decreasing with height, and in the stratosphere, it is increasing because of the ozone layer. That causes a difference between the way greenhouse gases warm the troposphere and cool the stratosphere. So, the fact that we have now observed warming in the troposphere and cooling in the stratosphere shows that we are seeing the fingerprint of the impact of human-induced climate change.

Now, you may all ask, why do we focus so much on the global mean temperature? That is because the global mean temperature can be easily related to the imbalance between absorbed solar radiation and emitted radiation from the Earth. This imbalance causes the increase in temperature, and this is due to a global cause, not a local cause. For all governments of the world to come to an agreement, it is essential that we have a global metric like the global mean temperature.

Why do we consider the increase in global mean temperature as a metric for climate change?

- The present increase in global mean temperature is caused by an imbalance between radiation absorbed by the earth from the sun and radiation emitted by the earth.
- The imbalance is on account of the actions of all human beings.
- If the temperature was increasing in only one part of the world, we can seek local solutions
- For all governments of the world to come to an agreement it is essential that we have global metric and everyone realizes that the increase in global mean temperature is caused by actions of all human beings

Everyone realizes that the increase in global mean temperature is caused by the actions of all human beings, and everyone has to now cooperate to reduce these emissions. For this purpose, we need to focus on the global mean temperature. Although we do not live in the global mean—we all live in various parts of the world—the global mean should not really bother our local climate. But it is necessary for global negotiation.



Now, we saw last year, 2023, that the temperature of the world, global mean, was higher than 1.5°C throughout the whole year from July 2023 to June 2024. This is the first time all the months showed a temperature higher than all the previous years, starting from 1850 to the present. So, it clearly demonstrated the role of human beings in controlling the global mean temperature.

Now, we use the simple model proposed by Professor K. N. Liou, which showed that the global mean temperature depends on incoming solar radiation (S), fraction of radiation reflected by the Earth-atmosphere system (ρ), fraction of radiation absorbed from the Sun (A), and the emissivity of the atmosphere (ϵ).

$$\sigma T_g^4 = \frac{S [2(1 - \rho) - A]}{4(2 - \epsilon)}$$

Note that this simple model(proposed by K.N.Liou of University of Utah, USA) is able to predict the correct global mean temperature based on just 4 parameters. They are the incoming solar radiation S , planetary albedo ρ , solar absorptivity A and infrared emissivity of the atmosphere ϵ . These parameters depend upon amount and type of clouds, infrared properties of minor gases, ice cover and vegetation.

So, we are able to show that the global mean temperature depends only on four parameters: incoming radiation, radiation reflected (albedo), radiation absorbed, and emissivity of the atmosphere. This enables us to understand how changes in these quantities affect the global mean temperature.

Hemispherical spectral emissivity

$$\epsilon_{\lambda} = \frac{e_{\lambda}(T)}{e_{\lambda b}(T)}$$

Hemispherical spectral absorptivity = $\frac{\text{Radiation absorbed}}{\text{Radiation incident}}$

$$\alpha_{\lambda} = \frac{dQ_{\lambda a}}{dQ_{\lambda i}}$$

According to Kirchhoff's law

$$\epsilon_{\lambda} = \alpha_{\lambda}$$

*for surfaces whose emission and reflection are independent of angle .
Such surfaces are called diffuse surfaces*

The other thing I highlighted in this course is the understanding of Kirchhoff's law. Kirchhoff's law says emissivity (ϵ) and absorptivity (α) are equal at a given wavelength. It does not say that emissivity and absorptivity are equal when you average over all wavelengths.

When we consider the incoming solar radiation, we have to look at the region 0.4 to 4 micron, where the average absorptivity is around 20 percent. When you look at the emission from the Earth-atmosphere system, the radiation is between 4 micron and 100 micron—there, the emissivity is 0.95. So, the total emissivity of the Earth-atmosphere system is 0.95, but the absorptivity of the Earth-atmosphere system is 20 percent.

So, the point is that emissivity and absorptivity are not equal if we average over all wavelengths. They are equal only at a given wavelength. That is an important point to understand.

Then we took the above equation and differentiated it, and showed how sensitive Earth's temperature is to incoming radiation, changes in the solar absorptivity, changes in the reflectivity, and changes in the emissivity. All these helped us to understand how the Earth's radiation changes in response to these changes.

How does the global mean temperature change in response to small perturbations?

$$\frac{1}{T_s} \frac{\partial T_s}{\partial S} = \frac{1}{4S}$$

$$\Delta S = 0.01, \Delta T_s = 0.75\text{K}$$

$$\frac{1}{T_s} \frac{\partial T_s}{\partial A} = \frac{-\frac{S}{4}}{4\sigma T_s^4(2 - \epsilon)}$$

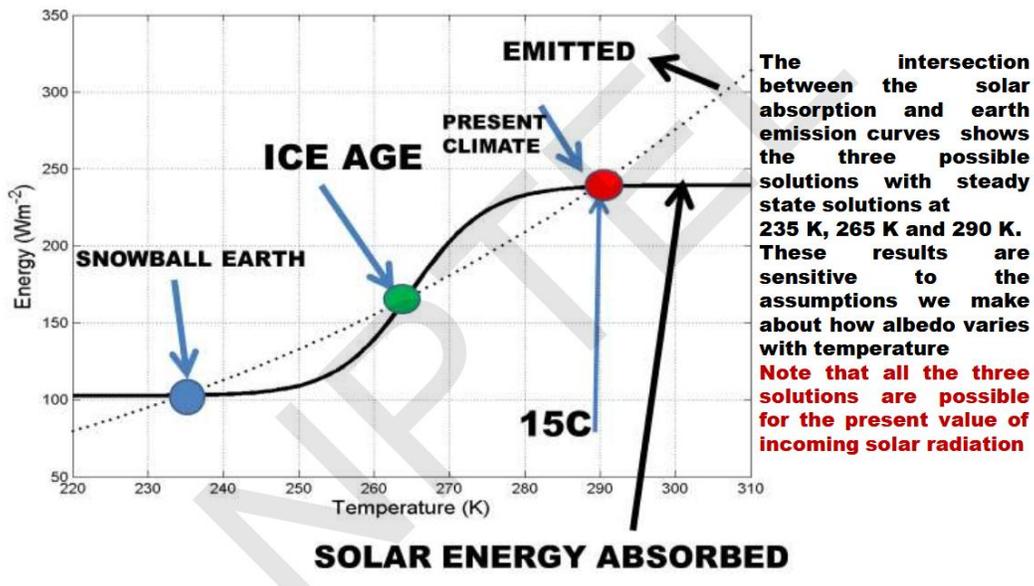
$$\Delta A = 0.01, \Delta T_s = -0.60\text{K}$$

$$\frac{1}{T_s} \frac{\partial T_s}{\partial r} = \frac{-\frac{S}{2}}{4\sigma T_s^4(2 - \epsilon)}$$

$$\Delta r = 0.01, \Delta T_s = -1.20\text{K}$$

$$\frac{1}{T_s} \frac{\partial T_s}{\partial \epsilon} = \frac{-1}{4(2 - \epsilon)}$$

$$\Delta \epsilon = 0.01, \Delta T_s = 0.75\text{K}$$



We also used a graphical way to illustrate how the emission of radiation from the Earth and absorption intersect at three points. These are the three possible solutions. We are in the present climate now, and about 20,000 years ago, we were in the ice age, and 600 million years ago, we were in a snowball Earth.

All three were possible, and we happen to be in the present state (red dot in the graph shown above). I will continue this talk in the next lecture. Thank you.