Audio file

118743-Climatechange.mp3

Transcript

All right, thank you everyone for joining this class. It's a pleasure to have my physics students, but also see the whole UPCSE cohort. So thanks for joining, and hopefully you find this topic interesting, whether you study physics or not. This is not a very technical talk, so just basic knowledge of science should allow you to understand that. But What you will see, and probably what you will guess, is that behind the study of the climate are many other scientific disciplines, and you could go very, very deep in each of those areas if you really wanted to understand the climate system to its full extent. So in one sense, it's a very multidisciplinary endeavor. And it's quite likely that almost no matter what you decide to do and specialize in the future, you will probably at some point deal with some of the issues that are being raised here. And you might even work with people who have an interest in using your skills in engineering, in physics, in chemistry, in biology to try to refine and improve their climate models. So we have about 45 minutes today. So I'll ask you to be quiet so no one has to shout in the room. But if you have any questions, just feel free to raise your hand during the talk if it's a short question or at the end if we have any time. And I'll just present the outline for this presentation. So today I'll give a brief overview of the state of the Earth's climate. So effectively, where are we today? And I think you will understand that it's necessary to give a brief history of climate science and understand past climate to be able to make sense of the changes we are experiencing and measuring today. And then we'll try to discuss the causes and the consequences of climate change, which is effectively leading to the last part, which is how we may want to attempt to solve the issue. And as you know, it's sometimes quite a contentious issue. And I think rightly so, because many, many decisions have to be made as a result of the diagnosis, effectively. And it's quite good and healthy that actually some debate is actually taking place about the pros and cons of specific interventions. I think what's quite important is that we as a society manage to come to a consensus on the state of affairs, on the diagnosis, and then that we should be having a lively debate about what to do about it and how to deal with the issue. So you may ask, what is climate? So I think the best, easiest way to define the climate is to define it as the average weather. So we're all familiar with what the weather is today. We're familiar with weather prediction because we are quite used to be looking for the weather predictions in order to predict what the weather will be like tomorrow, next week, perhaps in two weeks' time. But the climate is basically trying to ask that question for a longer period of time. And obviously you cannot do it with the same level of precision, but effectively the climate is the study that looks at the long-term weather changes over time for the Earth's climate system. So we are talking typically about 10 years to up to 1,000,000 years, and it very much depends on the time scale that you're interested in. But typically, beyond 10 years, you're dealing with the time scale of the climate. Now, it's important to understand historical climate change, And in fact, climate changes, it has changed for many, many reasons in the past, because it will allow us to understand the main drivers for our climate. So looking into the past is actually giving us a lot of information about the state of the climate today and where and how to model it properly for the future. And so in particular, we need to be designing climate models that are able to reconstruct the past climate changes. So the past, what we know about the past is a very good test for the models that we build. A model that accurately predicts the future would be expected to also be able to predict what happened in the past. And the issue of today is essentially what we call post-industrial climate change. So not the climate change that has occurred over very long time scales historically, but the climate change that has started to occur in the last couple of centuries, but of course more importantly in the last century, as a result of the development of industrial civilization. So the question for climate scientists is often, what will the state of the climate be at a future time point, a future that is long enough to be allowing us to make long-term predictions, but also not too far away because we need to also be able to adjust to the system. So the typical benchmark is the end of the century as a way to compare different models, different mitigation policies, for example. And what needs to be understood is somewhat summarized in that graph, although that graph does not really give the whole picture. It's a global temperature change. So what you see on the y-axis are the temperature anomalies. versus some long-term average over the last 200 years. And we appear to be observing an increase in the global temperature across the Earth system. So we are talking about sea surface, I'm sorry, well, sea surface or ground level temperature, so surface temperature measured at one or two meters over time. And that's typically where we live. And we appear to have been observing a trend of about half a degree to 1 degree increase over the last 50 years or so. And this has kind of not been updated on that particular graph. But the idea was to try to start to see the problem as it was perceived in the year 2000, when we started to see that trend materializing. You could measure temperature in very many different ways. And here we have two different temperature records. actual thermometers and proxies, so other measurements. So for instance, could be infrared cameras in space, for example, proxies to measure the temperature. And the idea was to try to combine as much information as possible to try to extract a trend that is as accurate as possible. But it's not just the temperatures, as you know. What we see here on this graph are the anomalies in terms of surface temperature at the top, but also sea level, at the bottom. And also in that case, for example, the northern hemisphere snow cover. So there appears to also be an increase in the sea level. So here it's measured in millimeters. So it's actually quite a small number for the moment. But small numbers add up, and sea level rise is something that actually is obviously not reversible in the short time scales. And then a lot of people live by the coast. So even a half a meter change might actually be requiring significant adaptation measures for that. And we started also to see in the year 2000 a slight decrease in the snow cover, and that's something we tend to be seeing more in regions like in the Alps. There are issues in Greenland as well. So it's not just the temperatures, but often the temperature record is the sort of primary source. Now there's also some geographic variability. But generally speaking, we tend to observe that increase over time across all continents on Earth. This is the global average temperature normally for the last century. What you can see here is that if you average it over land or over ocean, you see a difference. So the temperature rise tends to be higher over land. So again, when you hear the numbers that try to quantify climate change, remember this is the global average. but it will be more over land and less over ocean. So there are specific processes at play over land and ocean. The ocean, of course, is a massive thermostat. As you all know, the thermal heat capacity of water is very high. And so effectively, you've got a lot of the heat that is being absorbed by the ocean. So not so much of a change over the ocean, but significant change over land, which is obviously where most people live. So that's what we have to be concerned about as well. But we can look beyond the last 100 years where we have direct thermometer measurements. You could also try to reconstruct past climate changes by working out all sorts of, using all sorts of methods to try to do that. So one of the ways is to analyze tree rings, very old trees, and working out the rate at which trees grow. And in a somewhat complex but interesting methodology, one can actually obtain a proxy for temperature. So a proxy is an indirect measurement of a quantity via another one. And so the study of tree rings have allowed scientists to try to reconstruct temperature anomalies again, so differences, on the y-axis for the last 1,000 years. And again, we appear to be seeing a change here in the last 50, 100 years that seem to be higher than what we have observed in the past. in at least in the past thousand years. But you can go beyond that, actually. And if you study ice cores, if you talk to a glaciologist who work with physicists, they will be using ice cores that are drilled. Well, the best ones, the deepest ones are in Antarctica, where you can try to reconstruct the temperature record, here temperature differences again, for nearly a million years. So This corresponds here to 800,000 years. And we see quite large variations, actually, of a magnitude of, let's say an amplitude of about 5 degrees, easily. But the period of those cycles, if you can call it a period, is perhaps in the region of 50,000 years or 100,000 years. So extremely long time periods. In fact, those are astronomical time periods. That's actually not a periodic signal. It's A quasi-periodic signal. It's actually a combination of several periodic signals that are due to effectively astronomical parameters, changes in the orbit of the Earth, the angle of the Earth, and how the Earth spins around itself. Those periods, in terms of how the Earth actually moves in relation to the Sun, which is the primary source of heat for the Earth, actually drives the long-term climate change. So it's also important to know that climate has always changed, but what we are talking about usually nowadays when we discuss climate change is the recent climate change over time scales of 10 to 100 years. And as you can see here, you could barely see 50 or 100 years on this graph because that corresponds to 100,000 years. So what you don't want to have is to reproduce a climate change in 50 or 100 years that would be as large as a climate change that typically naturally occurs over a period of 100,000 years, because obviously you can see that the time scale for adaptation is obviously very different. So here you've got a nice picture of an ice core, and you can date actually the ice cores by seeing how deep you are, and sometimes you see those interesting marks that correspond to volcanic eruptions that have in the past actually essentially covered the whole area where you drill in dust. And all that layer can actually be retrieved in the ice core. So it's a very nice history of our Earth, basically. And drilling ice cores proves to be a very effective way to understand better where we come from and what the climate has been doing for the last million years or so. 1 million years about the old dust ice core. And that was an actual amazing technological challenge. to be able to drill, I think we're talking about two or three kilometers of ice cores. A lot of technological and engineering challenges just to get there. And then those ice cores are stored in labs like that. Obviously stored at below 0 degree temperature. And then they are stored, labeled, and then when scientists want to study a particular time in the history of the climate, they might request to be granted a piece of an ice core at a specific location, they would analyze the air bubbles inside the ice core. So here you've got an electron microscopy image of an ice core inside an ice core, and you can see very, very tiny air bubbles. And if you manage to melt the ice and retrieve, just get the gas out of the bubbles, you can measure the isotopic ratio of oxygen, for instance, and you can also show that in a quite indirect way the isotopic ratio of oxygen is a proxy for temperature as well. So you can try to reconstruct the temperature record by looking at the chemical content or the isotopic content of the air bubbles. So who would think that retrieving a tiny air bubble perhaps 3,000 meters below the surface in the Antarctic would actually tell you something about the temperature of the Earth about a million years ago. That's really quite an achievement as well. So I said we need to do a brief history of climate science just to know where we stand. So climate science started to be developed formally, so to speak, in the 19th century. So for the last 200 years, there's been a sort of consistent interest into bringing physics and other theories together to try to understand our climate. And mathematicians, geologists, physicists, chemists, all scientists together try to understand climate processes. And as you will see, hopefully I will convince you that this is a very complex system that requires knowledge from all sorts of disciplines. Effectively, We like to talk about this way in physics, but effectively, it's an energy conservation problem. And so climate science at its core is the study of the heat exchanges within the Earth system, as well as between the Earth and the rest of the universe. So to actually simplify, it's between the Earth and the Sun, because the effect of stars in other star systems is actually negligible. So effectively, it's the interaction between the Earth and its own solar system. But you can imagine the complexity of the situation. And the Earth's atmosphere, so the layer of gas at the surface of the Earth, actually was shown to play a very important role. So that was one of the big discoveries of the 19th century, was that the Earth's atmosphere was actually very important, and more important than people assumed, in actually explaining the current state of the climate. So I've chosen 3 sort of key figures, three scientists over the history of climate science, just to illustrate the sort of key milestones in our understanding of the effect of the Earth's atmosphere on the Earth's climate. So some of you might have heard about Joseph Fourier if you have studied mathematics. Some of you have heard about Fourier analysis, for instance, very useful for periodic functions. But Fourier was actually also interested in politics in France and was also very interested in other scientific problems, not just mathematics. And he had a very good friend called Horace Benedicto de Saussure, a Swiss geologist, and they thought a lot about what the atmosphere actually does to the Earth's climate. And Fourier postulated in 1824, that's his own words, that the temperature of the Earth can be augmented by the interposition of the atmosphere, because heat in the state of light finds less resistance in penetrating the air than in re-passing into the air when converted into non-luminous heat. So that's a complicated sentence, perhaps, because Fourier was using the words of his time. And probably today we would be talking about things like black body radiation, optical thickness of the atmosphere, the transmittance of the atmosphere, the albedo of the atmosphere. But the words of Fourier were effectively the first suggestion that effectively the heat coming from the solar radiation mostly passes through the atmosphere without being absorbed. But then when the earth is trying to cool, it also emits what he calls non-luminous heat. Effectively, that's what we now call infrared radiation. And he makes the assumption that this radiation that is emitted by the Earth actually cannot go through the atmosphere as easily, and it finds some level of resistance. And therefore, some of the heat that is being emitted by the Earth in the form of radiation can get trapped by the atmosphere. So the atmosphere works in asymmetric ways, if you want. And it doesn't treat the radiation from the sun in the same way as it treats the radiation coming from the Earth. And so that layer above the Earth actually plays a complex role. And Fourier was the first one to actually suspect, effectively, what we now call the greenhouse effect. Benedict de Horace, Benedict de Saussure, So the friend of Fourier, they worked together on this. They did a lot of climbing and mountaineering to study the climate at high altitudes as well. And they were amazing climbers as well. And we have here a very interesting depiction of the trip of Saussure in Mont Blanc in France, I mean, by the border between France and Italy. So as you know, the highest mountain in Europe, or at least in Western Europe. And the climb here dates back from, for those who can read, those years. It's also quite small here. It's 1,787. So Saussure, the geologist, was actually the third man to climb at the top of Mont Blanc, one year after the first two managed to reach the top. That had been a quest for the last 20, 30 years, a very intense quest to try to reach the top. Part of the quest was just trying to get to the top first because it was a human achievement. but a lot of scientists were very interested to bring their instruments at the top of Mont Blanc, at almost 5,000 meters above the sea level, 4,810 meters, to try to measure directly the state of the atmosphere up there, because obviously there was no other way. So climbing mountains was a great way to be making atmospheric measurements. And you can see a very interesting statue of Saussure in the town of Chamonix in France right by the Mont Blanc. And if it was not a cloudy day, you would see the Mont Blanc right behind them. Sorry, right on the other side, sorry, because they are pointing at the Mont Blanc in that particular case. So for those who ever go and visit the city of Chamonix in France, for those who love skiing, you will probably see some thanks to Saussure who played a big role in us understanding the climate as well as developing mountaineering essentially as well. A few decades later, an Irish scientist, physicist called Tyndall actually proposed, effectively rephrased Fourier's statement in more quantifiable ways because he made experimental discoveries of the fact that complex molecules, actually not necessarily extremely complex, but molecules, have the ability to absorb thermal radiation. So the absorption of thermal radiation, which we call infrared radiation for the Earth, actually is, can be absorbed by complex molecules. So that's effectively the study of spectroscopy of the molecules. And effectively he showed that radiatively active, and here it doesn't say radioactive, it says radiative. OK, so that means that they can have an impact on the radiative balance of the Earth system. And he proposed the idea that those gases in the atmosphere could have produced the mutation of climate which the researchers have tried to reveal. So the geologist revealed some changes. And now the physicists with doing experimental work on gases and molecules and looking at the spectroscopy of those molecules were able to actually confirm the importance of the atmosphere in regulating our climate. And a few decades later here in the last part of the 19th century, Svante Arrhenius, so those of you who study chemistry I'm sure have heard about Arrhenius, but he was a chemist, but of course not just a chemist and very interested in also in the influence of the physics of those molecules on the climate, published a very important paper in 1896. And the title of the paper is very clear, on the influence of carbonic acid in the air upon temperature of the ground. So effectively, about 125 years ago, Arrhenius published a paper that effectively is the subject of all conversations today. And not just that, but he actually made actual calculations, incredibly complex and long calculations, all made by hand. And he really later said that he almost regretted doing that because it was just so much work and it actually took a toll on his own sort of mental health, as we would say today. He estimated that if we were to double the amount of CO_2 in the atmosphere, the Earth's temperature would respond at the surface by an increase of 5 to 6 degrees Celsius. So he was the first to make an estimation of what we now call the climate sensitivity, which is by how much the Earth responds in terms of surface temperature to an increase in, to a doubling of CO_2 concentration. So the doubling is just a way to effectively compare different experiments. Of course, the CO_2 doesn't just double from one day to the next, but it's a way to compare different models to each other. So we call it the climate sensitivity. Now, very interestingly, what we find now is that the latest models estimate that the likely value of the climate sensitivity is between 2 1/2 and 4 degrees, but still with quite a lot of uncertainty. So interestingly, the estimation of Arrhenius was actually pretty close to what we are dealing with today. So it also shows that with somewhat elementary physics, one is able to actually get a good sort of back of the envelope calculation that would tell us approximately how the Earth is expected to respond to a doubling of CO_2. So a very important figure as well in the history of climate. So I'm trying here to just basically summarize the processes in play. So what we have here is we have the, I mean of course it's not to scale and in terms of size and distances of course, but the sun is sending Shortwave radiation, mostly visible, but a bit of UV, a bit of infrared as well. to the Earth, the Earth is absorbing part of it, also reflecting some of it. And the part that is absorbed is used for the Earth to warm up. So you can imagine the Earth on day one, if you could imagine that, would start to heat up because it would absorb energy. But as the Earth heats up, it also has to find a way to cool because the Earth cannot just heat up to infinity. Otherwise, the Earth would already be burning today or would have reached an extremely high temperature. The Earth is also a black body or a gray body, depending on the value of the emissivity at the surface of the Earth, but effectively it emits radiation at a lower temperature, and the Earth's temperature finds some equilibrium between the amount of heat received from the Sun and the amount of light, infrared radiation emitted from the top of its atmosphere. And there is basically an equality in terms of the flux of incoming radiation in the shortwave spectrum, so typically below 4 micrometers. And that's equal to the outgoing longwave radiation, typically above 4 microns. It turns out that if you plot the blackbody curves of the sun and the Earth, they really almost don't overlap. You have a shortwave component, a longwave component. And so part of it is absorbed. the other part is emitted, and there's got to be a balance between the two. And that balance effectively decides, determines the average temperature on Earth. And you can do very simple calculations to prove that the Earth temperature must be around the temperature that we measure here today, maybe 0, 10, 15 degrees, by just doing simple calculations like that. So the climate can change. We know a little bit about the history of the climate, but We also need to be able to distinguish the natural and the anthropogenic greenhouse effect, because obviously that's the key there, to try to distinguish what is natural, if you want, and what is supra-natural, if I may say. So one thing I would like to start saying, because there are sometimes misconceptions about that. I mean, Fourier and Tyndall have already said that as well, but the greenhouse effect is a natural effect. So we tend to talk about climate change associated with the greenhouse effect as if there was never any greenhouse effect before. But no, there's always been a very strong amount of greenhouse effect actually on Earth, which is the reason for why the Earth actually has liquid water and actually sustains life. So we owe to the natural greenhouse effect our presence here in this room, because life would not have occurred without it. So this is a wholly natural phenomenon, because the atmosphere has been around for pretty much as long as the Earth has been around. And the presence of molecules in the Earth's atmosphere have actually induced a natural greenhouse effect. And the most important greenhouse gas is water vapor. So H_2O molecules in the air represent the vast majority of the greenhouse effect. In fact, As I said before, without water vapor in the atmosphere, the average temperature on the Earth would be about minus 15 degrees. With water vapor and a few other gases, the average temperature on Earth is about 15 degrees. So there's about a 30 degree difference, which is only due to the presence of water vapor and a few other greenhouse gases. Of course, a bit of natural CO_2 and so on. But the concern of today are the anthropogenic greenhouse gases. So the greenhouse gases that are being emitted by us trying to run civilization. And the question is, how much do we expect an increase in CO_2 concentration, and not just CO_2, by the way, to affect the existing natural greenhouse effect? So we're talking about an enhancement of a natural effect that needs to be quantified. So we first need to be able to measure the amount of carbon dioxide before we actually make projections about its effect on the earth. And one thing that is actually very easy to do, I mean relatively easy to do, is simply measuring the amount of CO_2. You just have to go to a remote place which is far away from any source of pollution. So typically in the middle of the ocean is a great place to do that. And you can measure the amount of CO_2 here expressed in PPMVs. So that stands for parts per million per unit volume. So effectively it's, to say it mildly, if you have one molecule of CO_2 in 1,000,000 molecules of air, the concentration is 1 PPM. And you can see that the concentration from the 1960s to the early 2000s has obviously gone up in an extremely clear way. And the amount of uncertainty on that is actually very small. We observe on a yearly basis a very, very clear trajectory of increase of CO_2 concentration. So there's literally no debate about that. There's actually an interesting annual cycle between the summer and the winter, which is something to do with the asymmetry in the vegetation between the northern and the southern hemisphere. But that's a different story. But if you smooth it out, if you take a running average, you see a very, very clear increase. And here we're talking about from 300, which is the typical pre-industrial CO_2 level, to 385 in the year 2010. And the current value now is 424 PPM. That's the average measured in 2024. So you can imagine here already 424, we're already out of the screen. So CO_2 is rising. There's obviously no question about that. And nowadays, because we are also able to track the emission of CO_2, we can not just measure the amount of CO_2 in the air, but we can relate it to the amount of CO_2 that is being emitted. And that gives us an idea about how the carbon cycle works, because not necessarily all the CO_2 that you emit ends up in the atmosphere. There's also some carbon uptake. But now that we can measure the emissions as well as the concentration, we can try to reconstruct the carbon cycle to try to predict what CO_2 levels we might get at a certain period of time under a certain emission scenario. OK?

So this is measured in Hawaii, actually. But not just CO_2 is actually changing. Here we see methane and nitrous oxide, so N_2O, but other derived compounds from N_2O are also being measured. And you can see that going back here about 2,000 years, there's been a sharp increase from around 1800 of all CO_2, methane, and other pollutants as well. So sometimes if you track pollution, this might also be a proxy for tracking the emission of CO_2. because those things that tend to be connected to each other. It's a little bit like when you're in a room like today, you might actually be measuring CO_2, not for the purpose of measuring CO_2, but as a proxy for the quality of air. And if you suspect that the virus might be in the air, if you track the amount of CO_2, that indirectly tracks the potential amount of virus in the room, because we know that CO_2 gets emitted by our breathing, and the more CO_2, the less ventilation, and the less ventilation, the more virus you would get. So a lot of proxies are being used, but they're also there to sort of confirm the measurements we make and to gain assurance that the measurements we make actually make sense. So when we see all those gases increasing at a high rate, somewhat together, that also confirms what we are observing. So here you can see CO_2 is on the left, PPM, and CH_4 here in PPB, it's parts per billion. So parts per million for CO_2, parts per billion in methane. So there's less methane than there is CO_2. But as you might have heard, methane actually is a very active gas in terms of trapping infrared radiation. And so although the amount of CH_4 is less, its effect on the climate is actually also relatively significant. So we have to take that into account. So the prediction of climate change is really the purpose of that. How we measure and how we predict climate change depends on our ability to model it. So we use very large computer models to try to put all the data we have and run the models, which means ask the model to solve the physical equations of the system. So those are very complex differential equations that are being put together by the physicist. And you're asking the computer to solve this ensemble of equations. to try to predict the state of the climate at future time points. And those models, those computer models, they are being tested and they are being calibrated based on real data. So what you can do is you can run the model for now until, if it's a weather prediction model, you can run it for next week. Then you wait until next week and then you see what measurements you've actually made. You can test and calibrate your model. And that's something that is being done on a continuous basis. to always make sure that models improve and reproduce all the events that we're interested in. But obviously, as I state here, it's very complex processes. You have to involve biological, chemical, and physical processes in the whole system. So I'm sure you've heard about the IPCC, the International Panel on Climate Change. It's a group of scientists of the United Nations that basically aim to collect all the peer-reviewed research being produced all over the world, and they produce on a periodic basis every four to five years a big report that summarizes the current knowledge on climate change. So typically the IPCC reports are your most likely best source of information to get a picture of the state of the climate and the update in terms of the predictions that are being made for the typically for the end of the century.

But quantifying the uncertainties is very important. So I've talked to my physics students a lot about uncertainties, but you can imagine here that if I say, oh, the climate will increase by 5 degrees at the end of the century, if you don't know my delta t value, the plus or minus 1, 2, 3 degrees, then it doesn't give you much information. So a lot of work is being put into trying to understand and quantify the uncertainties. because politicians at the end will need to make a risk assessment based on the uncertainties that the scientists can produce. Okay, so that's a picture of the climate system. So the idea is to show you that this is a complex system and that all those processes go together and all of them have to be put into an equation, into a computer model and being run. So that's obviously, it's a simple cartoon, but it's an extremely complex system to model. You model it using a grid, You cut the Earth into squares, or most likely cubes, because you have to also stratify the atmosphere, and you try to solve the differential equations of the system at the boundaries of each of those cubes to try to basically produce an image of the state of the climate now or in the future at a certain resolution. So that's a low resolution system and a low resolution model. It's less intensive in terms of how much computer power it requires. And every square here corresponds to a value here in that case of the temperature model at a certain period of time. That's actually trying to model the past. You can see 1822, that's a model that's trying to reproduce past climates. But we now also have supercomputers. So the Earth Simulator in Japan is a very good example of that. essentially a lot of computing power together to try to run more refined, high resolution, spatial and temporal resolution climate models to try to produce effectively better quality models like this, for example. But nowadays you will have heard that machine learning is being used more and more for weather prediction as well as for climate studies as well. The big advantage of machine learning is that it actually takes less computing power, but of course it has to be validated. But the current results, and we are talking about very new results, are really quite promising. And it's quite likely that in the future there will be some sort of combination between deterministic climate predictions, sometimes called numerical weather prediction, as well as AI together to try to get the best the best match between the computing power required and the accuracy that is needed for the predictions. So that's a Nature paper from April of last year that shows the big impact of AI in climate studies. So the IPCC, as I said before, has loads of graphs that are very interesting. And you can see, for example, here the temperature anomalies over the last few centuries, so here the last 2,000 years. And what's interesting is that they try to distinguish what is being observed with what could be modeled without the interference of human CO_2 levels. So you can run the model without the CO_2 from human activities. You run the same model with the CO_2 and you try to match with the measured data. And what we clearly see is that we are able to distinguish the two. That means we are able to assess that the change that we measure is due to the emissions of CO_2 and other greenhouse gases. But you could also break it down into different parts. So for example, the human influence is about 1 degree overall, but actually here the greenhouse gases explain about 1.5 degree of increase. So more than the overall, because some other human activities actually cool the climate. It turns out that pollution, for the most part, actually acts as a reflective layer, and therefore the solar radiation bounces back, and actually it cools down the planet. So interestingly, CO_2 and CH_4 increase the temperature, but pollution tends to decrease it. So what we observe today, the one degree that we observe today, is actually a combination of 1.5 degrees that would be measured if there was just greenhouse gases. and about minus 0.5 degree due to pollution. So if you reduce pollution, you might actually increase climate change. So you really have to know those things when you make those sorts of decisions. So you can break it down in all sorts of parts, but those are the key parts. It's basically CO_2 and pollution are the two drivers. Now depending on the emission scenario, how much CO_2 we expect to emit in the future, you expect to see different types of response. So here are different scenarios of the IPCC. called with those fancy names that try to predict for the century how much CO_2 we are going to be emitting based on the economic data and so on. And those turn into climate projections. So here, temperature warming in the different scenarios. I said we see it in many other areas, not just temperature, sea level, but here you can see Arctic sea ice, for example. This is where we were before. That's what the models are saying. And this line here says practically ice-free. It's quite likely that regardless of the scenario, we might never have ice in the Arctic, or at least in the summer, almost regardless of the model. Because most of the models that are the most realistic today, in terms of CO_2 emissions, actually produce no ice at all. in the Arctic, at least in the summer. And this also has consequences. There are feedback loops going on, because if you've got less ice, you've got less reflection, and even more heating. So the ice over the Arctic, for instance, acts as a positive, I'm sorry, well, as a feedback loop that actually could lead to a positive feedback loop. Ocean acidification, you might have heard about that. So the pH of the ocean is kind of slightly alkaline, but actually it's becoming more and more acidic as the pH gets closer to 7. because CO_2 and H_2O can be in equilibrium with carbonic acid. So when CO_2 gets into the ocean, it becomes more acidic, and it has also consequences for the biological processes going on in the ocean. And those biological processes can have an impact on the atmospheric processes as well. So you can imagine the coupling of all those things. And that's the sea ice. Typically, we're expecting about 1 meter of sea level rise by the end of the century, but some models are very scary, and we don't really know if they are correct. And the one thing you don't want to even think about is what would happen if some of the ice on the Antarctic were to melt. Because this is the giant monster that no one-- I mean, people look at this, but that's a very scary part, because there's a potential of 10s of meters of sea level rise in the Antarctic. At present, we don't think the Antarctic will melt. even in those scenarios. But if it does, the potential for sea level rise is very high. So people are starting to monitor the Antarctic very, very closely, because this might be, I mean, this is the elephant in the room, if you want. We know the Arctic is going to be melting. We expect more water to be flowing, and we expect also the ocean to expand, because when you increase the temperature, you increase the volume. So that is what is captured by that. But then all the rest is what happens with the Antarctic. And honestly, we don't know much at the moment. A good sort of information is the British Antarctic Survey, BAS, in the UK, based in Cambridge. They produce excellent data and very good lectures on that. So I just want to show you this photo. This is the Earth estimated with a 5 degree temperature below the average today. Effectively, if you reduce the average temperature of the Earth by 5 degree, you expect to see that level of sea ice. spread across the earth. So this is where we are in the UK. So just to show you that 5 degrees on average for a very sensitive climate system is a lot. So when we talk about plus 5 degrees potentially, we have to expect very significant changes. OK. So the climate is changing because of the burning of fossil fuels. And the rate of burning of fossil fuels is much larger than the natural rate of the carbon cycle itself. And that creates this imbalance. So it needs to be addressed for a range of reasons, and we could agree or disagree, but I believe there's an ethical, existential, and economic reasons to be addressing that very, very clearly. So depending on your particular interest, you will probably have to be looking into what happens with the climate anyway. The technological solutions, I believe, will end up allowing us to solve this issue. Currently, there's a big debate about energy production. So there's a debate about what is the best energy mix we need to have. We need to have less fossil fuels. That's a given because CO_2 levels have to come down. And we need to electrify a lot of usages, but we need to work out in which way. There's been a lot of push recently about solar and wind, but those energies are highly intermittent. So of course, there's no energy if there's no wind, and there's no energy if there's no battery, if there's no sun. So unless you have massive battery capacity storage, which we don't have at the moment, intermittent energies are definitely not the only source. And so we need to continue stepping up other forms of energy. Hydroelectricity is very useful, but we are at full capacity already in most countries. And nuclear fission, so nuclear energy effectively, civil nuclear energy, I believe is the way to go for us, at least for the next 50 years. until we can work out a grid that could work with renewable energy sources. So those are nuclear power stations. I love them, so I want to promote them. I believe this is the cleanest in terms of CO_2 emissions. The more compact, the most dense, and in the end, the less dangerous energy production source in terms of electricity. Really amazing energy source. This is hydroelectricity, as you know. But that's pretty much full capacity. Solar is great because we receive so much sun from, so much solar radiation from the sun. And wind could also work, but it's also very contentious because people don't like wind farms. And they have all sorts of issues as well. So they are becoming a bit out of fashion for good reasons. So I believe in the future you will see less of that and more of that, which I believe is good news. So we are here today. As a society, we are trying to deal with it. It's a very, as I said, contentious and hot topic. There are a lot of social movements also trying to influence the way we make decisions. In 2009, there was a big conference called the COP15 in Copenhagen, where perhaps there was the first realization that we really have to do something about it. In 2015, the COP21, which is the Conference of Parties, the United Nations organization, if you want, met in Paris in 2015 and agreed on an accord to try to limit the anthropogenic climate change by 1.5 degrees. Whether we're going to manage, it's not clear. It's likely we might be having to go over that a little bit. But we know that if we go beyond 1.52 degrees, the feedback loops are going to start becoming problematic. So we are tracking the evolution of our climate. and we will need to reduce the amount of CO_2 in the air. That is for sure. So the final thing is we need to become as quickly as possible carbon neutral, or at least as close as possible to that. So we need to reduce carbon emissions. We need to make decisions that are rational when it comes to energy. Not ideological, but rational. That's extremely important. We also need to find technologies that remove CO_2 from the atmosphere, because that might be a very good way as well. But currently we can capture it, but it's very hard to remove it, because removing it requires energy. But if you consume energy, you tend to emit CO_2, so it's a bit of a complex problem. But long, term, it's likely we'll be able to control CO_2 levels by being able to remove some of it. Again, the time scales, we don't know the pace at which technology advances. So it might be ready in 10, 20, or only 100 years. So in the meantime, we need to reduce CO_2 emissions. And then there's a big debate, and I encourage you to think about it or to do some reading about geoengineering. That means, is there a way that we could artificially interact with the climate to try to reduce the additional heat from the sun? That means engineering the climate. This is complicated, and this has potentially many issues, but People are seriously asking whether we should consider that now, because if you don't even study that, there might be a moment where you need it, and the solutions are not ready. So a lot of people are working on geoengineering as potential solutions as well. For example, the emission of particles in the stratosphere to try to reflect solar radiation to reduce the amount of heat. But again, you can imagine you have an idea, and then you can imagine very quickly all the problems that come behind. So again, complex decisions to make. So I'll just leave you with this very beautiful picture of the Earth, where you can observe the thickness of the atmosphere. Most of the, 90% of the mass of the atmosphere is within the first 10 kilometers. So that's essentially what the atmosphere looks like. And that atmosphere gives us a 30 degrees greenhouse effect that allows life to be sustained on Earth. So we need to treat that system as a very delicate system. and ensure that we have a good future for us all. So thank you so much for this, and hopefully you have a good discussion.