Climate Change: How Concerned Should We Be?

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Date: 02 November 2014

Preacher: Dr. Martin Barlow

[0:00] Martin Barrow. Thank you for the introduction, Olaf, and thank you for everyone who helped set up all the bits of high-tech that we have here.

So I wanted to talk about this. Of course, it's a topic where there's lots of controversy, information, and misinformation around.

And so I offered to give this talk sometime in August or thereabouts. And then I... It's not my area of research, I should say, so what I've done has been sort of, with the base knowledge I have, assembling information from various books and so forth.

And so I want to give a summary of my viewpoint of where things are, and as you go on towards the end of the talk, you'll see sort of the answer that we're intending towards in order to this question.

Martin. Yes. Could you give your talk from behind the... Oh, sorry. ...so that it can be recorded? Sorry about that. Yes, thank you. A good point. That makes it slightly more awkward to me.

[1:11] I'm still able to see my slide, so I'll talk from here if I may. Yes, fine. Thank you. So let me just start with... Thank you for that point.

Okay, so let me just start with a couple of general slides on science. So a classical thought experiment, actually, of Galileo was dropping two balls from the Lenin Tower of Pisa.

There's a little joke here. It says if there were computers in Galileo's time, and it shows him dropping two computers from the Lenin Tower of Pisa. But he drops a wooden ball and a metal ball from the top of the Tower of Pisa, and the question is how long do they take to fall to the ground?

Now, in high school, where I went to the A-levels in England, a simple calculation which I could have done in high school, just taking into account Earth's gravity and Newton's laws, can be done with pen and paper and gives you an answer.

But if you want more detailed answers, there are a number of other effects which would play a role. Air resistance, a big role. The rotation of the Earth.

[2:22] Tidal effects on the Sun and the Moon. Probably extremely small, but they would still be there. Variations in the gravity of Earth due to mountains and so forth. Even more exotic effects like general relativity and so forth.

All of these will have tiny effects on your answer. And the outcome is it is not possible to get a final definite answer. Some smaller effects always have to be neglected.

So the way science works is you start with the big effects, then you go down to the smaller effects. You have to make some kind of judgment as to which effects, which of the smaller effects you should take account of and which you haven't.

And so the outcome, the sort of byline of this is science works in answer to any practical problem by successive approximations. Another brief remark is on causes.

So let me tell you a story. You come back after an absence in your house and you find a vase that was on the table has fallen over and broken.

[3:26] This is the sort of cause we see in everyday life. So perhaps it was a cat. Perhaps it was a toddler. But if there was also an earthquake, you probably wouldn't bother thinking about the cat and the toddler.

So once we've decided on one cause like the cat, we don't then think, well, maybe the toddler also did it or maybe the earthquake also did it. So we look for just one cause. But there are other things that we meet in everyday life where looking for one cause is not necessarily the right way of doing it.

And here's an example. You own a shop and profits are down. Now, it might just be due to one factor. But quite likely, it's a combination of several effects. The economy, the rent you're paying, the salaries you're paying, changes in what customers want and competition.

And it might just be that one of these is the dominant cause, but it might be that several of these factors are occurring together and you have to take account of them. And it would be a mistake to say, well, because the rent went up, I don't need to think about any of the other causes.

There may be multiple causes of this effect. And in the case of the climate of the earth, we're much more in the second case where there are multiple effects going on rather than just one effect like the broken vase.

[4:42] Another point is you're in a shop. The same effect that is profits down at different times may have different causes. When profits went down in 2000, it might be because of a recession.

Now profits are down again. It might not be a recession. It might be because of competition from the Internet. And so you mustn't think that because of a particular cause at one time having this effect, therefore, you should never look at any other possible cause at other times.

Now, on to the science. The earth's climate, by which we mean the average weather, is a very complicated system and it's influenced by many factors.

Obviously, heat from the sun, the earth's atmosphere, as we'll be talking about in a bit. Changes in the earth's orbit around the sun, distributing the times when you get more, slightly more, slightly less heat from the sun.

And over long geological periods of time, changes in the position of continents. All of these are believed to have effects on earth's climate. And the climate has varied considerably over the last 65 million years.

[5:51] So here, I hope you can see it reasonably well, is an approximate picture. I mean, there's always going to be, with these graphs and people trying to work out what the climate is in the past, there's always going to be some sort of uncertainty.

But roughly speaking, what we see is 65 million years ago, the climate was a lot hotter than it is today. The climate today, zero on this picture, is about there.

This is, in this period, the climate was perhaps 8 degrees, 10 degrees higher than it is now. Then there was a period about 35 minutes ago, when Antarctica became glaciated.

There was a warmer period. Then over the last 20 million years, the climate has been gradually getting, over a very long scale, been getting colder. We've just done here a lot of recent oscillations.

And we'll move on to the last 5 million years to look at that. And this is 5 millions of climate change from Settelman-Cores. The left-hand and right-hand degree here, these are 2 degree intervals.

[6:59] And we see a gradual cooling of the climate with actually increasing oscillations. There was a period of 41,000-year cycles, and then more recently a period of 100,000-year cycles.

And there's a lot of evidence and consistent theories that these long cycles are due to the changes in the Earth's orbit around the sun.

And I won't go into that unless people ask me later. So that's the last 5.5 million years. And here's now blown up again the last 500,000 years. And we're in a period which globally people in climate would call ice ages.

We have ice ages with interglacials. These are the interglacials here, which are rather short, sharp peaks. And basically we're in an interglacial now. If we didn't do anything, in a few more thousand years, the Earth will get cooler again.

And in perhaps 10,000 or 15,000 years, we'd be back to having ice sheets across the North American continent. And temperatures will be 6 degrees cooler than they are now.

[8:06] So that's what's been going on. These fairly regular oscillations at 41,000-year, no, 100,000-year cycles over the last half million years or so.

And these are temperatures actually from ice cores in Antarctica. And here now is the temperature for the last 2,000 years.

Now here, the scale on the left is 0.2 degrees. So there's a lot more uncertainty in these. Because we're looking at things at a much finer scale, there's more uncertainty here.

These are various different reconstructions. They tell somewhat different stories, but broadly the same. There was a warmish period about 1,000 years ago.

Zero on the scale is sort of temperature now. It might have been warmer 1,000 years ago than now. It was about as warm. Then the climate got cooler. There was what's called the Little Ice Age, about 1600, when the Thames, for example, froze on a number of occasions.

[9:07] And then more recently, we've had a rapid rise in temperature in 2004. It's like the last risk there. And as I said, there's some controversy about exactly the scale of these things.

But this is the general picture. And here now is what people call the instrumental period. That is when we actually started measuring temperature with thermometers and things.

Starting with 1850, the grey, which you may not be able to see very well, is the uncertainty. So basically we see a sort of roughly constant period up to 1900.

A rise from 1900 to 1940. A flattish period from 1940 to 1970. A sharp rise from 1970 to 2000. And then not very much change since about 2000.

So that's what's been going on over the last 150 years. So the recent temperature rise. Now, when Galileo did his thought experiment with dropping balls from the Tower of Pisa, one of the reasons was to criticise the dominant theory of how bodies behave when they fall, which was the Aristotelian theory.

[10:23] So when we're looking at the cause of something, we should start by looking at what the established scientific theory is. We should see if it makes sense. We should see to the extent to which it should be criticised.

And then if it is defective, we may then need to look at alternatives. And the standard theory held is that this recent temperature rise is due mainly to carbon dioxide emissions by human activity.

And that goes under the grand title of anthropogenic, which means due to human beings, climate change and or global warming. And the theory rests on three pillars.

So the first pillar is a scientific theory based on well-established, in fact, 19th century physics of how gases in the atmosphere absorb and emit radiation. The second pillar is that CO2 carbon dioxide levels in the atmosphere are rising due to human activity.

80% of this is due to burning fossil fuels and 20% due to deforestation. And the third pillar is that temperatures are actually increasing at about the level predicted given the science and the change in carbon dioxide.

[11:30] So those are the three pillars. Now, if one of them were missing, then the theory would be on extremely shaky ground. It really needs all of these three pillars to hold it up.

So let's go through and look in more detail at the three pillars. And I'm going to, because one is most complicated, I'm going to start with number three and work backwards in my list.

So temperatures are increasing. The picture fairly clearly shows that they're not rising on a year-to-year basis. Or even a decade-to-decade basis.

There's a pretty flat period from 1940 to 1970. But if you look at periods of 50 years or more, you can see a clear upward increase. I don't think it's easy to argue that temperatures are not increasing.

Next, let's go on to carbon dioxide levels in the efforts. So modern measurements start in about 1960 when a physicist called Keeling, with a very accurate carbon dioxide measure, installed it on a high mountain, Monola, in Hawaii.

[12:46] And he was quite surprised to find these little oscillations every year, which is due to vegetation growing in the northern hemisphere, absorbing a bit of carbon dioxide.

So the carbon dioxide is at its minimum in October, and then it rises again in the winter. But as well as this annual up-and-down oscillation, there is a steady rise in carbon dioxide after about two parts per million every year.

And there are sort of little wobbles in the curve, but it's going up and up. My data here ends in about mid-2008 or something.

It's now just about 390. Actually, it's now... The temperature is now just under 400. Hello, Gary. Do you want questions now, or do you want to wait until later?

Well, I'm not sure. It depends what your question is. Okay, I want to go back to the previous slide. And I just wondered if you could explain the temperatures that are being measured there. Is that a composite of air and water, or just air, or what?

[13:56] I believe these are surface temperatures on the... I mean, it's Earth and ocean. This is the average temperature over the whole of the Earth. Earth and ocean. Yes. So temperatures are now...

Carbon dioxide is now up to about 400. It's a little bit under 400. Due to this annual oscillation, it'll stay under 400. It was over 400, I think, earlier this year.

It's now under 400. It will go over 400. And in a year or two, it will go over 400 and stay there for the rest of our lives and our grandchildren's lives. We can calculate...

Now, what's the cause of this rise in carbon dioxide? Well, we can calculate from economic data how much fossil fuels are being burnt each year and how much carbon dioxide is going into the atmosphere from that.

We can also estimate how much is being added by other human activities, the main one being deforestation. If all this carbon dioxide went into the atmosphere, concentration would rise by about four parts per million a year, while the current actual increase is more like two.

[14:58] And the difference is probably due to absorption of carbon dioxide by the oceans. And this actually causes another problem, ocean acidification, which I'm not going to say anything about. But the oceans are actually getting more acidic.

And when I prepared this talk, I did some calculations, and I was actually surprised to find out how much carbon dioxide by weight we add by our daily activities. Annual emissions per capita emissions in Canada, 14.6 tonnes of carbon dioxide a year.

And you say, good heavens, can I really possibly be emitting... How can I possibly be emitting 14 tonnes of carbon dioxide a year? When I fill my car, I add about 50 litres of fuel.

It comes out in a hose, so I don't actually realise how heavy it is. That fuel weighs 35 kilograms, so I'd have trouble carrying it. If you've ever carried a fuel can, you realise fuel is heavy. On combustion, this adds 115 kilograms of carbon dioxide to the atmosphere.

So every time I fill up my car, basically I'm adding a tenth of a tonne of carbon dioxide to the atmosphere. And that's... I was surprised, actually, how much that was.

[16:03] 30 people in this room will breathe out about 1.2 kilograms of carbon dioxide in an hour. I did that calculation just for interest's sake. But you don't need to feel guilty about that.

The carbon dioxide in this... The carbon in this carbon dioxide will have come from food that you've been eating, the snacks and those that we had earlier. And hence, ultimately, from the atmosphere of our plants.

So, you know, you don't need to worry about your own personal breathing in and out. And here's an estimate for what's been going on in the last 300 years.

This data here would be from icicles and things like that. And roughly a level of... Between 250 and 280 in the periods up to 1750.

And then a gradual rise due to the human activity, fossil fuel burning. And then a much more rapid rise in the post-1950 period. And the black curve here would be the...

[17:05] ...actual measurements due to Mona Lower. And then the thin black line here is ice cortator. And in the 6th of August, it was up to 397.88 parts per million.

And as I said, it will go over 400 in a year or so. And we'll come down again. So, finally...

So, I've discussed briefly the first two pillars. First, that is, actual temperature rises, actual carbon dioxide rises. And finally, now I want to talk about the most difficult thing, which is the science of atmosphere and radiation.

And this requires some sort of physics, which I learned at A-level. And probably people in North American universities would learn in first or second year physics classes.

And I can't give you... I can't say too much about this, but I have to say a bit. So, all matter emits energy in the form of radiation. We are emitting infrared radiation.

[18:09] The hotter a body, the shorter the wavelength. And the sun, which is at 6,000 degrees centigrade, emits most of its radiation in the visible part of the spectrum. Bodies at our temperature...

Well, at the sort of general temperature of the Earth, emit most of their radiation in the infrared. We can see through the atmosphere, and that means that the atmosphere is not absorbing radiation in the visible part of the spectrum.

So, the Earth's atmosphere is largely transparent to radiation in the visible spectrum. So, the sun's radiation in the visible spectrum comes in. Some of it gets absorbed, but a lot of it reaches the Earth's surface.

This warms up the Earth's surface. And this radiation... Then the Earth's surface re-emits that radiation in the infrared. And some of the infrared radiation is then absorbed by the atmosphere, reflected back to Earth, warming it up.

So, we have an extremely complicated picture here, showing what's going on in terms of global energy flows in watts per meter. So, I hope you can see my little pointer.

[19:13] 341 watts per square meter comes in from the sun. There are lots of flows here. Some of it gets directly reflected back by the atmosphere and clouds. Some of it comes to the Earth and warms up the Earth.

Let's miss out some of the complications here. There's a big radiation by the Earth going up into the atmosphere. Some of this then gets reflected by the atmosphere in various ways down again.

And, in fact, if you look, 161 watts per meter is coming by direct radiation. 333 is coming by indirect radiation. So, indirect radiation is actually a lot bigger than direct radiation.

But some of the radiation from the atmosphere then gets emitted out and finally disappears into space. And then there are various other effects due to clouds and evaporation and so forth, which I'm not going to go into.

This slide here gives a net absorption by the Earth of about 0.9 watts per square meter. In other words, these flows are not completely imbalanced.

[20:19] There's a net absorption of radiation by the Earth here, according to this slide, and that would mean that the Earth somehow or other is going to get warmer, just as if you turn on the electric heater on your stove and start warming up the water in it.

Heat is going into that water and it's going to warm it up. So, these are the... And the basic idea... Okay, let me go on to the next slide. Okay. Even more complicated.

This shows the spectrum. Here's infrared radiation, which is heat.

This is all the thing we call heat radiation. Here is a visible spectrum. Most of the visible spectrum is not absorbed by the atmosphere. Quite a lot of the infrared radiation is absorbed by the atmosphere.

And here, on this part of the slide, let's go down to the bottom. What this little grey peak here means is that radiation at this frequency in the infrared is largely absorbed by carbon dioxide.

[21:28] There are some other little peaks here due to carbon dioxide too. Water vapour also absorbs radiation, and in fact absorbs much more radiation in many more different frequencies than carbon dioxide.

So, what happens with the water vapour or carbon dioxide in the atmosphere is it absorbs the radiation, then re-emits it. Half of it, roughly speaking, goes upwards and half of it comes downwards.

So, if there wasn't any there, all the radiation would escape. With some of it there, some radiation goes up and some goes down. The radiation goes down, will then get re-emitted, but the net effect is a slight warming in the Earth's, on the Earth.

Overall, I mean, the Earth is warmer than the Moon. Due to the atmosphere, the Earth is about 30 degrees centigrade warmer than the Moon. They're essentially the same distance in the Sun. Now, it's not an easy calculation, but it's not really tremendously complicated.

It's been known how, since the 19th century, so it's the sort of calculation you can do with pen and paper and log tables and many, many hours of work. How to calculate how changes in gas concentrations affect the amount of energy emitted by the Earth.

[22:45] And what we find is oxygen and nitrogen, the main components of the atmosphere, are not involved in this. It's only atoms, actually, with more from three, molecules with more from three atoms, which are involved in this.

And there are three main players. Carbon dioxide, CO2, methane, carbon with four hydrogens, and water vapour, H2O. Increasing the concentration of these, according to the standard theory, will increase the radiation reflected back to the Earth by the atmosphere, and so warm the Earth.

So that's the basic theory. Now, of these three gases, water vapour has the greatest effect, then methane, then carbon dioxide.

So carbon dioxide is the least important of the three main players. However, in thinking about the human activity, we also need to know how long additional gas put into the atmosphere will stay there.

Water vapour doesn't last very long. It condenses out in clouds in a few hours for a few days. Methane lasts about eight years before it breaks up into water and carbon dioxide. Carbon dioxide takes a few hundred years for some of it to be absorbed by oceans, and tens of thousands of years for the big effect, which causes carbon dioxide in the atmosphere to go into equilibrium, which is it reacts with rocks to form carbonates.

[24:12] So ultimately, the Earth has correction mechanisms in place, which tend to return gas concentrations to equilibrium values. For methane, it doesn't take very long, but for carbon dioxide, it takes thousands of years.

So carbon dioxide is not the most important greenhouse gas because of its effect, but because of the time that it stays in the atmosphere.

Now, let's talk about water vapour a bit. In terms of effect, this is the most important greenhouse gas. But over a timescale of decades, it works as what people would call a feedback, not as a forcing term.

So if we have a complicated system like the atmosphere, a forcing term changes the behaviour of the system, and a feedback term reacts to the forcing, but does not cause long-term change.

So I tried to think of a sort of everyday example of this, and I came up with the following story, which is not completely plausible, but let me tell it to you anyway.

[25:19] So imagine that you've bought a restaurant and there's a chef there. Yeah. And you go to the chef and you say, well, there aren't very many customers in the restaurant.

And the chef says, yeah, well, you know, the point is that people come into the restaurant when they see other people in the restaurant. What we need to do is hire a bunch of actors, get them into the restaurant, make them look as if they're enjoying themselves, and then we'll get lots of customers.

So you do what the chef says, you hire a bunch of actors, you get people coming into the restaurant, but the food is lousy. And once the actors have gone, the people go, and you're back to where you were.

So the actors and the crowdedness of the restaurant is acting as a feedback term, and the food quality is the forcing term.

So you sack the chef, whose only idea of improving the restaurant is to hire actors, and you get another chef who actually can cook well. And initially there aren't so many customers, but people find the food is good and they come.

[26:25] And because people see the restaurant has got customers in it, you get more people coming. So the food quality here is the forcing term, and the number of customers in the restaurant is the feedback term.

So that's my restaurant story. And basically the idea of water vapor in the atmosphere is the same. It reacts to temperature. When the earth gets warmer, water vapor increases, and that makes the earth's temperature increase more.

When the atmosphere gets cooler, the opposite effect occurs. But one of the major uncertainties in the science of climate change is the overall role of water vapor on clouds.

So after my story, we want to talk about feedback. And as I was saying, this is one of the major uncertainties in the current science. There are various feedback effects, not just water vapor, but let's keep things simple and just think about water vapor.

Now, according to the radiation calculations based on, which, as I said, based on 19th century science, people, as a handy figure, think about the effect of doubling carbon dioxide.

[27:39] Doubling carbon dioxide without feedback would leave to roughly a 1 cent 10 degree temperature rise. But when the atmosphere gets warmer, it can hold more water vapor, more water evaporates from oceans and so forth.

And so the amount of water vapor in the atmosphere will increase. That means that more greenhouse gases, water vapor is a greenhouse gas that absorbs more radiation, reflects more radiation back to the earth.

That leads to a further, maybe 0.7 degrees centigrade temperature rise. Temperature rise is more, but that further temperature rise increases, causes the water vapor to increase more.

So that leads now to a 0.7 times 0.7, which is a 0.49 degree rise. And so it goes on. Well, fortunately, the overall effect of this is not the temperature goes on indefinitely, but ultimately, in this simple example, we get a 3.33 degrees centigrade rise.

So because of the feedback effect of a 0.7 degree rise for every 1 degree rise, this then goes on and gives us ultimately a 3.3 degrees centigrade rise.

[28:53] Now, if the feedback factor were 1 instead of 0.7, then we get the 1 degree rise, and we get another 1 degree rise, and we get another 1 degree rise, and so it will go on. And people will call that a runaway greenhouse effect.

That is what's believed to have happened to Venus a billion years or so ago. But the good news is it won't happen on Earth, at least not for several hundred million years.

Now, here's the summary, therefore. More carbon dioxide, methane, and other gases lead to the Earth radiating less heat out into space. The Earth is in, here's another key term, perhaps, is in radiative imbalance.

In other words, more radiation or energy coming in than going out, and will then warm up. A warmer Earth will radiate more, and so equilibrium will be restored, but at a higher temperature.

So that's the basic theory about what's going on in terms of anthropogenic climate change. How much? So a key number is what people call climate sensitivity, which is the ultimate increase of temperature due to doubling of carbon dioxide levels from the pre-industrial level of 280 parts per million to a level of 560 parts per million.

[30:14] And climate CO_2 now is about 400, it was 280. Levels, according to current economic trends, the increase level will reach 560, doubling around 2075.

And in the various reports of the IPC and other scientific bodies, there have been estimates of climate sensitivity over the years. So a 1979 report in the National Academy of Science estimated it to be 1.5 to 4.

The first IPC report, 1.5 to 4. The second, that's a misprint, that's the third, I think, 1.5 to 4. The fourth, 2 to 4, sorry, 4.5, not 5.4.

And the fifth one changed it back to 1.5 to 5.4. So the story has not changed since 1979. Little change, but also little improvement in accuracy.

I think what one would say is the 1979 report, this was a rather wild guess. In fact, they just had two climate models. One gave a rise of 2, one gave a rise of 4.

[31:21] So they said, well, the uncertainty is probably about 0.5. And then they gave those two figures. Now people are much more certain about the general range.

But as you see, there's still a considerable variation between the most optimistic, which would be 1.5 estimates, and the most pessimistic, which would be 4.5. And the uncertainty is due to unclearness about the effect of water vapour, clouds, and various other feedback effects.

So what I've described so far is simple science. If we go back to thinking of Galileo, this is the first stage of things where we do things by calculations which can be done by, more or less, with a calculator and a log table and so forth.

Much more complicated models called global circulation models try to stimulate Earth's climate, taking into account positions of the continents, clouds, ocean currents, snow cover, etc. So these models are essential if one is to say what is going to happen to climate in a particular area, like, for example, Vancouver.

The disadvantages are that they're too complicated for anybody to understand. It's a complicated system. So, you know, if you've got a complicated system, you may just have to use a model which is too complicated to understand.

[32:42] Let me just say that the basic math in these models is the mathematics of fluid dynamics, the way of airflow, and so forth. So I met somebody who'd worked as a mathematician for Boeing for many years, and I said, you know, in the old days when they built an aeroplane, they needed to know how the very shape of the aeroplane would have effects, so they built wind tunnels.

And I said, do you use wind tunnels any longer? No, he said. They're really inconvenient, and we can do it much better by computers. So now they use the equations of fluid mechanics to predict how the, you know, the shape of the aeroplane wings are going to have the effect.

So this is reliable mathematics. These equations are complicated. You can't solve them effectively except with a computer. And these global circulation models are actually much more complicated in the aeroplane models because the aeroplane models just have to consider airflow, velocity, and pressure, and so forth, whereas these models have to take into account all these other models.

Here are two projections from these models. One is the Antarctica will warm less than the rest of the Earth. I can't say why. It's a bit isolated from the rest of the Earth because it's sort of a continent on its own surrounded by southern oceans.

And on the whole, wet areas will get wetter and dry areas will get drier, but also temperature bands or climate bands will move north.

[34:11] So for Vancouver, it's wet. It will get wetter, but maybe there's also a bit more of moving north of climate bands, so we might gain from that.

So I've given you the standard theory. Let me now give you my evaluation. Here, in recap, are the three pillows.

And as I would say, all of these three pillows seem very solid to me. The scientific theory, based on 19th century science, I would have liked to have actually gone and done some radiation calculations myself, but it was too complicated to do that.

There's been a clear actual increase of carbon dioxide due to human activity, and there's been a clear actual increase in temperature in the last 150 years. So as I said, all these pillars seem very solid to me.

However, as you're probably aware, there have been quite a lot of criticisms and objections, and I'm just going to briefly address some of those. One is the temperature has not driven much over the last 150 years.

[35:21] The observations are due to the urban heat island effect. The point is, one of the oldest temperature records is from Greenwich. Greenwich is a park in London. It was perhaps more or less out in the country in 1850.

It's now surrounded by lots of, well, it's still in a park, but there are a number of, a lot more houses around it. The idea is, cities are getting hotter, well, the rest of the earth is not getting hotter.

I would just say that a number of people have tried to find this, but there are temperature records, there are temperature gauges which aren't in cities. People have done the statistics, and they find that this effect, you know, it exists for some temperature gauges, but it does not explain the rise.

Some people say that human carbon dioxide is not rising due to human activity. I think that's completely untenable given the rise in carbon dioxide and the fact that we have economic data on how much fossil fuel we've burnt.

People could argue that the radiation calculations have not been done correctly. That seems extremely implausible to me. The physics, although beyond me, is not beyond a whole bunch of people.

[36:35] And if you could argue that the radiation calculations have not been done correctly, the whole theory would fall apart and it wouldn't be that hard to show that it was wrong.

People have argued that past temperature rise is due to some other cause. That is the rise that we've seen since 1850. But any such argument has to do two things.

It has to explain why the conventional theory is invalid and then provide a plausible alternative. So let me give you another of my little business stories. You buy a shop or you own a shop and you find that starting in January 2014, profits are down by about $550 a month.

So you go to the manager of the shop who you're employing and you say, hey, why are profits down? And he's humbles and hers and talks about the internet and business and so forth.

Then you look at the records of the shop and you find that the rent went up by $500 in January. You say, hey, look, the rent went up. Oh, yes, he said, but that's not really the effect.

[37:48] It's due to all these other things. So in the stories I've got, you have a clear explanation of why your shop is in trouble. If the manager's going to explain it's not due to the rent, he has A, to explain why the rent is not, the rent increase is not the cause, and B, he has to provide some other cause.

And any, you know, any argument that the past rise is due to some other cause has to do two things. It has to remove the conventional explanation and it has to provide a plausible alternative.

And a final criticism, an objection, is that there's been no temperature increase over the last 15 years. So, here is a picture of the last 50 years. I couldn't get a good picture from the internet, so I just did one in Excel.

You see roughly constant climate up to about the 1970s, a rapid rise in the 1990s, and then no obvious increase over the last 15 years.

So, decade by decade, the last decade, temperature has not increased, but nevertheless, if you look at the broader picture, you do see a clear increase.

[39:04] Certainly, this holding was not expected by people in the climate science area, and, you know, there's a debate about what exactly is going on here.

As I said, if we look back at the overall figure, we see a clear increase not from decade to decade, but from over periods of 50 years or so, there was actually a period of 30 years from 1940 to 1970 when things did not increase.

And so, you could certainly cherry pick the data and find periods when the climate is, when the temperature is not increasing, but if you see a graph which just shows the temperature over the last 15 years and doesn't show you the whole picture, you might guess that the person is trying to mislead you a bit.

So, let me now give you some, what I, I've given some criticisms which I think are not reasonable. Here are some more reasonable line of criticism.

And that is that the current estimates of climate sensitivity, which I'm going to call CS, are too high. Remember, this is the amount by which temperature will ultimately increase due to a doubling in carbon dioxide.

[40:15] And the IPC estimate is 1.5 to 4.5 centigrade. The most distinguished academic climate critic, Richard Linson, suggests about 0.6 degrees centigrade.

And to do that, he actually requires negative feedback, in other words, a rise in temperature causes more clouds, clouds of the right kind reflect radiation back into space, that causes a lower increase in temperature.

And I would say there's some legitimate room for debate here, but views of the sensitivity are less than about 1 degrees centigrade have little support.

There are two distinct efforts of getting estimates. The first is by scientific models like the global circulation models, so forward models based on the physics. A second effort is to look at past climate changes and make statistical estimates based on that.

And both lead to figures in this rather wide range of 1.5 to 4.5 degrees centigrade. So, less distinguished than Richard Linson, but more local to Vancouver, is Patrick Moore, who was actually in Greenpeace and is now rather a critic of many aspects of the ecological movement.

[41:32] And here are some quotes from an interview that he gave a while ago. And I think it's interesting to see here what a reasonably responsible, but not completely responsible, climate critic has to say, the things that he agrees and the things that he is not saying.

There is no dispute over whether CO2 is a greenhouse gas, he says. In other words, the basic radiation theory that I've described, he's agreeing. The fundamental dispute is about water in the atmosphere.

A warmer climate will result in a higher level of water in the atmosphere. All of the models used by the IPC assume that this increase in water vapour will result in a positive feedback in the order of three to four times the increase in temperature that will be caused by the increase in CO2 alone.

So I think there are two statements in this thing which I've highlighted which are not really supported by the evidence. The first is, this is in fact, he's explaining climate sensitivity in layman's language.

We've seen the IPC says 1.5 to 4.5. He's saying, they're saying it's three to four. Then the other thing that he says is these models assume that this increase.

[42:42] So he's saying that was put into the models. Now, that's not the case. The calculations of climate sensitivity are something which comes out of the models. Into the models goes basic physics and so forth.

The climate sensitivities are not an assumption in the model, they're an output of the model. So as I said, I think he's not being quite straightforward in those two statements here. And then the final statement, again, talking about negative feedback.

Many scientists do not agree with this. Actually, there aren't that many. Or do not agree that we know enough about the impact of increased water to predict the outcome. I think a lot of people would say that there's a wide variety, you know, there's a lot of uncertainty, including the IPC estimates, which are 1.5 to 4.5, which is a very wide degree of uncertainty.

So if a certain increase in CO2 would theoretically cause a one degree, centigrade increase in temperature, which is basically what the, you know, this is the increase that actually, you know, is the sort of pre-feedback estimate.

If there was negative feedback, the temperature would rise would only be 4.5 centigrade. And so he's probably going for the Linson figure of 0.5 or 0.6. But as I said, there's not a lot of support for such a low, for high level of negative feedback and such a low value of climate sensitivity.

[44:00] So I'm coming to the end of my time. What will happen? So I've talked about science. Now let's just say a little bit about what happened. Some people say, well, it would actually be good if the world is warmer.

Good for who? Climate change will have winners and losers. Canada will probably be a coldish country on the whole gain. But other countries like Bangladesh, which is hot already and close to sea level, will not win.

And losers will outnumber winners. And there's a simple reason why losers will outnumber winners. Current patterns of human habitation are adapted to the kind of agriculture that we can have.

So if you have two regions, one region where agriculture is working and one region where agriculture is not working, lots of humans will live in the region where agriculture is working and not many will live in the region where agriculture is not working.

Climate gets warmer, this region becomes an arid desert and this becomes nicely fertile. All the people here have to move there. But that may not be so easy, there may be borders in the way and certain sort of inconveniences would attend the farmers in Bangladesh moving to northern Saskatchewan.

[45:23] there may be obstacles in their path to make that awkward. So any change from our current situation is going to be uncomfortable for some people.

So there are people like Olav who will be able to say much more from that, but here is my brief summary. Two degrees centigrade rise, moderate effects globally, severe impact for some regions.

Four degrees, severe impact for many regions, and six degrees, which is the difference between temperature now and the ice ages, very severe impact for many regions.

The greatest adverse effect will be for already poor countries, which tend to be around the equator and hot. And the sorts of things that people predict are sea level rise, heat waves, droughts in some areas, more severe but fewer topical storms.

So can anything be done? And here I would mention that we could point to what somebody called a toxic polarisation debate.

[46:28] The following statement is to deal with global warming means we have to destroy capitalism and our economy. So now this is advocated by some people on the right as an example to do nothing.

We can't destroy capitalism and our economy. It's advocated by some people on the left in the hope that it will lead us to destroy capitalism. So I don't know what planet these people on the left are if they think that talking about global warming is going to make people abandon capitalism.

So you can see that both these groups would like us to think that in order to deal with global warming we are going to have to completely change our economy and our way of life.

An alternative view which I think the least one should give serious attention to is the view that action is costly but affordable. Here is carbon use in metric tonnes per capita.

Perhaps not surprisingly one of the oil producing countries, Qatar is at the top. USA and Canada, this is a different figure from the one I gave you before, it's a different year I suppose. Russia are 12, Germany, countries in Europe are approximately as wealthy as USA and Canada but they have roughly half the carbon dioxide emissions.

[47:41] Switzerland, cold in the winter but surprisingly low. China emerging about the same as Switzerland, India a poor country with a very low per capita emission.

Just interesting to see. They correlate roughly with wealth of country, India being the poorest of these countries but there's a lot of variation. And here are some possible actions that we overall can take.

A carbon tax will act to reduce carbon tax. Somebody I met from the Suzuki Foundation party was saying it's actually the small carbon tax in BC had in fact already had a significant impact.

Move from coal to gas for power plants. Per unit of energy gas produces a lot less carbon than coal. Move away from fossil fuels for power generation power plants.

And some people in the ecological movement hate nuclear power plants but I think they're just being, well there are reasons to be concerned about nuclear power plants but I think compared with the harm that other things do we have to view that they are probably a good thing.

[48:53] So more nuclear plants. Solar power has become amazingly, has gone down in price by about tenfold over the last decade and is now surprisingly cheap. Wind power and research into new technologies, I think I misspelled that, such as nuclear power from thorium.

So thorium is a radioactive element like uranium but the thorium plant cannot melt down and it can't be used for bombs.

So there's some disadvantages in using thorium reactors. Some research on that is being done in China and France, none in North America.

And the final possible action is what people call geoengineering. Modify Earth's climate to mitigate temperature rise. There are various ideas. Mirrors in space are hopelessly expensive and impractical but stratospheric sulfur injections, you fire shells containing sulfur into the upper atmosphere, these reflect radiation away from the Earth.

The cost of 20 billion a year, quoting somebody says, surprisingly affordable compared to the other ones. There are problems with geoengineering.

[50:06] It doesn't quite restore things to where they were. You get warmer nights and nights will be warmer than they were before. But I think that if we're going to do anything at all, all of these things are going to have to be put on the table.

No, nothing should be sort of ruled out. forever. And I think that's the end of my talk. Yes.

OK.gomberg Thank you.