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Title	*What will it take to avoid 2, 3 and 4+ degrees?*
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Speaker So, the question I was asked to address was: what will it take to avoid x degrees of warming, two, three, four, whatever you wish. And it actually follows very naturally from Jason's. A lot of what I'll be talking about is actually conceptually quite similar to what Jason was talking about, but hopefully we will be able to enforce some of his messages. And of course, I have got to thanks several co-authors on this. Several plots I am showing you, the new ones at least, were produced by Neil Bowman, who has just recently joined our group.

Just for the people here for whom this isn't their routine, daily activity. I don't know if there are any of those people left. But the usual answer – it tends to be only the enthusiasts – but nobody cares about mitigation, everyone just wants to know about the scare stories don't they? Okay, so the usual answer you get, is that you have got to aim to stabilise the atmospheric concentrations at some PPM. And you have got to do this be reducing emissions by z%, relative to 1990 by some date.

So the honest answer is we don't know, and we won't know for sure unless we try. This is actually the point at which I could finish my talk, although I think it is a message that we do have to make sure gets conveyed very loudly to people meeting, for example, in Copenhagen in December. The only way you are going to find out what it is going to take to avoid any given level of warming, is by reducing emissions and finding out how the system responds.

We can model till the cows come home, and we certainly will, but it is not. . . you are not going to know until we start this next experiment. That said, before the fire us all, we may still be able to say something useful, provided we ask the right questions. And the importance of asking the right question is illustrated. . . I will talk about the wrong question briefly. The standard approach, which 95% of the people meeting in Copenhagen will think is the question they are trying to answer, is x degrees equals y ppm, that requires z percent by 2020 or 2050.

That is the way that everybody thinks about this problem, and it is the wrong question. So this is why it is the wrong question. This question originates of course from the ultimate objective of the UNFCCCC, which poses the implicit question: what is that level in the atmosphere that would avoid dangerous climate change.

So to answer the UNFCCCC's question, you need to know the climate sensitivity. And as you all know, the `[[Charny 0:02:37]]` in '79 came up with a sensitivity range of 1.5 to 4.5. And 2007, do the math, however many years later, and basically the range hasn't fallen. By the way, if the climate sensitivity is three degrees, then a two degree limit implies that we can go to a 445

PPM. One of the hot debates for Copenhagen is should we aim for 350 PPM. Which is now a global campaign to get people behind – recently endorsed by Nick Stern – that we should all aim for 350 PPM.

What does this mean, and why? Why are people aiming for this? Well the worry here is again, because you are asking the wrong question, you find yourself tying yourself in knots to answer it in a way that makes sense. So the argument that is generally handed out, for why we should aim for 350 PPM is illustrated by this diagram here. Which shows the carbon dioxide concentration associated with different levels of equilibrium warming.

First of all, if you assume a standard three degrees climate sensitivity, and then people cite, "Oh but Hanson 2009 have shown palio-climatic evidence." Which implies that way back in the distance past, temperatures were six degrees higher when carbon dioxide levels were... that's after ice caps melted and so on. So even Mark Linus can join those lines up and say, "Oh well the climate sensitivity must be six degrees." Mark is a very intelligent person, he told me so yesterday lunchtime.

So, here you are... I followed this line, this is just a log curve by the way. I'm sure Mark is good at logs. And there you are look, 350 two degrees. Okay? Hey presto. That is why we need to aim for two degrees, because Jim Hanson has shown this paleo-climate evidence that climate sensitivity is really six degrees. That is the wrong answer. Because what actually happens is the system follows this curve, then eventually your ice caps collapse and it wobbles up there. Then of course you try and cool it down again, without any ice caps you end up higher than where you were to start with.

Okay. So the danger with this sort of argument is if you are saying, "Well the IPCC thought the climate sensitivity was three degrees, but they got it wrong. Jim Hanson has shown it six degrees, so we need to stabilise at 350 QED." The problem – there are lots of problems with this. First of all, to get an IPCC like consensus, that the climate sensitivity is six degrees, will – I assure you – take a long time.

Jim Hanson will say that is because the IPCC is populated by dinosaurs like myself, who take a lot of convincing. But I don't think I am the only dinosaur on this one. I think I have got some allies on that front. Melting ice sheets of course, for this six degree sensitivity to manifest itself, may take even longer. So your targets basically apply to some indefinite date in the future.

Also there is a fundamental logical problem here. If the aim is to save the ice sheets, then why use a climate sensitivity value which assumes the ice sheets melt. You don't have to be `[[Bjorn Lonborg 0:05:40]]`, I don't think he spotted this one yet, but he probably will. Okay, none of this argument is necessary. The emission policies you need to avoid more than two degrees of warming are the same regardless of the very long term concentration you aim for.

The problem with this whole argument is that you are asking the wrong question to start with. Asking what is the very long term carbon dioxide concentration of humanity should be aiming for, is not a helpful question, because we can't answer it using existing science. We can't answer it using any conceivable scientific investigation that we can perform today.

Here is a better question and a different story. Okay, so this is a study published early this year, which Jason was a co-author one. It is actually very similar to the study that Jason was telling you about, that they are doing under the avoid program. Generating lots of idealised co2 scenarios, and looking at the... how the temperature responds using a simple climate model.

So the crucial point of this is... the assumption is that we are aiming to stabilise temperatures, not concentrations. So having achieved a rate of emission decline, we can just assume our descendants carry on making emissions decline at that rate until temperatures peak. This means they don't have to go to zero, but they do have to go pretty damn close to zero.

So this of course will give us a great argument for the panel discussion on the... whether or not there really is an emissions flaw, and we will come back to that later on in the talk. But I am not

assuming... one of Jason's cases where the emissions flaws are assumed to be zero. So I am not looking at the response to an emissions flaw in say 2200.

So here are lots of scenarios. Okay, the crucial property of all these scenarios is that... the red and orange ones for example, all represent cumulative emissions close to a trillion tons of carbon. If we look at the response to them, here we are, there are emissions on the left and the temperature response on the right.

And you can see that if you are prepared to cut at 8% per year, this is just reinforcing Jason's point, you can postpone the time of the emissions peak to the 2020's. But you have then got to come up with a convincing story as to how you are going to cut by 8% per year all the way through to 2100. You are going to keep that 8% reduction going in order to keep your integral. The integral under these curves, the total amount of carbon you release into the atmosphere is the same, so that blue area is the same as that blue area. These tons of carbon are borrowed from our descendants then if you like.

But the crucial point is the climate system doesn't really care very much. There is a small difference in late 21st century temperatures. The actual peak rate of temperature change, which you might think was a key determinant of ecosystem damage, actually isn't very different between these three curves. What is different is in the high case, this peak rate of temperature change is sustained a little bit longer before it levels off. And also, notice the uncertainty in the response is larger than the difference between these curves.

It really doesn't matter when we release this carbon, what matters is how much we release. And lots of people have been saying this. Kevin and Alice Bowes said this last year, Susan Solomon said it, we've said it, it is kind of an obvious thing to say. But it does have important implications. Because it is not what they're talking about at the moment for Copenhagen.

Here's the problem. If you are just looking at emissions in 2020, by just plotting 2020 emissions here against cumulative emissions, similar to some of Jason's plots. We didn't coordinate these talks as you can probably tell, but you can see that the colours show the most likely peak warming, and the colours run horizontal, okay? So it doesn't matter – I should say Neil produced this plot not me – but the point is, it doesn't matter. If you fix the cumulative total, that fixes your peak temperature, it doesn't matter how much of that you are emitting before or after 2020.

Interestingly, for this sort of class of continuous emission profiles, 2050 happen to be quite a good indicator of the risk of cumulative emissions going over a trillion tons. And that is a very simple... there is a very simple reason for that. Again, it is just geometry. These lines tend to cross over around then, so how much you are emitting in 2050 is actually, for this overall shape of scenario, a good predictor of what you are going to emit in total. That is instantaneous 2020 emissions.

That is actually why coincidentally, if you are aiming for two degrees,2020 emissions is probably quite a sensible thing to focus on. But you have got to acknowledge that it is not fundamentally what the climate system is responding to. It is only interesting because it happens to be well correlated in this class of emission scenario, with what really matters, which is the total.

There is a lot of enthusiasm for, and this is `[[Malter Meinhausan's 0:11:04]]` fault, for emissions between now and 2050. In fact Jason made the same mistake in his talk, proving therefore that we haven't coordinated enough. Or that I haven't been talking to Jason enough. He is still using the budget to 2050 as a guide, this is less good even than 2050 emissions themselves. Because again, go back to this graph. The amount I emit between now and 2050 is actually less relevant to the total, because of course it is all about how much you borrow from before and after 2050, than 2050 emissions are themselves.

So it is a rather counterintuitive result. The actual rate of emission in 2050 is actually better than the budget to 2050, as a guide to overall cumulative total. This is important because the WBGU proposal, and indeed everybody else and everybody at `[[DEK 0:11:55]]` thinks it is

the budget to 2050 that matters. And I told Malter this many times, but he refused to change it. So here you are, remember this diagram. Next time somebody is talking to you about the budget to 2050, ask them what do you plan to do afterwards? Because that is what matters. It is the budget overall. Mother nature doesn't care about dates at all. Not even long dates.

Here we are, there is the peak warming summary from our study of a function of cumulative emissions. And this is where we start to get more relevant to the topic of this meeting, because we are looking at higher cumulative emissions and higher temperature changes. So notice the overall... how this overall area of possible response evolves. And I was just going to point out there is a very nice link between this result and various other studies.

This is showing you that same information, just there are some little error bars here instead. That is the UK climate change committee recommended budget for a 50% chance of beating 2%, that's Malter's number, that is uncertainty range. So Malter actually proposed a limit down here, so as to get a 75% of beating two degrees. This by the way, sorry it is rather faint. This range is the confidence interval on peak warming proposed by Matthews et al, and a paper which came out shortly after ours. As you can see they are somewhat optimistic than we are, because they are using different assumptions about the amount of Co2, or different estimates of the amount of Co2 induced warming to date.

Okay, so that just shows that everyone is kind of singing from the same hymn sheet. We are all getting roughly the same numbers, and this is how it evolves in the future. this of course is the point where I have to stress, I can't of set this up and did this study focusing on low... using a model that was intended for low emission scenarios. As soon as... because of the title of this conference, I am now going to show you some figures about how it evolves when you go further into the future. but I am very uncomfortable with using simple models, when you go out to more extreme magnitudes of warming. Because you just know that the relevance of the model to the real world is just going to break down at that point.

So just for your eyes only so to speak. Here is what happens if you add two trillion tons. We bump up peak warming to around, most likely to around three degrees, and three trillion tons bumps it up to around four degrees. Interestingly, it is not going up entirely linearly, and there are various interesting reasons for that. Notice that this curves here. And in fact, one of the reasons is very simple: the log rhythmic dependence of Co2 forcing on Co2. In fact, Neil `[[Bowman 0:14:53]]` reckons that explains most of this curvature. And that, we can rely on because we know that Co2 is a log rhythmic driver.

On the other hand, when you are going up here and there are other things kicking in, like methane `[[feedbacks 0:15:05]]` and so forth, then the predictions of simple models like this one are less and less relevant to the real world.

Let's just see how it all relates to what's down there. That is past emissions, that is conventional oil and gas. They found some more recently so maybe that bar is wrong. That is conventional oil, gas and coal, and that is including unconventional reserves. So there are plenty of fossil fuels down there. Which brings us to why this is not just an academic point. I quote a senior member of the civil service, in the Department of Energy and Environment Change. Who said, "This is completely uninteresting, it is just an academic point." I really resent the fact that he uses "academic" as a derogatory.

So Co2 matters because Co2 accumulates, but other gases don't. therefore if you are going to trade off different gases, you are potentially going to do things which are counter-productive if you end up emitting more Co2, and reducing the emissions of a short-lived gas. That matters because I bet we will do lots of that sort of thing. We need to limit cumulative emissions of carbon dioxide if we want to avoid dangerous climate change. There seems an incredibly simple statement, that it would be good if the worlds' politicians understood that. I don't think it is just an academic point that they should understand that.

Postponing emissions peaked... this is more controversial but it's true so you have to accept it. Postponing emissions peaked to 2020, does not actually physically commit us to two degrees. It commits us to potentially unfeasible rates of emission reductions after 2020 if we are to achieve two degrees. These two statements are not the same, and if we reach 2020, and emissions are still gently rising. I would much rather have been saying that second thing for ten years than the first thing. And you have got to see why. Because if you have said that you're doomed if you don't peak by x date, then if we don't peak by x date what can you say? Apart from, "Well we're doomed." Which is not a helpful thing to say.

So we have got to be very careful here. And a lot of the focus, date in particular, a lot of the rhetoric about the need to peak by x date is potentially extremely dangerous. Because it doesn't fit with the science, saying anything which isn't totally supported by science is always dangerous. But it is also a hostage to fortune as to what you are going to say later. And crucially of course, this case for limited cumulative emissions to less than a trillion tons, doesn't depend on any post AR4 science. It doesn't depend on, you know, Stephan's new model for sea level rise. And it doesn't depend on Jim Hanson's latest estimate of climate sensitivity. This is absolutely bog standard climate science.

There is of course a very simple implication which I wanted to flag up. Because John `[[Sharnhoober 0:17:58]]` mentioned this, if we know that there is a limit on cumulative Co2 emissions, we are not quite sure what the limit is but we are not too far away. There is a very good chance that we are going to miss it. So it is very hard to avoid the implication that we need to be building a capacity for negative emissions.

This is an interesting graph that Neil Bauman produced in his masters thesis. We have very good students here in Oxford, they do good masters projects. This shows you how emissions might have to evolve if you assume that you learn as you go along so to speak. About what it is going to take to avoid two degrees of warming. So here, well he wasn't quite a good a master student because he didn't quite avoid two degrees of warming. But he did pretty well. Actually there is another graph which does even better. But he did a lot better than the politicians in Copenhagen are likely to do anyway.

As you can see here, crucially there is a very large grey area down below zero there. There is a good chance as we adjust emissions through the century, to avoid two degrees of warming, we are going to discover too late that emissions are going to have to go negative. So we are going to have to build a capacity for that to be possible. Okay. So here we are. This matters because there is no point arguing over sustainable `[[decapator 0:19:14]]` emission rates. It is like sharing out the last tuna. Okay?

Measures to reduce 2020 emissions will only help if they are part of package to limit cumulative Co2 emissions. Okay. So an exclusive focus on 2020, which appears to be `[[DEK's 0:19:29]]` focus, or at least it was the last time anybody spoke to me. They don't talk to me anymore, maybe that's why. Because it is potentially counter-productive. For example, carbon sequestration doesn't really make sense if all you really care about is 2020 emissions. Because it is a very expensive and rather slow way of reducing emissions by 2020.

However, if you are thinking about the cumulative total of carbon sequestration, it is essentially what it is all about. So it does make a big difference. We would like therefore, the parties to the UNFCCC to acknowledge the needs to limit cumulative emissions. We are not saying that they need to specify a number. It would be far too soon for them to do that now. But it would be a very good thing indeed if they could simply accept the principle that cumulative emissions will have to... carbon dioxide emissions will eventually have to cease. And they will have to cease before we exceed a given total if we are going to avoid dangerous climate change.

Because remember, we didn't save the ozone layer by rationalising deodorant. Think about it.

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