Presenter: **Professor Christian Jakob - *2017***

Title: Modelling the future of our climate- Beyond crystal balls - (18:18)

Time	*Dialogue*
00:09	Thanks very much everyone and welcome. My name is Christian Jakob. I work for the School of Earth, Atmosphere and Environment here at Monash University and I have come to talk to you about an age old dream of human kind, which is predicting the future. We always want to predict the future and we always wanted to predict the future. We go to great lengths to predict the future. For instances we use horoscopes, we read tea leaves, we employ crystal balls and people actually pay a lot of money to know about the future by those means.
00:41	It wouldn't be a STEM Talk if I was going to tell you about how meteorologists read tea leaves to predict the weather or the climate. So you might guess that science can actually help make some of the predictions that we are particularly interested in. And we actually experienced a silent revolution. It's silent because none of you will have noticed, but every one of you uses the outcome of this revolution of twenty century science every day. And you are using it in this form. You go on the Bureau of Meteorology website and you look up what the weather is going to be tomorrow, in three days, in five days and next week.
01:21	And I bet you never thought about how they actually make these forecasts. More importantly something else has happened over the last couple of decades, and that is we have noticed that our climate is changing. If we stick a thermometer into the earth, as is done here we find that over the last 100 to 150 years since the beginning of the industrial revolution the earth has warmed by about a degree. And not only would we like to know why this happened and what happened, we would also like to know will continue, what might happen in the future and what might the consequences be for all of us if this trend of rising temperatures continues.
02:05	Not only do the temperatures rise, a degree doesn't sound a particularly large amount does it? It doesn't really frighten us if it is a degree warmer, but it turns out that a degree warmer globally has consequences globally which are much larger than just that one degree change. So for instance, as shown in the graph at the bottom right, sea ice over the arctic has reduced in its extent by almost 50%, not quite yet, since the early 1980's. So we have a strong impact of this warming of the planet and all sorts of systems.
02:40	We know it's us and we are not going to talk about this today too much, but we know that the warming of the earth goes together with an increase in Carbon Dioxide in the atmosphere. In pre-industrial times the concentration was 280 parts per million (Don't worry too much about the units) but the number was 280 (ppm) and the number is now 405 (ppm). This is as of last week (Aug 2017) and the earth is currently breathing in Carbon Dioxide so by the time it is breathing out again which is when the Northern hemisphere goes into winter it will be up above the 410 (ppm) mark, we think.
03:15	So this is a large change in carbon dioxide. We have looked for the sources of where that carbon dioxide might have come from. Might it have come from natural sources? And the answer is simply no. It has come from human activity. So knowing the temperature has gone up. Knowing that carbon dioxide in the atmosphere is the cause. Knowing that we have added that carbon dioxide and that our industrial activity will continue, a perfectly legitimate question you may have is "what is going to happen to the temperature of the earth in the next fifty to one hundred years?

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04:01	And this is where science has evolved beyond what any of us would have imagined even in 1950 so it's a very short period of time by scientific standards. So what do we need to do to make this prediction? What do we need to do to find out what might happen to the Earth's temperature and other things on earth over the next one hundred years? Well we need three ingredients. One you will have heard about but probably never thought about what it means, is we need a climate model. We need a model of the climate and most models you will encounter in day to day life are extrapolations of past observations, some sort of statistical assumptions are being made.
04:28	Climate models are very different. Climate models start off with the laws of physics, some of which are depicted here on the left. These ones are particularly the ones that apply to the atmosphere and they are very familiar things to those of you who studied mathematics and physics even in school because they are Newton's second law – Force equals mass times acceleration. Nothing secret about this … very simple law. It's the law that mass is conserved ... can't be generated and just move around. It's the law that energy is conserved and there's a law how gases that we have in the atmosphere might behave in approximation.
05:06	From these laws we can calculate the sorts of things that we would like to know about the weather and the climate. We can calculate the winds. That comes from Newton's second law. We can calculate the temperature and we can add further laws, conservation of moisture in the air for instance. So that's ingredient number one and it's kind of fascinating to know that your weather forecast, your climate predictions all start from those laws. They do not start from data or extrapolation of what happened over the last 3 days or the last 10 years. They start from the laws of physics. That's very important to keep in mind.
05:39	The second thing as it turns out and as it will become clear in the next few slides is you need a big computer. The picture up there is of the biggest supercomputer on earth. It's actually in China. It has 10 million 'Cores' as they call them now. They use to be called 'Processors' but processors have more than one computation per core these days. This thing has more than 10 million. If you have an iPhone 7 then you have 4 and if you have an iPhone 6, I'm sorry to tell you, you have only 2 Cores in your iPhone.
06:08	So this thing has 10 million and just for fun it uses 15 megawatts of power. That's 15,000 vacuum cleaners running at the same time … something like that. So it's a very big computer. The third thing we need is that we need to know is what will human do about emitting CO2 in the future? And that's actually very uncertain. We don't know and we can't predict it so what we have to do is we have to develop some scenarios. And people go away and develop those scenarios and I want to point out two on this graph on the bottom right.
06:50	The green curve is the scenarios where we are really really conscious citizens and we actually start reducing emissions of CO2 by about 2020 which is only about 3 years from now. And then we reduce the emissions to zero by about 2060, 2070. So that's a very ambitious scenario. And then the other one we will use later is the blue one, which is the business as usual scenario … we just keep going and we pay no heed to the idea that our planet might be changing and we might have to do something about it. Keep those two in mind because we will come back to them.
07:17	No we have the laws of physics, why not solve everything on a piece of paper and give you the answer and say the answer is '42' like it would be in the Hitchhiker's guide to the Galaxy. Unfortunately it's not that simple. So to implement these laws on a computer we need to make approximations. OK. And the first approximation is that we need to divide the earth up and we need to divide it like it is depicted here. In the horizontal we make little boxes and in the vertical we make little onion layers. The atmosphere becomes layers of onion and together that makes cubes.

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07:50	And then we calculate the wind, the temperature and all the numbers we are interested in, each of those cubes. Now the laws of mathematics tell us, make the cubes as small as possible to get a more accurate answer. The computer says 'No', for those of you who watch Little Britain. Computer says No. Simply, even the biggest supercomputer on earth does not allow us to use sizes of these little cubes small enough that we would be satisfied with. So we need to make compromises.
08:19	Current climate models have horizontal sizes of these boxes of about 100 by 100 kilometres that's because we need to do a lot of calculations and we want to run them off for 100 years, not just for the next 5 days like a weather forecast would. You can see the consequences of these approximations on this slide. Is anybody from Tasmania in the room? Can you spot Tasmania on this map? It's gone. So you can already see the consequences of this approximation. If you want to make a climate prediction for Tasmania with this kind of model (this one by the way is 250 by 250km boxes) you would be out of luck.
08:57	So we cannot make a climate prediction for Tasmania using this model. New Zealand is slightly better off. North Island, one box, South Island, one box. You can already tell that is not going to give a very accurate prediction because of the mountain over the South Island are very important and they are clearly not well represented by a single box that represents the entire South Island of New Zealand. It gets worse. We need to make further approximations.
09:23	By making these boxes we are excluding certain things that happen in the atmosphere from being included in our calculations and it's all the things that are smaller than our boxes. So in the example here it's thunderstorms. Thunderstorms are quite small. You know it covers a few kilometres by a few kilometres, so if you have a 100 km box and you average over it all thunderstorms are gone. That wouldn't be a problem if thunderstorms weren't important to the climate. Turns out they are.
09:50	So we have to reintroduce them by what I call little models in a big model. And the little model in the big model, an example for this is on the top right here, and that's my own personal research. That is devising these little models of thunderstorms as they live in our big climate model. And we end up with a whole set of other equations that are these little model but gain we made another approximation. So by this point you should ask, well given all of these approximations how good are these models?
10:21	Oh before I tell you that I will tell you one other thing. I only talked about the atmosphere. The climate system isn't just the atmosphere. It is also the ocean. It's also the land. It's the ice on the earth. All of them interact with each other to make up our climate. So not only do we need models of the atmosphere we need a model of the land surface. We need a model of the ice. We need a model of the ocean. Many of them start with physical equations. The ocean for instance is just another fluid, just like the atmosphere.
10:50	Except the atmosphere is a gas and the ocean is a liquid, but the laws that govern both are not that different from each other. We have since discovered that keeping our vegetation constant during the calculations might be a bad idea because as the climate changes the vegetation might change, as the vegetation might change, the climate might be influenced by that vegetation change and we need to take this into account. So these models have become very very complex and very very complicated.
11:18	How good are they … finally? On the left hand side you see a diagram which shows lots and lots of little coloured curves. Each of those curves is one climate model on earth. There are about 35 in this picture. They are run all over the world by different countries, so there are 3 in America, 1 in china, 2 in japan and so on and so forth and 1 in Australia. They are all put together and they all try to simulate the climate of the 21st century … just the last century.

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11:47	And the black curve is the observed temperature and the little wiggly curves are one climate model each trying to represent the temperature and the red thick line is the average of all the models. And what you can see is that to first order the climate models do quite a good job of representing the temperature increase in particular in the 1980's to the 2000's. They then diverge a little bit towards the end of the period. That's well understood.
12:13	But you can also see there is quite a bit of uncertainty in this. Every model is slightly different, right, so together they follow the path really well and we can make some good predictions from them, but there is uncertainty in our ability to estimate how the climate behaves. On the right hand side we see rainfall. Now we see errors in rainfall and they are a few %. Where it doesn't rain much it can go up to 100% but we don't really care much because it doesn't rain much.
12:42	This looks like a lot, but remember how we started. We started by writing down the laws of physics, Approximating them and putting them into a computer and it's actually quite remarkable that we are reproduce to first order how rain fall is distributed on the earth. This is an average picture. We can even reproduce reasonably well how this changes obviously from season to season, but also from decade to decade in the climate system.
13:10	All right. So what about the future then? If we are confident we can make some predictions. What do these uncertainties imply? What do we know? What don't we know from these climate models about the future? The top left graph is perhaps the most important one. That's the evolution of the global mean temperature and the blue line is the low emission scenario that I pointed out earlier where we are really doing something really quickly.
13:32	The red one is the business as usual. The thick line is the average of all the models and the shading indicates the range of the answers we get from the various models. Several things to note. You've all heard about climate model uncertainty and maybe we can't do anything about climate change because we don't know what's going to happen. Well the first thing you see from this graph … the biggest uncertainty, isn't coming from the climate models.
13:57	It's actually coming from what humans will do, because the difference between the red and the blue is much larger than the spread with in each of them. So they diverge by about (the year) 2050, and we will know which emission scenario we will be following independent of how good or bad our models are at predicting global mean temperatures. Then there is model uncertainty, which we already discussed, which comes from these approximations that we have to make along the way.
14:25	The bottom graph, just underneath the temperature graph shows the sea ice in the Arctic in September, at the end of the summer, in the Arctic and we see that in the business as usual scenario, pretty much from 2060 onwards the Arctic will be ice free in Summer. There will be no more ice. Whereas if we follow the more ambitious reduction scenario we get the blue lines and we will always have Summer ice in the Arctic in Summer.
14:52	Now you may not care if there is ice in the Arctic in Summer and you may even look forward to a cruise but other beings that live in the Arctic are quite worried. On the right you see maps of temperature change on the top and precipitation change at the bottom. I put this in because I wanted you to get a sense of the uncertainty. So where there is a little stipple on these maps, again the left is low emission and the right is high emission, top is temperature and bottom is precipitation.
15:20	And really, everywhere where there is a little dot on these maps we have confidence in the answer because all the models say the same thing. They have the same sign and the change is much larger than the natural variability that we encounter by just observing the current climate. So for temperature when you hear predictions about climate temperature you can be pretty confident that we are doing a very good job on those.

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15:45	The bottom one is precipitation and there isn't that many dots and instead you see this 'hatching' (#) all over the map, especially for the low emission scenario but over Australia even for the high emission scenario most of this is hatched. And what that means is there is large uncertainty. The models really don't agree very well, and even where they agree the change is small compared to the variability that we experience from year to year in the current climate.
16:10	So we are really not very confident about making predictions about rain fall, and again this comes about because of the uncertainty we introduce by having to represent things that are smaller than grid boxes in different ways by using these 'little models within the models'. Rain fall is almost always a small scale process that almost always falls from small scale clouds in the atmosphere. Alright, bringing us back to where we started and also to where I started my career, how good's the scientific revolution then been for us?
16:44	Well if you don't really care about what happens in a hundred years and you do care what happens 3 or 5 days from now every day, and don't pretend you don't … most people are obsessed by weather forecasts, here's an evolution of the quality of the weather forecasts from the place where I started my career – the European Centre for Medium Range Weather Forecasts. Deemed to be the number one in global weather forecasting on earth using numerical models.
17:10	The top lines, the thick lines are always the Northern Hemisphere. The bottom lines are the Southern Hemisphere. Blue is day 3-4 forecasts and the measure as shown on the (vertical) axis is a measure of quality, so as it goes up the quality has gone up. Red is 5 day forecasts. Green is 7 days forecasts. Yellow are 10 day forecasts. And what is amazing about this curve is the one thing that you can read from this is that, we can make a 5 day forecast that is as good as a 3 day forecast was 20 years ago.
17:41 18:18	So the gain in the science of making weather predictions is about one day per decade. Alright? So we are getting better and better so to conclude I could have told you that today would be a miserable day about 5 days ago when I could have only told you 20 years ago, 3 days ago. That's actually a big gain if you think about not just you and your umbrella, but industry, agriculture, places that have to plan based on the weather and based on the climate as well. So thank you very much.