At the Annual Conference of the Club of Rome,
Ottawa: 20th September 2013

Sensitivity, Non-Linearity & Self-Amplification in the Global Climate System

By David Wasdell

(Director of the Apollo-Gaia Project)

View the presentation recording at:
https://onsync.digitalsamba.com/play/wasdell/14146-cor-dw-keynote.

An Introduction to the Programme for the Day.

Ted Manning: Good morning ladies and gentlemen. We are going to start now. We have a sterling speaker coming to us long distance. We are experimenting with a new technology which we believe will certainly lighten the ecological footprint of this conference, and you will excuse us if we do a little bit of manipulation in front of you. This is the first time this particular technology has been used for an international conference. I would like everyone please to be seated and we will spend a couple of seconds introducing you to the day. The focus of this conference is on the Governance of the Commons and the reason that we have focused in this area is that the whole planet depends on common resources. Our institutions, as we learned yesterday, are not robust. At every scale we have challenges that need to be met and we are trying to bring together people to address these issues, talk to us about the success stories, what works and what doesn't, in order that the planetary resources, those common resources on which we all depend, continue to provide the functions on which our livelihoods and those of everyone else depend. ….. I would like to just turn this over to Robert Hoffman. He is going to come and introduce our speaker who will come to us long distance and hopefully successfully.

An Introduction to the Speaker.

Robert Hoffman: It is my pleasure to introduce David Wasdell, there is a full biographical package here: http://www.meridian.org.uk/About/Director/Pro-About_the_Director1.htm. I first met David in 2005. We met by accident when we were on the first day of the conference [Club of Rome Annual Conference in Norfolk, Virginia]. We were both boarding the bus to go from the hotel to the conference facility. I happened to sit by him and we became engrossed in conversation and it turned out that we both shared a systems view of the world. I didn't know at the time that David had been invited to make a keynote presentation at that conference on the subject of climate change. David's background wasn't in climate science. His background was in social systems, and social feedbacks. But David had been drawn into the area of climate change and had begun to see that the nature of climate change was a challenge that might involve feedback. Along the way he had begun to apply systems thinking into the climate system. So he introduced a very insightful paper in which he outlined a model of the climate system with all its feedbacks. It became clear from that that climate science was persistently under-estimating the impact and speed of climate change because it was unable to handle a number of important feedbacks that were probably part of the system. His message was not particularly well received from the perspective of the modelling profession. But it became clear that his analysis was fully justified. We are still dealing to this day with large systems models (climate models) that are persistently under-estimating the speed and magnitude of climate change. So I think David is an ideal person to address us, a) because of his background in institutional change and b) because of his work on climate systems.

We are experimenting today with the use of interactive technology. David will be speaking to us from Meridian House in London. With the hope that these kind of facilities can be used in climate talks and in more frequent meetings without the need to travel. I think that is all I have to say by way of introduction so over to you David.

Presentation by David Wasdell.

Robert thank you very much indeed and hello Ottawa, this is London calling. This is the opening comment isn't it? Robert thank you very much for that introduction. I think it must be 8 years almost to the day since we met at Norfolk Virginia and I remember it well.

Introduction to the Technology.

I was fascinated to pick up one of these books, ["Bankrupting Nature: denying our planetary boundaries", a report to the Club of Rome by Anders Wijkman and Johan Rockstrom] you probably have come across it! I think one of you, knows the content very well indeed. Anders, as you were looking at the possible solutions to some of the crises that we face, towards the end of the book, I remember you noted "at present 3 different categories of transformative solutions are emerging" and the first one you mentioned was "new technologies that deliver the services we need with less demand for energy and resources, such as replacing physical meetings with video conferencing." Well, I salute the Club of Rome for making the future come into the present. We will see if the technology is adequate for the task at the moment. It is getting better year by year. This is the first time that I have ever done an inter-continental presentation in this form. It is the first time the Club of Rome has been involved in this way. The moderators who have put the technology together at your end have had a learning curve that is steeper than vertical. But I think we have got there just about and if there are any problems, we can solve them as we go. We have got a moderator at this end, 2 moderators there, we have a telephone

link going on full time and hopefully we can ride the surf. I thought just to open up, you will see I am changing the format and going into a presentation mode.

This picture of the earth was taken a little earlier because you were still in darkness at that time, and so was I. So I thought I would say, well I know where you are – you are in Ottawa and where on earth is David. Well the answer is I am somewhere up over the top rim here just in the darkness and the technology enables us to communicate across the continents.

This is the great park of Greenwich, with the great Meridian line coming out through here. This is Wren's palace, and across the river you will see rising the towers of Canary Wharf, the

great development done by the Canadian developers the Reichmann brothers and they of course built the Battery Park at Manhattan Island in New York.

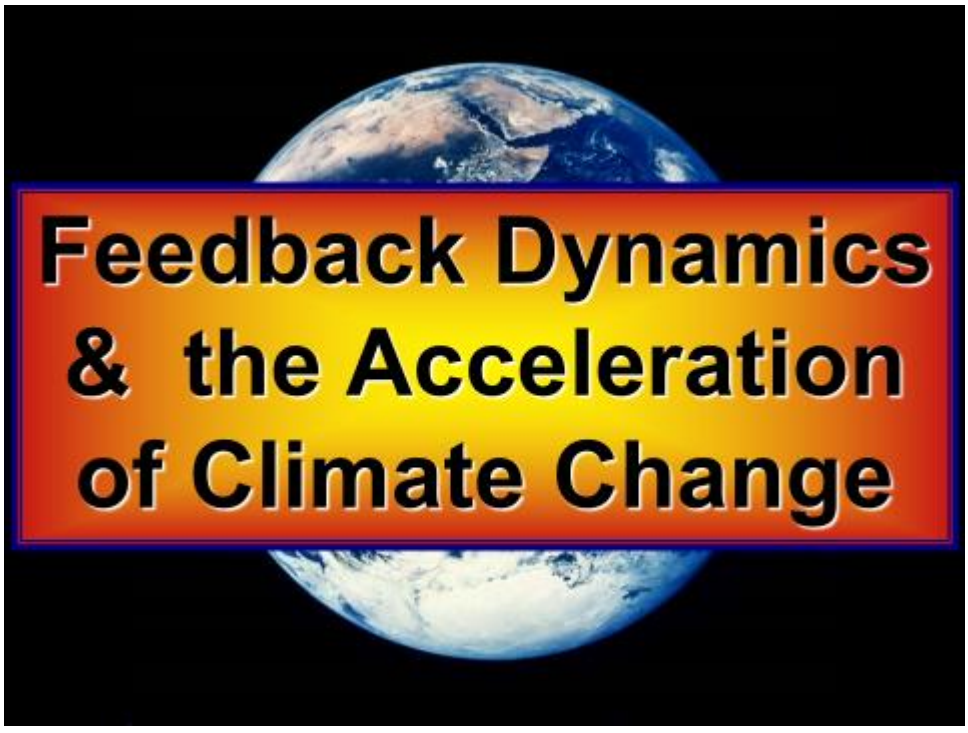
Now if we just go up into that domain and look across it from west to east, there you see this great line of symmetry from the initial circus here on the riverbank, through the Canary Wharf tower, out through the docks to the Millennium Dome. Running south to north is another line of symmetry up through the roads that you don't see, across a bridge that was not yet built when this was taken, up this spine road, and across here right to the front door of Meridian House which is where we live.

If you look very carefully through that window in the top right corner you will see me waving to you across the continents.

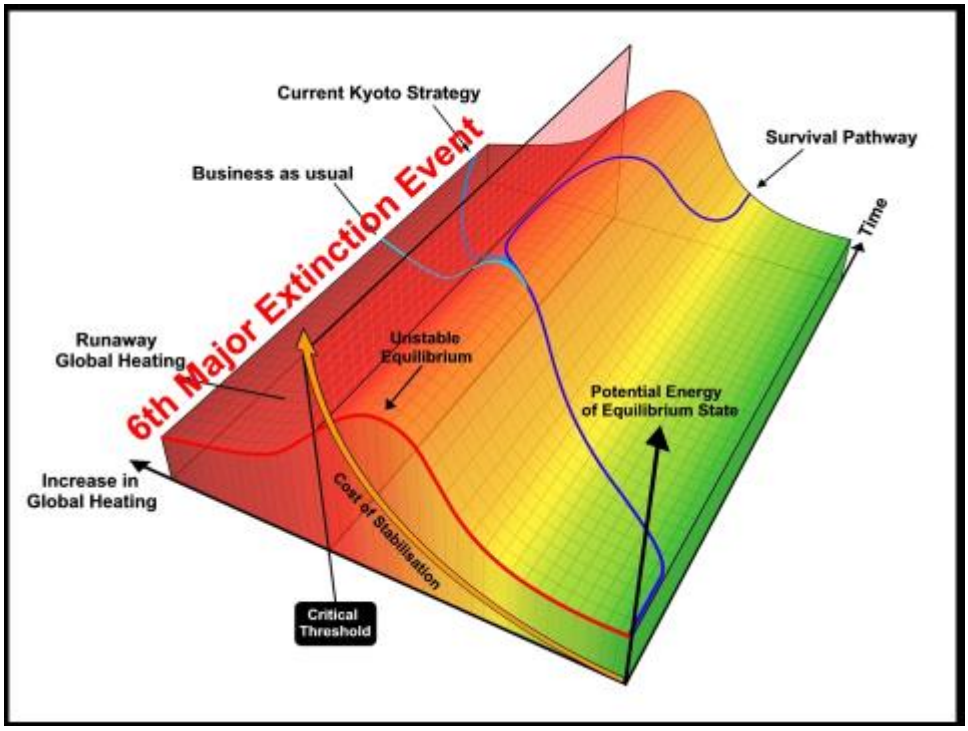
So that places me in my right place and you in yours and we are just connected through modern technology that enables us to share time and space in an extraordinary way. I think Robert is right that the technology does open up the capacity for the Club of Rome to become a learning system, connected world-wide in real time and to move expert material from place to place without having to pay airfares or hotel fares and bankrupt local chapters and so on.

Background to the Apollo-Gaia Project.

Anyway from my study here in Meridian House I look back, Robert, on the 8 years since we met. You are absolutely right that the fundamental points we were looking at at the time were the feedback processes in climate change, feedback processes which accelerate and amplify the effects of the human system.



Now just before I was invited to Norfolk, Virginia, we had put together a paper on feedback processes and had come up with an understanding that was a bit like this.



It is a topology of climate change that ranges from the safety of the Holocene, undisturbed by the industrial revolution, the emergence of carbon dioxide emissions that push us upwards and over a tipping point towards catastrophic behaviour, an extinction event and the overall threat of runaway global heating. Where were we on that? Well we were somewhere up towards the summit and in danger of moving across it into the downward slope of danger. The task was to stay this side of the tipping point and emerge with a solution that would give good quality survival for the future of humanity. And at the end of my presentation in Norfolk, I made these comments:

"That we will need to convene with the utmost urgency a global analysis and modelling capacity to test the conceptual feedback model, to quantify the complex feedback system, and to determine the time frame of its behaviour" and to do that somewhat better than was being done in the computer models of the day. Then I went on like this:

"We need also" – and this is to do with institutional behaviours isn't it **– "to develop and operationalize an emergency strategy to move our global society towards a negative carbon economy"** – (that is a draw-down economy) – **"within the shortest possible timescale. And also to develop the most effective institutional instruments to manage the transition."** And as you have been speaking in the last day, we realise that the institutional instruments that we have in place are not fit for the task of solving the problems of the global problematique.

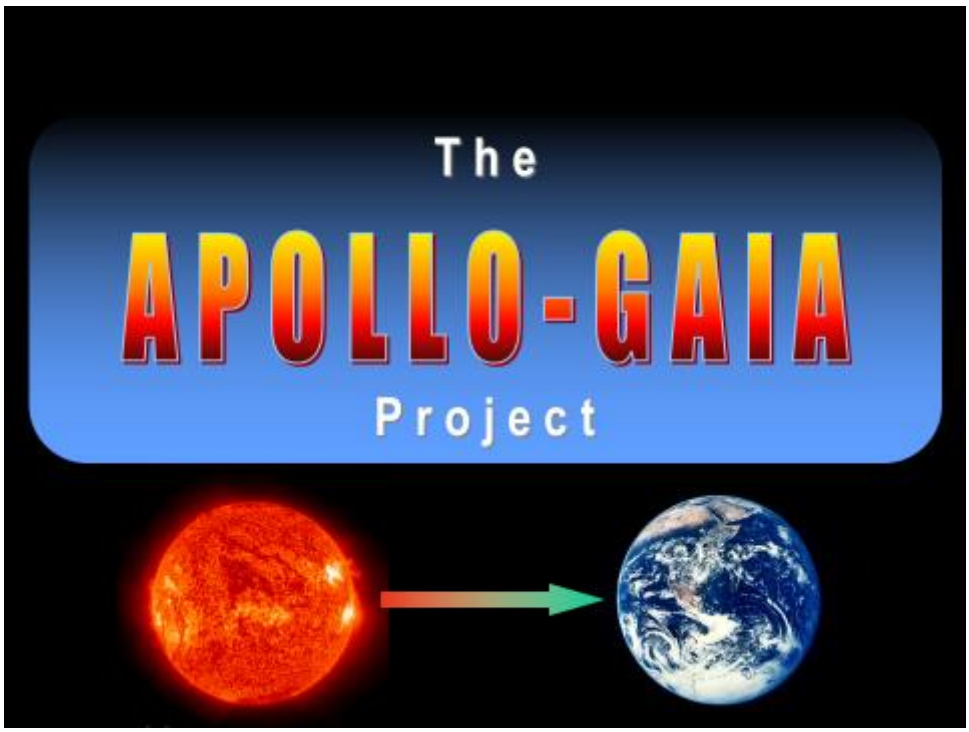
Well that was in September. I worked closely with John Schellnhuber from the climate research institute in Potsdam and we were looking at tipping points and complexity. I did a seminar with him at the Royal Academy in Brussels about 9 months later after which I was facilitator and rapporteur for one of the European Commission conferences on complexity science. John was one of the participants and it was there that he made this point:

He said: **"The possibility of a tipping point in the Earth system as a whole, which prevents the recovery of stable equilibrium and leads to a process of runaway climate change, is now the critical research agenda requiring the concentration of global resources in a 'Manhattan project' style of engagement"**. And then he concluded:

"All other work on impact assessment, mitigation and adaptation depends on the outcome of this over-arching issue".

He also said in private and several times later on in public, that he saw this agenda as "absolutely scary". No institution in the world was prepared to put funds into its research. Even Potsdam itself was not able to do that. The fear was that any such institution would be seen as scary, fear-mongering and alarmist. And I am not surprised I need a drink of water at this point!

Anyway, we were left with the agenda. I went and briefed John's team in Potsdam, and then had some time later on with Jim Lovelock here in the UK. We rejected the "Manhattan" name for the project and eventually came up with the name of the "Apollo-Gaia Project".



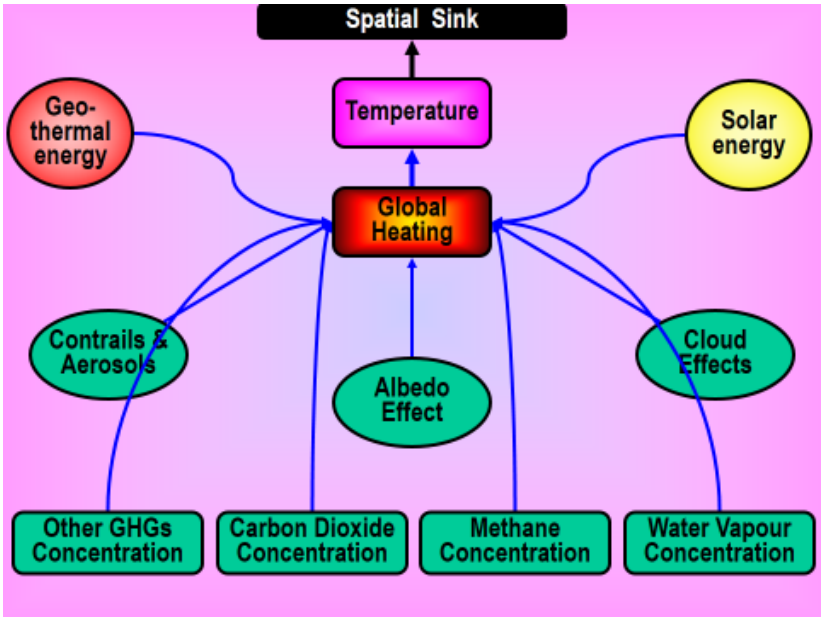
Apollo and Gaia – the sun god and earth goddess are joined with a hyphen. In the visual the energy of the sun comes to enliven the earth. The influence we have made has changed the constitution of that little layer of atmosphere, so thin, that shields us from outer space. As we have changed that layer, so the incoming energy has become a threat to life on earth.

So the Apollo-Gaia project had everything to do with the relationship between solar energy and life on earth and the attempt to restore stable behaviour in the Gaian climate system.

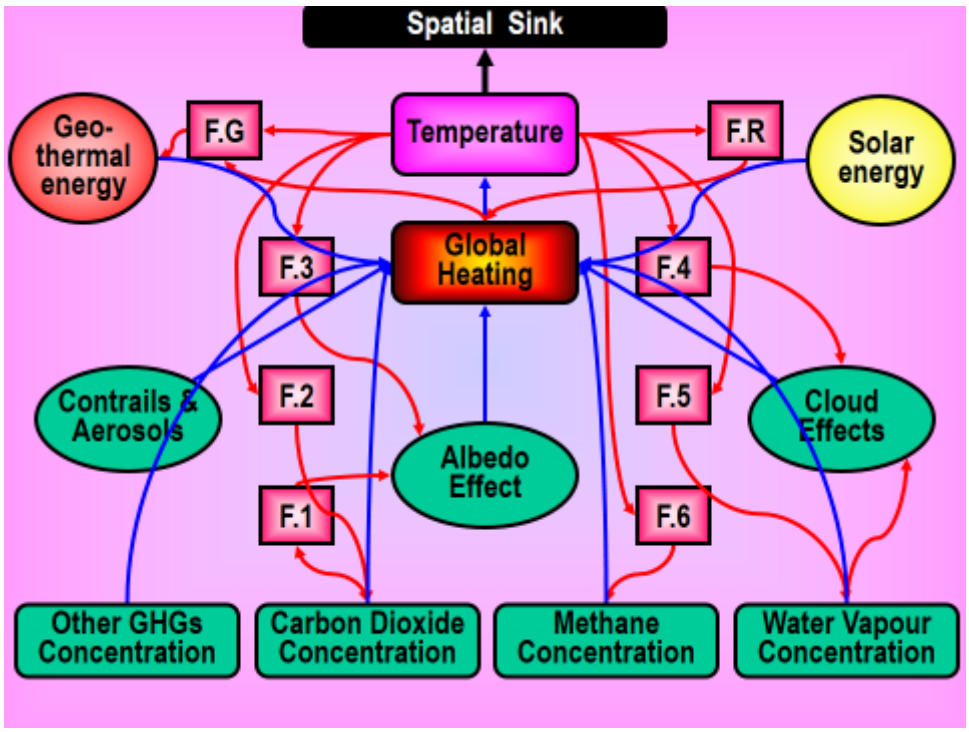
And it is my privilege and a joy – I was originally asked to produce a report for the Club of Rome – but this is the best we can do, so today we have a "Presentation to the club of Rome", rather than a book. Maybe the book follows, I don't know. And I have been asked to provide a scene setting keynote for the rest of the Club's conference here in Ottawa.

Developing the conceptual model of Feedback Dynamics.

Without more ado, the first thing we had to look for was the dynamics of the complex climate system and to produce some kind of understanding of what made it work.

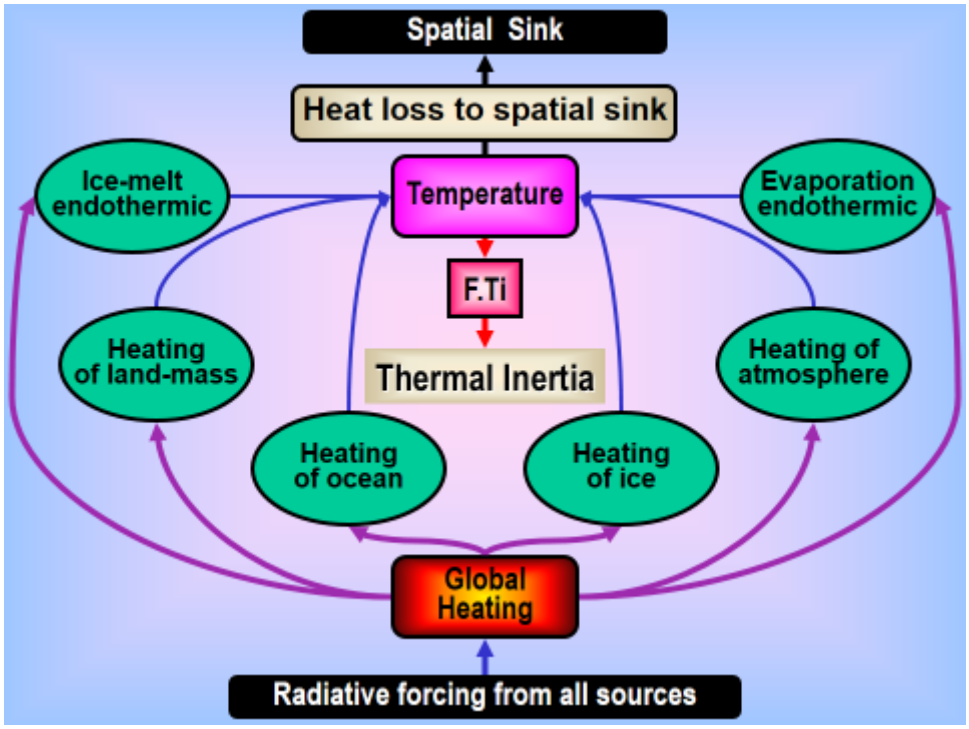


We identified the different drivers, from solar energy and energy from the centre of the earth. We looked at the greenhouse gases of water vapour, methane, carbon dioxide and others. We looked at the effect of particulates in the atmosphere and also aircraft trails, reflection from earth's surfaces and the cloud effects – which are so difficult to model. All of those drive global heating, the energy exchange between earth and space. As the heating affects the inertia of the system, so the temperature goes up, and then we radiate more energy to space itself. It was a very simple, inclusive model.



Then we began to identify the feedback processes. Many, many of them, and we clustered them. We put them into little groups that were driven by particular drivers and had effects on particular targets. So, some were driven by temperature, others were actually driven by carbon dioxide concentration itself. And as the feedback clusters operate on the drivers, so the drivers operate on the heating, and the heating drives the temperature, and the temperature goes up, and we radiate more energy back into space. But as the temperature goes up it activates more feedbacks, which operate on the drivers, which take the heating up, which puts the temperature up, which increases the feedback system. So we have this incredible feedback process on feedback process, in which each feedback mechanism affects the behaviour of all the others. Some of them are very complex and strong and fast, others simple, slow and weak, a hugely differentiated complex system.

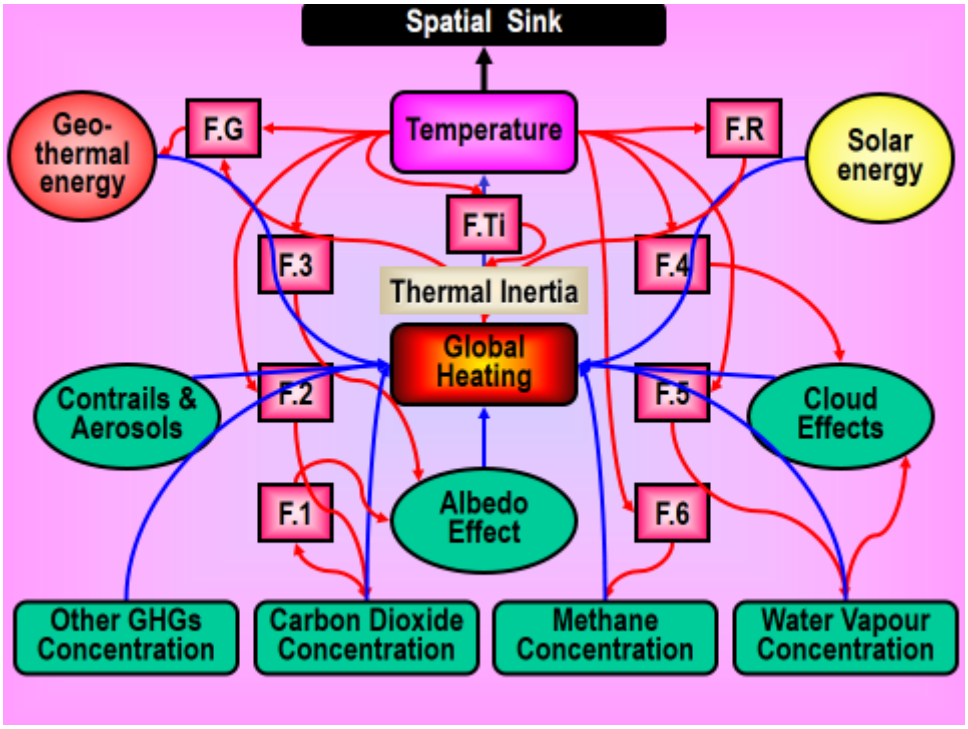
Then of course there is the gap between heating and temperature, and that is a huge one. The earth is so inert, it is a massive system to heat and we explored the inertia of the system like this. Here is that gap expanded.



The heating energy goes into the oceans, into the landmass, into the atmosphere, it also heats ice of course. As the ice reaches melting point, a lot of energy goes into the phase change from solid to liquid and from liquid to gas, evaporation and melting. So all of those processes are in that gap between the heating and the temperature change.

Then we found, and this is quite a new one, that there were some feedback processes between temperature and inertia. So the hotter it gets, the less inert the system became, and the faster it heated. It was getting more and more difficult to model.

We put Thermal Inertia back into the original system like this and there we have a conceptual model inclusive of all feedbacks, all their interactions, the inertia of the system, the drivers and the outcomes.



Our aim was to produce a systems dynamics model using some of the resources from WhatIf technologies and from Robert Hoffman's group. We brought together professors from Europe and other people involved in systems analysis to see if we could put the equations together and develop a dynamic model that would have a much better outcome than the current range of computer modelling.

It was not to be. What we found was, we could get the basic equations going all right, but when we started to identify by how much does each specific feedback contribute to the system - putting the quantification in - there was so much uncertainty about each feedback mechanism, let alone their interactions, let alone the inertia of the earth, that any outcome of this process would be really so uncertain as to be unusable as a strategic basis for decision making.

I remember the ending of that 4 years of work and that sense which Robert described to me as 'tragic' or 'a tragedy'. Looking back, it was both a tragedy and a triumph, I think. It was a breakthrough. We said basically there is no way that this approach is going to yield the answers to the fundamental questions about the amplification of human intervention in the climate system that we needed in order to make decisions to answer the problems posed by the global problematique.

Now, one of the things I am finding - and maybe you are too - is that in a presentation that comes across in this medium, it is difficult to maintain that personal contact. I am talking to my screen here, and I can see a few faces in the audience, but there isn't that personal feedback that I have when working as a presenter in the space. Also I think for yourselves, you will find the downside of the technology takes out some of that sense of personal rapport. On the other hand it does have certain advantages as well and we want to explore those as we go on.

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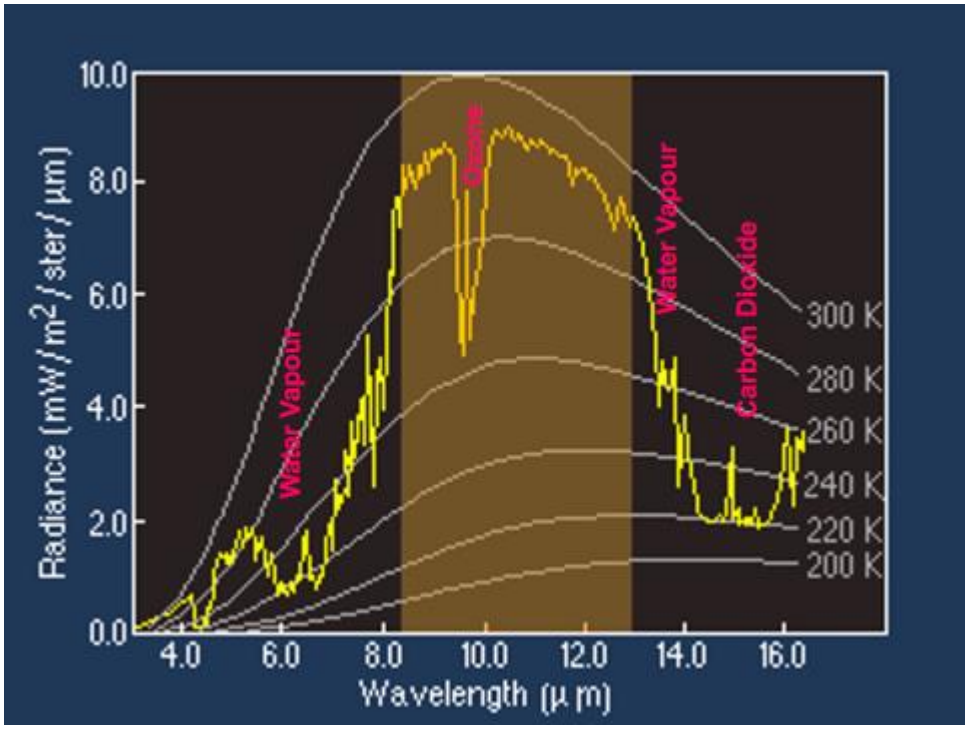
A new approach to Climate Sensitivity.

So we started over anew. We said we needed to look at the question of climate sensitivity – by how much does the system of the earth amplify what we were doing to it in terms of the human disturbance of the climate.

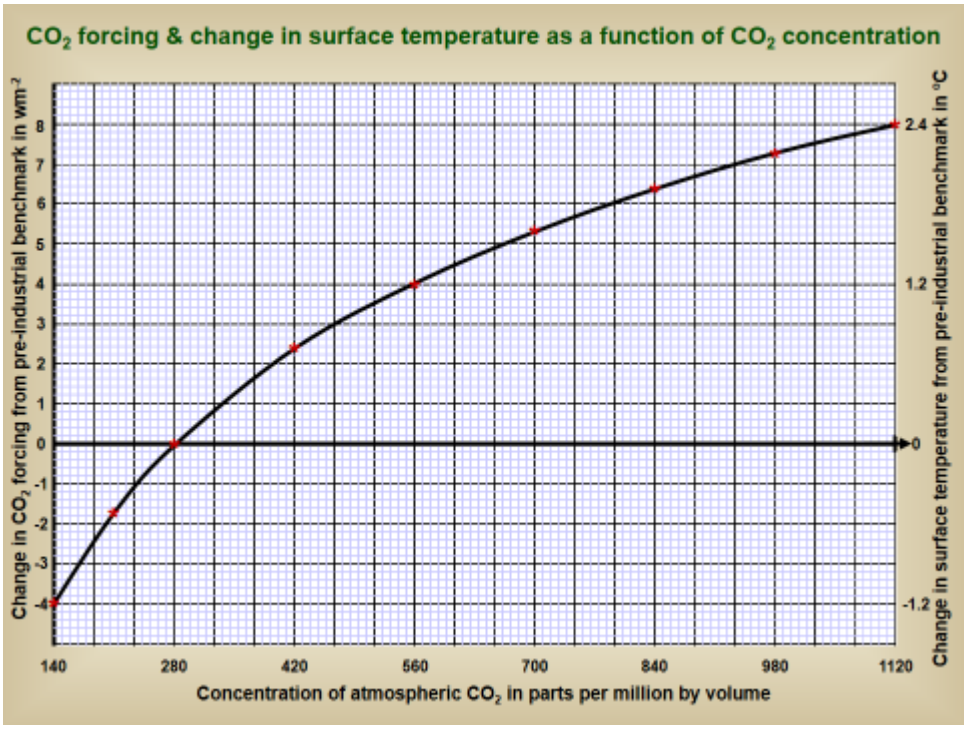
We started with very basic things. I think this is one of the most difficult slides to explain and I will do my best.



On the right hand side we have temperatures of theoretical planets at different surface temperatures which are radiating infra-red energy at different wave-lengths of the spectrum. On the vertical axis is the amount of energy that they are putting out into space. Our own planet without any greenhouse effect has a temperature of about 255 degrees, so it would be radiating just under the white line for the 260K planet. But of course we do have greenhouse gases in the atmosphere. We have carbon dioxide and water vapour and ozone. Water vapour absorbs at two different wavelengths, 6.0 as well as 14.0. And so the outgoing radiation is inhibited by the greenhouse gases. That means the temperature of the rest of the planet has to go up to push the energy out through the windows that are open, in order to balance the energy budget between incoming and outgoing energy. Straightforward once we understand it.

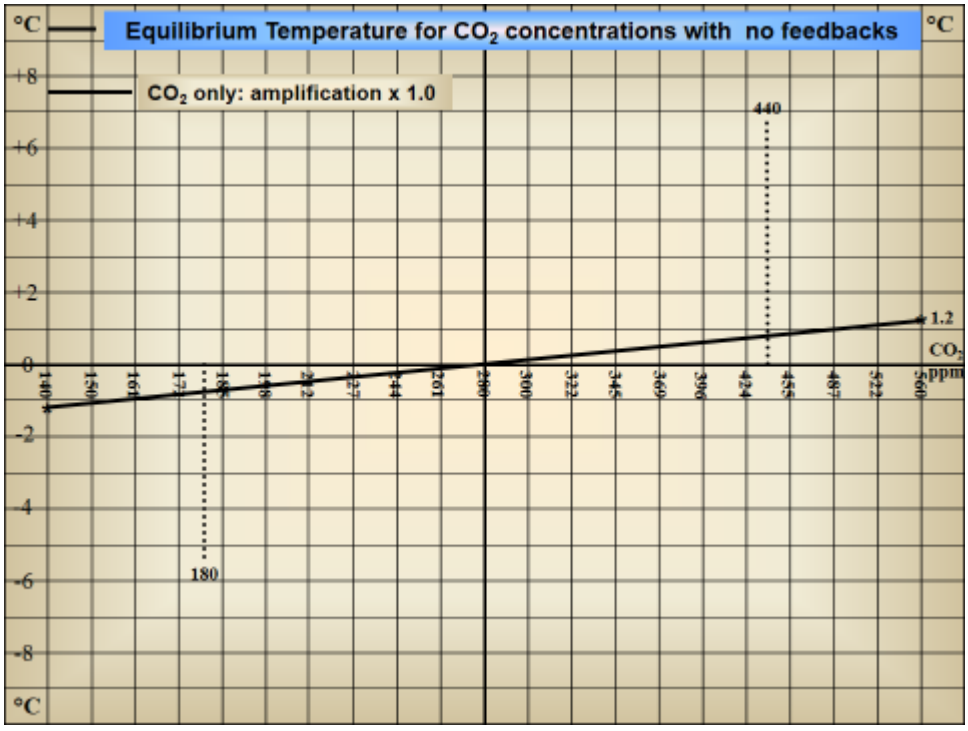
Now then, if we increase carbon dioxide concentrations we push down on this area of the yellow curve. That means the temperature has to go up in order to push the energy out more through the windows that are open. The more we push down on this area of the curve, actually the more we saturate that particular area of the waveband and the less effective carbon dioxide becomes as a greenhouse gas.

So it is an odd relationship that has this kind of shape. For each doubling of the concentration of carbon dioxide, we inhibit about 4 watts per square metre of energy going back out into space. So from 140 to 280 parts per million we inhibited about 4 watts per square metre. For the next doubling – 280 to 560 – we inhibit another 4 watts per square metre.



For the next doubling – 560 to 1120 – we inhibit another 4 watts of radiation. And the temperature has to go up about 1.2 degrees to compensate for that blocking of infra-red radiation. So the temperature increase for the first doubling up 1.2, for the next doubling up another 1.2, for the next doubling up another 1.2, and if carbon dioxide was on its own with no feedbacks, that is the kind of pattern you would have.

Now the first breakthrough was creating a visual presentation of this which was more simple to work with than these logarithmic curves. Mathematicians will appreciate them, the rest of us don't.



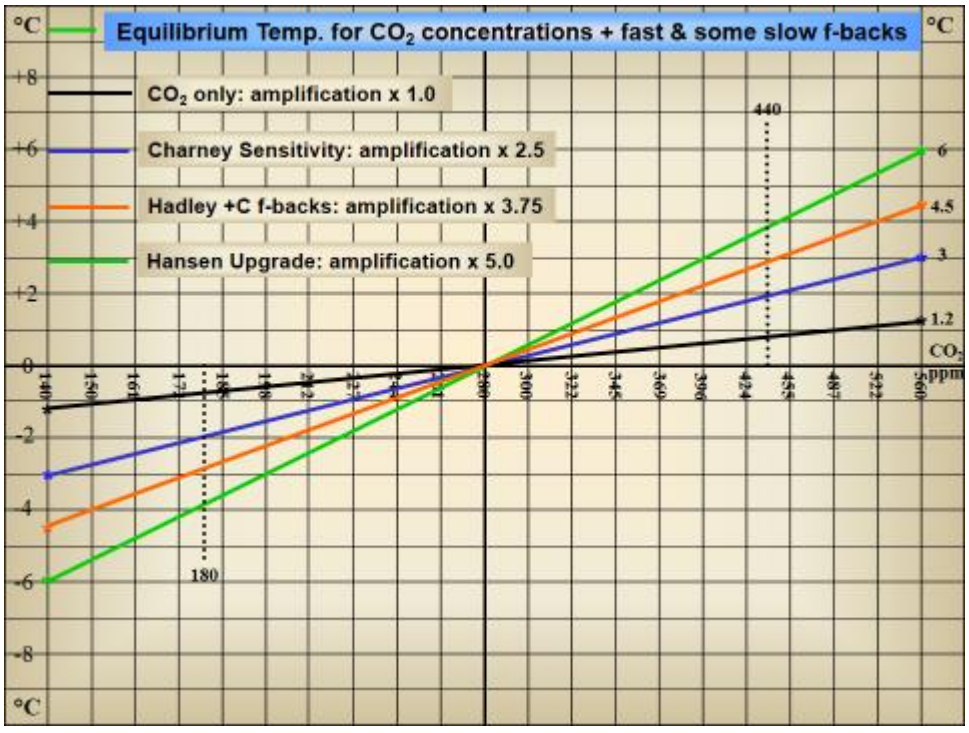
So what we did was we created a scale in which each doubling had the same distance along the horizontal axis, which looked a bit like this and then we put the effect of carbon dioxide onto that. Straight lines are easier to handle. For the mathematicians, it is a semi-logarithmic scale to base 2, but we don't need to worry ourselves about that too much.

So there we have about 1.2 degrees between 140 parts per million and 280. For the next doubling - up to 560 - another 1.2 degrees. Then we could have another doubling beyond that which takes it on. I put two little dotted lines in here. The first 180 parts per million is where it was at the bottom of the last ice-age, and 440 parts per million, which is where the scientists (and politicians particularly) thought it would be safe if we didn't put the concentrations beyond that.

One of the first things we noticed was that the strength of the forcing effect of the carbon dioxide between 180 and the pre-industrial benchmark was almost exactly the same as the forcing effect of carbon dioxide between the pre-industrial benchmark and the 440 parts. So you would expect the same change in the system between the last ice-age and the pre-industrial as between the pre-industrial and the 440 'safety margin'. That was not what the computer systems were showing us.

So next we are going to look at **the relationship between carbon dioxide forcing and climate sensitivity by examining feedback processes.**

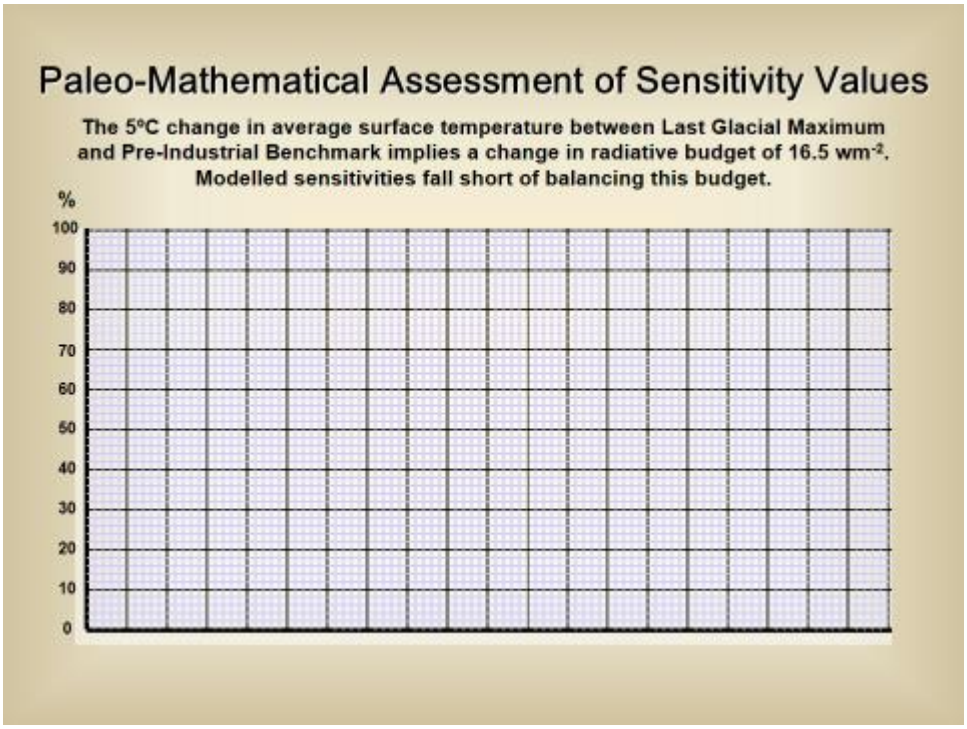
Here is the first set. 1979 saw the work of Jule Charney and the first group of very primitive climate models looking at very fast feedbacks: water vapour, some clouds, reflection from surface floating ice. They said they thought that the feedbacks would amplify the effects of CO_2 by about two and a half times and give us an increase in temperature at equilibrium of about 3 degrees. Fascinatingly our current computer ensemble does handle fast feedbacks and almost exclusively those feedbacks, and comes up with roughly the same expected temperature rise for a doubling of carbon dioxide.



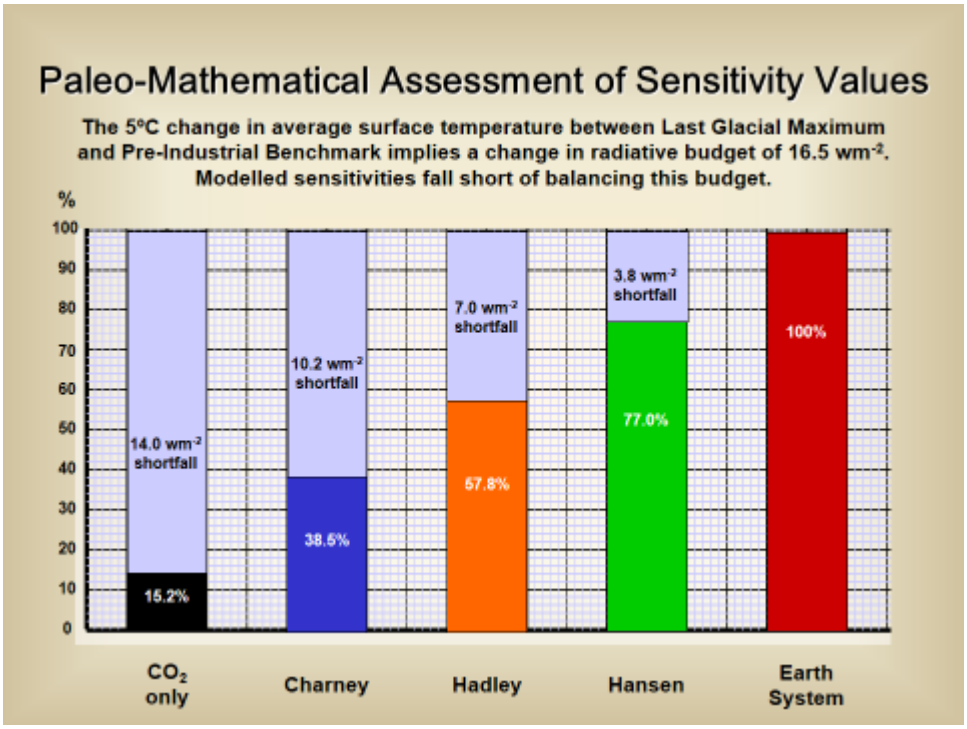
They explicitly excluded some of the vegetation feedbacks, the carbon cycle feedbacks. When those are added in - as they are in this slide from Hadley (our own meteorological office research station in the UK) - we see that the carbon cycle feedbacks increase the amplification to about 3¾ and put the expected temperature rise up about 4½ degrees. Then Jim Hansen said we are not dealing with the long term ice feedbacks from land-based ice mass and when you bring the shift in reflectivity from that over long time periods, we have a different kettle of fish. We would expect an amplification of the carbon dioxide signal strength by a factor of about 5, and a probable long-term change in temperature of around 6 degrees for a doubling of CO_2.

Now what you see is that the more sophisticated our understanding of feedbacks, the higher the sensitivity goes and the greater the amplification factor. So I suppose the question is, "is there some figure towards which our computer facilities are slowly moving, namely the overall Earth System Sensitivity, or the way the whole system does really behave in reality?"

Well we can assess the models so far, a little bit like this:

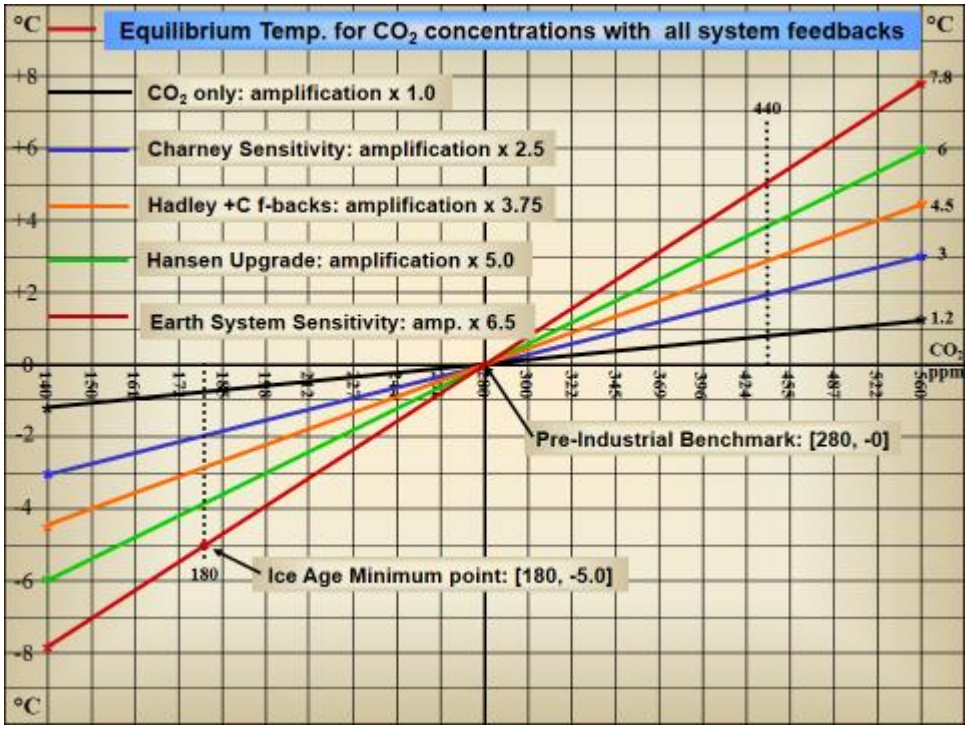


The grid is complex, but you will get the gist of it. I know from the back of the hall and the size of the screens you probably can't see the figures but I will explain. On the left side we look from absolutely no use at all to 100% effectiveness in dealing with the balancing the radiative budget. Along the bottom I am going to put different modelled approaches. And moderators I am going to expand this quite significantly in the middle in order to get the wording, I hope that is on screen, if you move it down to the centre of the screen with the task bars. What we find is that between the last glacial maximum and the pre-industrial benchmark we had a change of about 5 degrees centigrade, and for each degree centigrade that the temperature has gone up it has compensated for about 3⅓ watts per square metre of increase in the greenhouse inhibition of infra-red radiation. So there has been a change in the radiative budget of about 16½ watts per square metre.

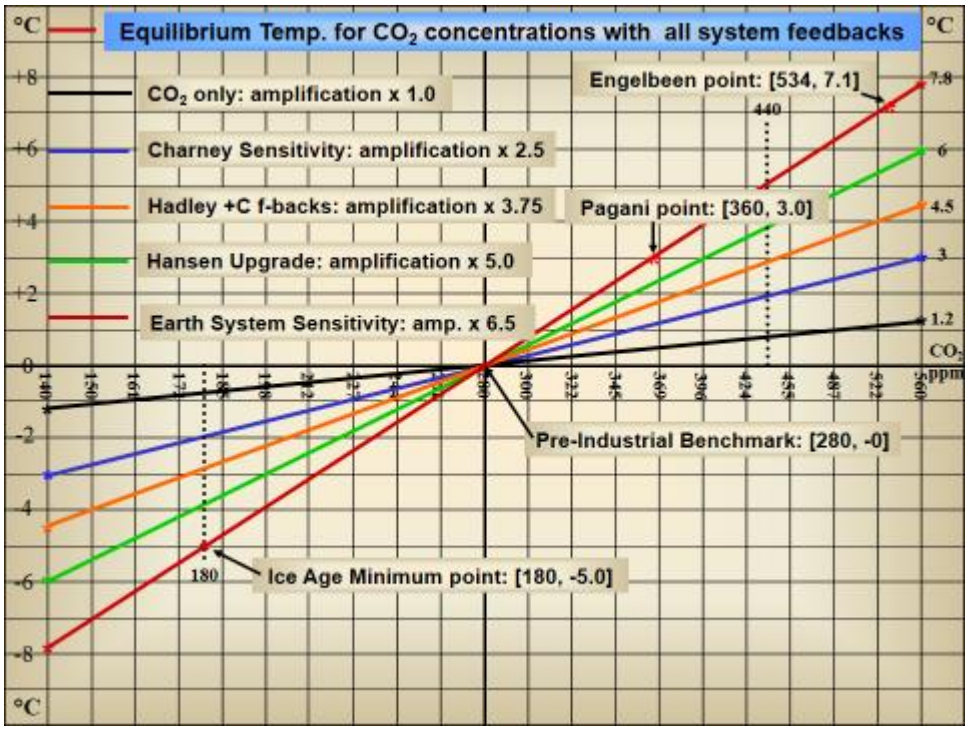


Now carbon dioxide on its own is only responsible for about 15% of that. The fast feedbacks bring us up to dealing with about 40% of that, if we added in the carbon and vegetation feedbacks we shifted towards 60%. Jim Hansen's work on land-based ice masses put it up to nearly 80%, but is still nearly 4 watts per square metre short of what was needed to balance the budget. So there is of course an Earth System Sensitivity – the way the whole planet responds including all feedbacks known and unknown, fast and slow, large and small and all their interactions, which determines exactly how the planet itself responds to such an intervention.

So what does Earth System Sensitivity look like? That was the question. Well we were able to go back to first principles on this and say do we have any benchmarks?



The answer was well yes we do. At the bottom of the last ice-age we had a concentration of around 180 parts per million and the temperature was about 5 degrees below the pre-industrial benchmark. Now straight lines that have two points on them can be drawn, so here we go and we can draw a line through those two points and that represents the first attempt at the full Earth System Sensitivity, which is showing us a temperature rise of around 7.8 degrees when the carbon dioxide is doubled and an amplification of around 6½ times the effect of CO_2 on its own. Well, could that be checked? Yes it could.

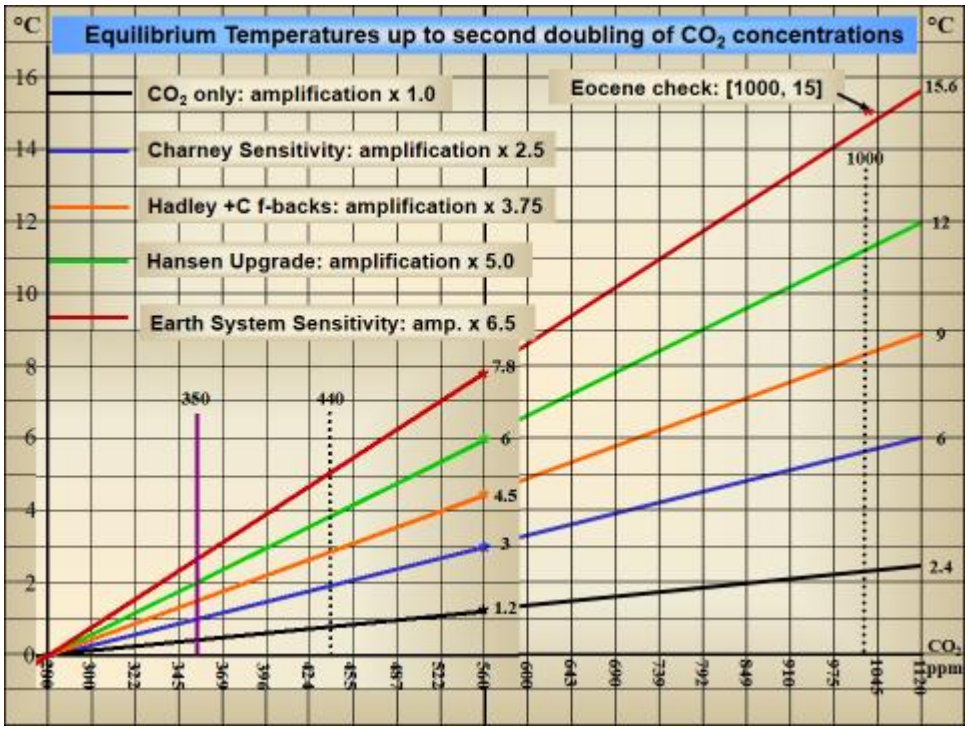


There was a regression analysis looking back at work in the last 4 or 5 ice ages and their intervening periods that gave us another point on the graph that was up there, pretty well on the red line. Then there was the work of Marc Pagani and his team looking back at sediment cores for 50 – 60 million years and that was showing up a sensitivity and an amplification factor that gave us about 8 degrees for a doubling or halving, so we put that on the line here. Then we were able to do a mathematical cross check.

And again I need to expand that and adjust its position on screen so that it can be seen, could you put that up centre screen, I think you have scroll bars, if I put it up a little bit more you will have scroll bars and you can adjust its position.

Mathematical Cross-Check: Radiative Damping Coefficient = 3.3wm^{-2}°C^{-1}
Radiative increase (Ice-age minimum to Pre-Industrial Benchmark) = 16.5wm^{-2}
CO_2 contribution = 2.54wm^{-2} Feedback contribution = 13.96wm^{-2}
Hence **Amplification Factor = 6.49** **Sensitivity = 7.79 °C**

Now what we said was for every degree rise in temperature an extra 3⅓ watts per square metre is emitted to space, so between the ice age minimum and the industrial benchmark we found 16½ watts per square metre of extra greenhouse gas effect had been brought into play. The carbon dioxide contributed about 64% of a doubling, about 2½ watts per square metre, so the feedback system did the rest – about 14 watts per square metre. If you divide 16½ by 2½, (that is the total change divided by the contribution of carbon dioxide) then we get the amplification factor for the Earth System of around 6.49 which is as near as dammit to 6.5. And when you multiply that by the effect of CO_2 on its own to give the sensitivity, we got 7.79 which was pretty well spot on 7.8. So the mathematics seem to say this is pretty well spot on.



There was one further benchmark we could put on. About 40-50 million years ago the concentration of CO_2 was about 1000 parts per million and the temperature was about 15 degrees above the pre-industrial, so we had a point up here which was also pretty well on the

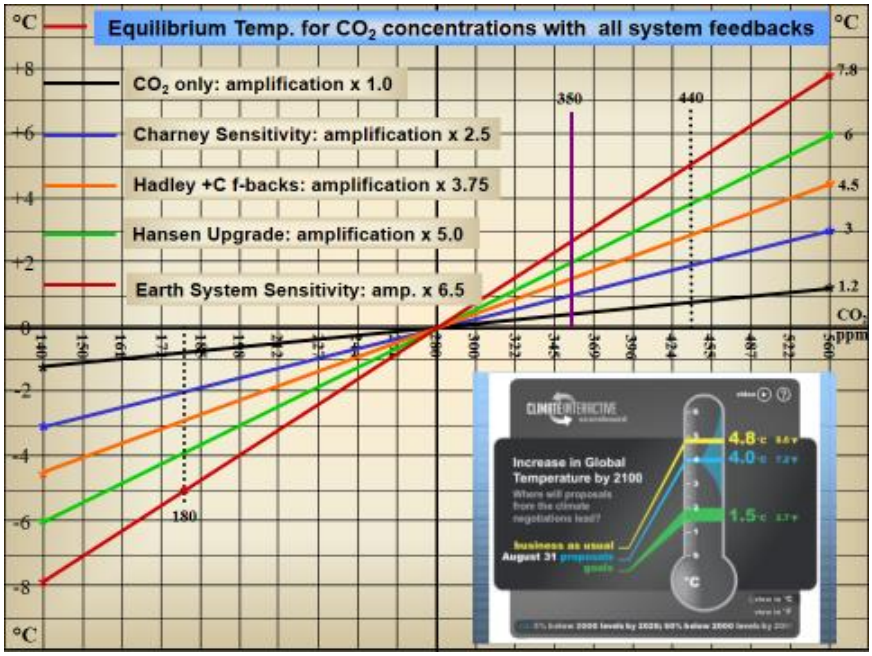
straight line. Now obviously sensitivity actually changes slightly according to what feedbacks are operative at that point in the system, but on average it seems to stay really quite stable around the gradient of that red line and the implications of that are awesome.

Implications of the value of the Earth System Sensitivity.

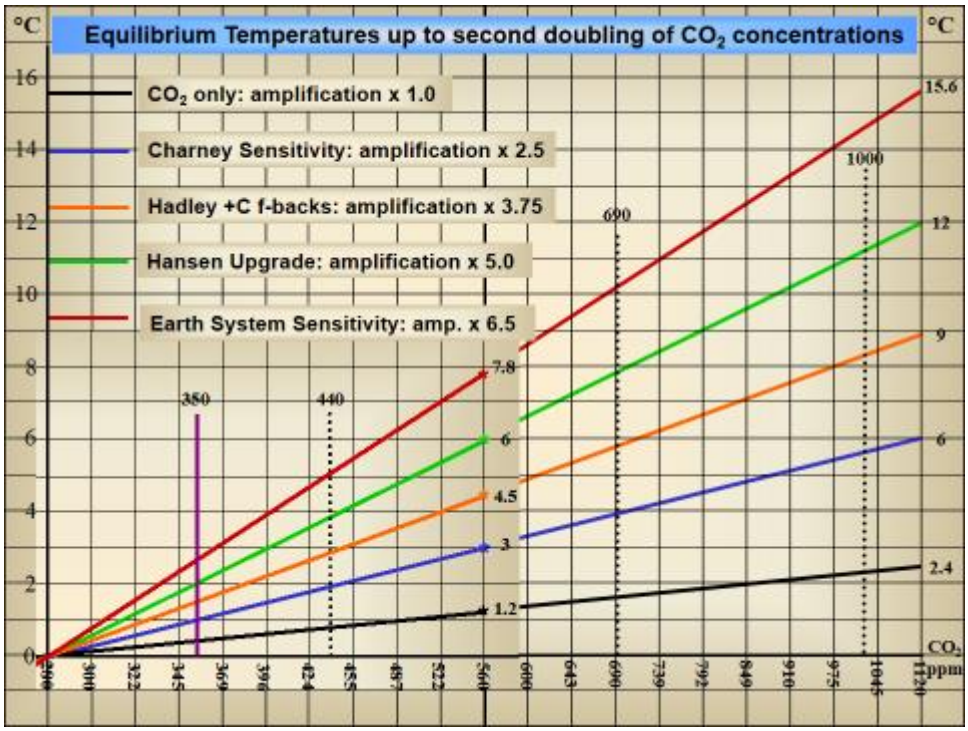
Firstly at 440 parts per million our computer ensemble – which is driving the international negotiations – is saying you would expect something like 2 degrees change. The Earth System Sensitivity indicates that change is going to be more like 5 degrees, not 2 – ouch. And then there is the question of how much temperature change is there in the pipeline. Well at the moment we are about 400 parts per million, about here, aren't we? And our computer ensemble says well we have gone up 0.8 already, there is about another 0.8 still to come from what we have done already. But the Earth System Sensitivity says ah ha, just a minute the eventual temperature is going to go up about 4 degrees as a result of what we have already done to the system. Then there is the issue of the budget approach. If it is safe to go up to 440 parts per million before we reach 2 degrees and if we are only at 400 now, then there is still plenty of room in the sky-fill site, we can go on emitting, we have got a ration that we can put out there and then we can fight like mad between the developing and the developed countries for the right to do that amount of emitting. That is one of the messes that we have got ourselves into in the climate negotiations.

But as soon as you recognise that the Earth System Sensitivity indicates that for a 2 degree change we passed the threshold that would get there when the concentration reached about 330 parts, then there is no budget. There is only a huge debt. The sky-fill site is already overflowing and needs to be emptied, not added to. So the whole basis of our climate negotiations is called in question and has to be reversed from distributing a budget to drawing down a debt. It is a little bit like the economy really isn't it.

Now that also feeds in to the simulator that was put together to assess the effects of the promises from the nations as to how much they were going to reduce their emissions by 2050 and so on.



The Cancun promises that started off in the Climate Accord from Copenhagen have actually been made the legislative basis for our current position. They reckoned that if all those promises were kept – which is highly unlikely – we would be seeing a temperature increase of around 4 degrees by the end of the century. Oh, but they said specifically they excluded all the carbon feedbacks and several other feedbacks so this was possibly a bit conservative but they didn't know how much. Well we can see that it was very conservative indeed!



Four degrees by the end of the century using only the fast feedbacks predictors: so we have to expand the graph to include the next doubling don't we. 4 degrees – here it is – intercepts with the fast feedback line about here by the end of the century. Now by the end of the century we will have achieved about 70% of the equilibrium temperature change and all the other lines are looking at equilibrium, so about another 30% brings us up to about here. So the promises indicate around the 1000 parts per million mark and a temperature change at the end of the century of about 10 degrees and an eventual equilibrium of more like 15 degrees. That is what we are committed to on the course of emissions reduction that is the current negotiating platform. It is catastrophic, absolutely catastrophic.

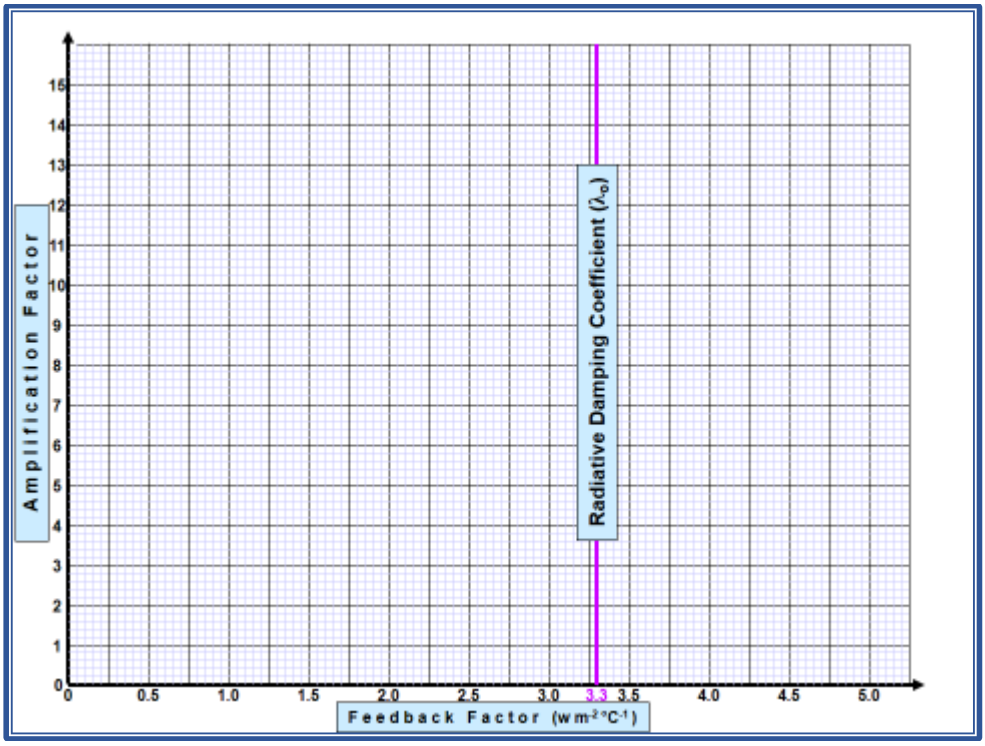
And so we see that the breakthrough in understanding Earth System Sensitivity really changes our understanding of the global problematique and puts it onto a completely different footing. Even the 350 dot org campaign to bring it back from our current concentration to something like 350 ppm, only reduces the outcome rise in temperature to about 2½ degrees. Since our current understanding is that 2 degrees is too much, we ought to come back in our eventual temperature aims to around 1½ or even 1 above the pre-industrial benchmark. We have got a job on our hands.

This sets new parameters, a new paradigm for the development of institutions, for the management of global commons and so on, which is the subject now of the conference that you have.

Non-linearity in the Global Climate System.

Now I have a few minutes left and I am going to use it now to take us on for the next stage. This material up to this point was presented at the 3rd Global Conference on Global Warming in Lisbon in 2011. By then we were already beginning to work on the next stage, and that is looking at instability in the climate system – non-linearity in the climate system. The fact that these lines are looking so stable and straight-lined but the reality isn't like that.

We are going to look now at **non-linear dependence of the amplification factor in its relationship to feedback strength**. Non-linearity in the climate system is a massively amplified threat to the understandings that we have had in the past. I make no apology for this section being more technical and if you are already asleep I apologise for that – I know it is early in the morning! This is one of the most important breakthroughs in the whole field of climate science.

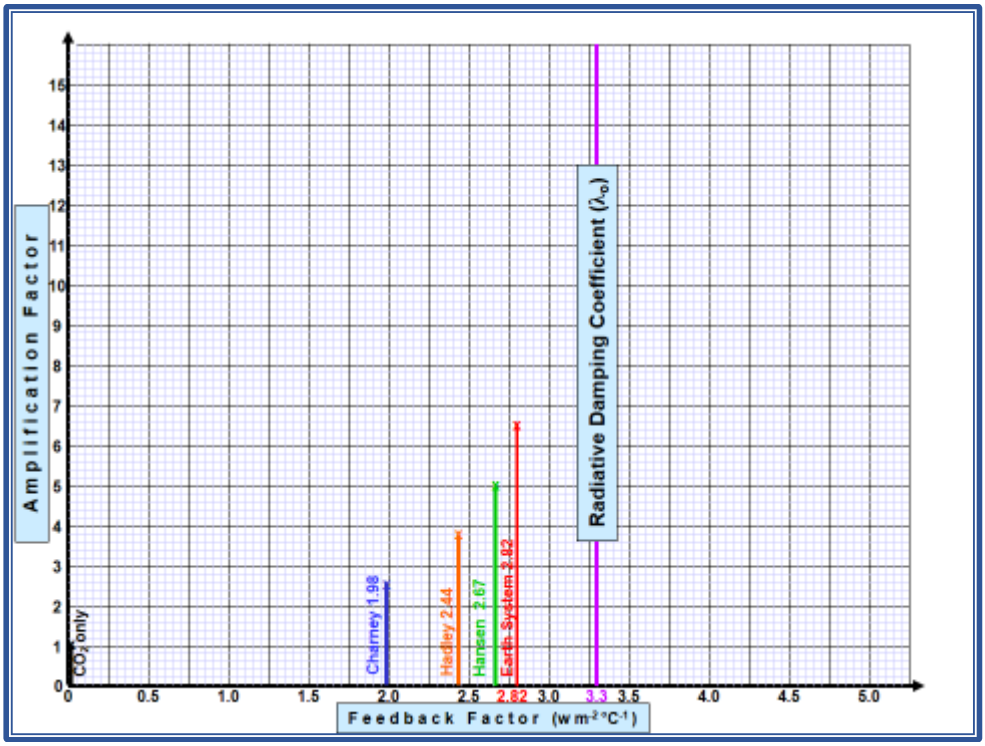


On the vertical axis I am going to plot the amplification factors that we have already seen and been familiar with. Along the bottom I am going to plot the strength of the feedback factor and that is the amount of watts per square metre contributed by the feedback system of the earth for every one degree change in surface temperature.

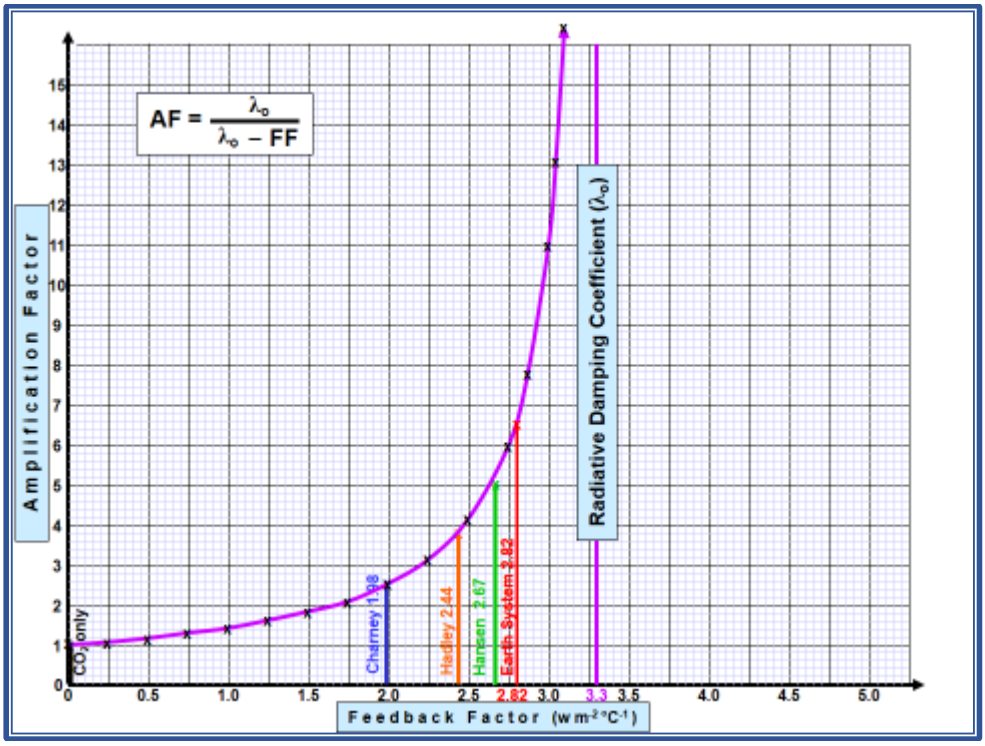
I have put in here what we call the radiative damping coefficient – that is the extra watts per square metre that go out to space per degree rise in temperature - in a sense that is the negative feedback that constrains climate change and reduces it back to an equilibrium. So if that is the damping factor, this is the accelerating factor.

Let's put on the different effects. Carbon dioxide of course had an amplification factor of 1 and no feedback in it at all, so it is right down here. Then we brought in the fast feedbacks, and they had an amplification factor – you remember – of about 2½ and if I can read it on screen nearly 2 as the feedback factor. Add in the carbon feedbacks and they had an amplification of 3¾ and you can see that the feedback factor increased. Hansen's work on ice

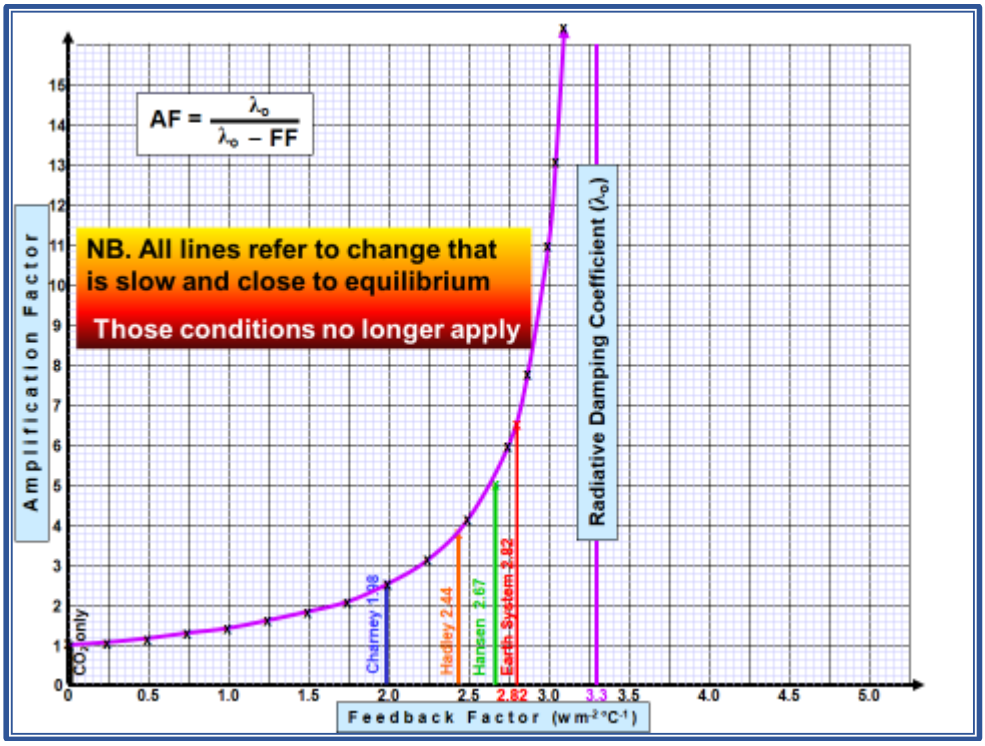
field dynamics multiplied the effects of CO_2 by about 5 and had a feedback factor that put it up there on the scale. The earth system – which is the way the total system behaves, towards which all these others are approximations – amplified the effect of carbon dioxide by 6½ times and had a feedback factor of about 2.8.



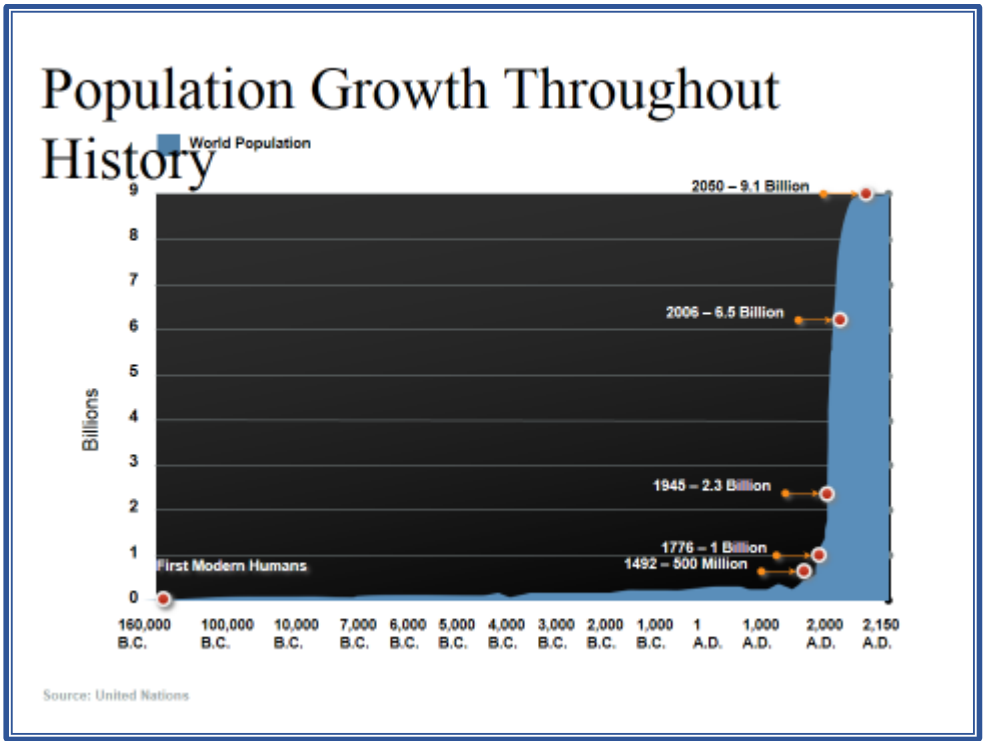
Now those aren't a straight line. In fact – again for the mathematicians – they are points on an equation like this where the amplification factor is the value of the negative feedback over the difference between the negative feedback and the accelerating feedback. And of course the closer accelerating feedback gets to the damping feedback, the smaller that bit becomes and the bigger the amplification factor becomes.



In fact it goes off to infinity as the feedback factor approaches the damping factor and our computer systems, our models, break down in this area. Fascinating isn't it, the current model ensemble is operating around here (FF=2) where small changes in feedback have comparatively small changes on amplification and sensitivity – that feels fairly good. But the earth system is operating at this area in the curve (FF=2.8) where small changes in feedback have big effects on amplification and output temperatures.

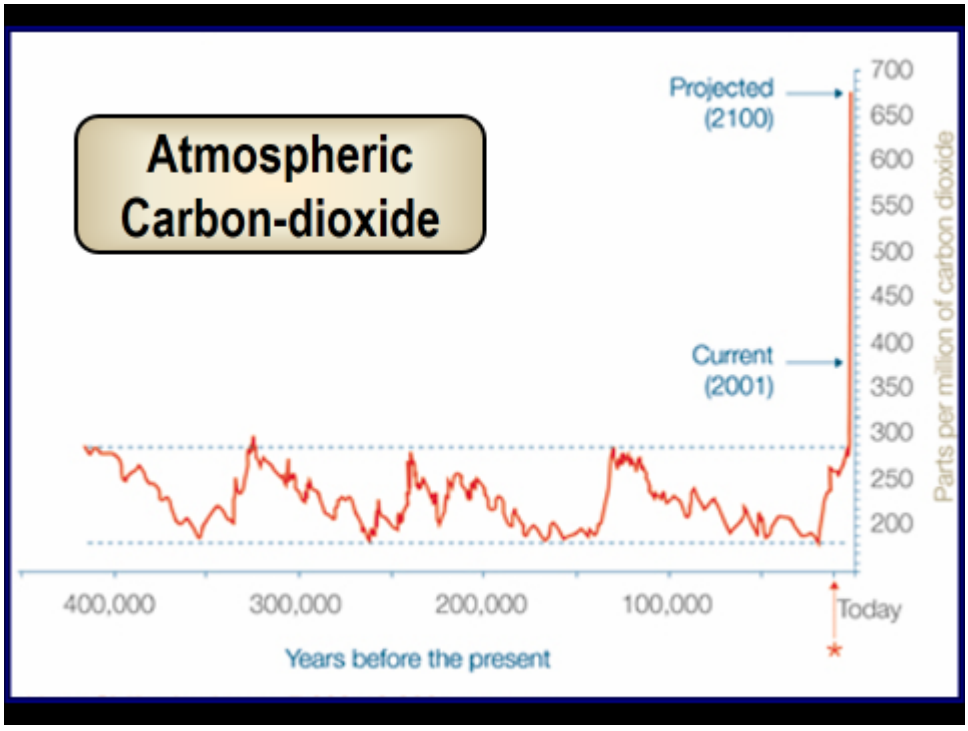


Then we hit a problem. All the work on climate sensitivity has been done around issues of very slow change and very close to equilibrium behaviour. That is no longer so. Why?



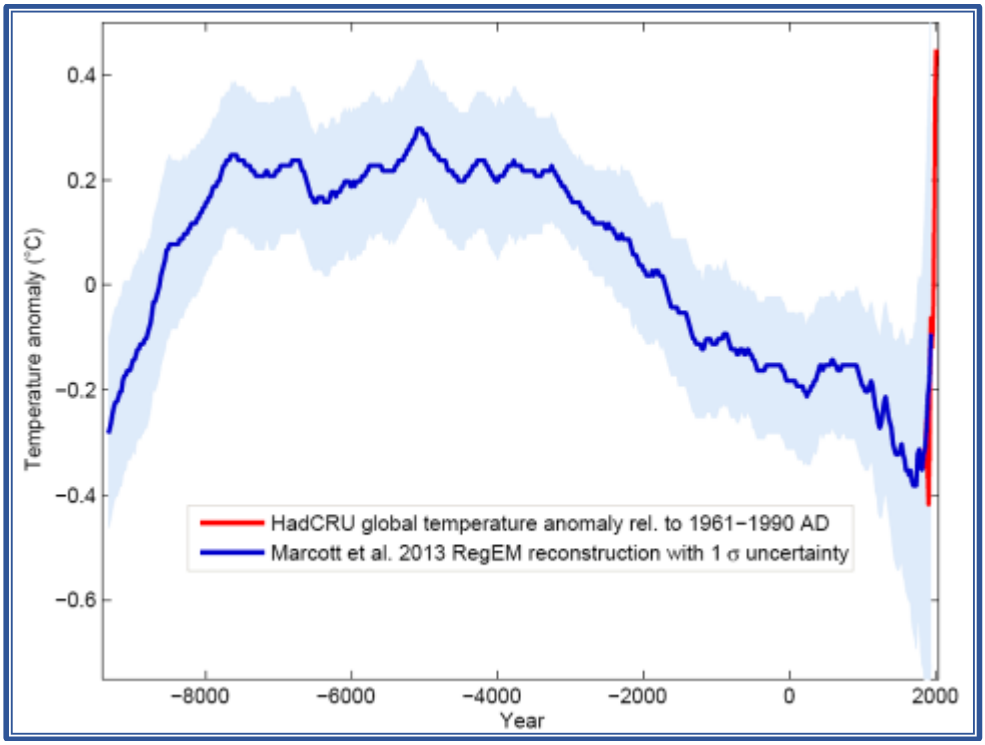
Well population has exploded with the massive amount of extra energy liberated from our fossil reserves. The energy used per head of population has also increased, so the energy used is much steeper even than the population curve. And the pollution per unit of energy – CO_2 produced in order to give us the use of one unit of energy – is also going up.

So the CO_2 emissions are going up faster than the energy, which is going up faster than the population, which is exploding extraordinarily fast in geological terms.



Atmospheric carbon dioxide oscillated between the glacial minimum and the warm periods, glacial minimum/warm, glacial minimum/warm, glacial minimum/pre-industrial and then took

off. We are up to 400 this year and predicted to go possibly way over 600-700 by the end of the century unless there is major, major change in what we are doing.



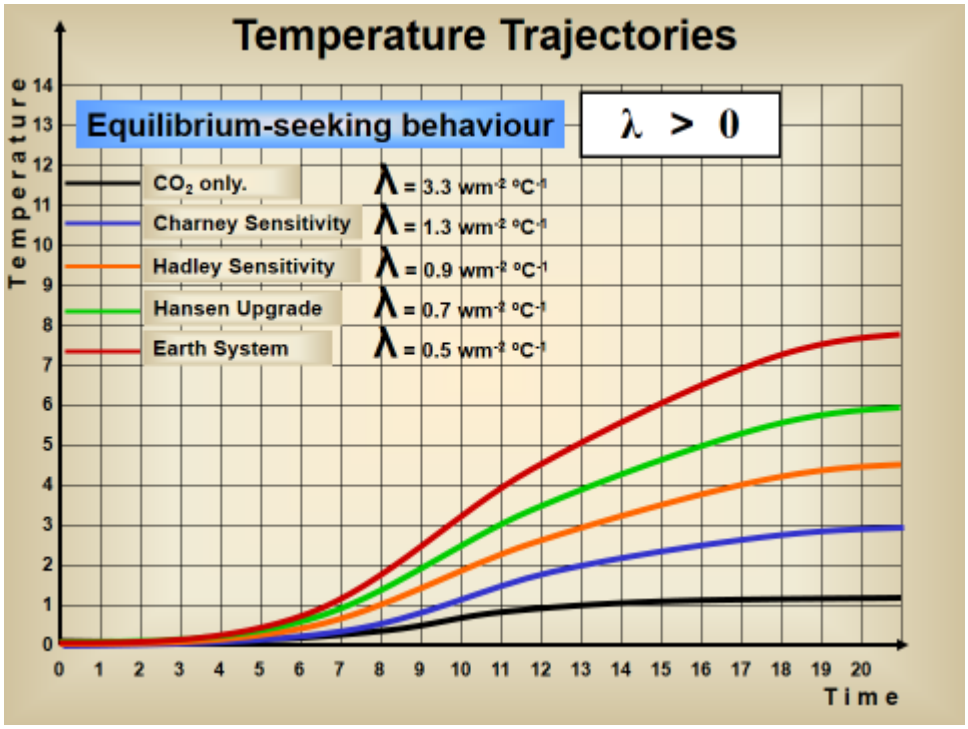
However, the CO_2 going up, the temperature goes up. This is the latest multi-parametered check on temperature for the last 8000 or 9000 years, just the warmish period between the last ice-age and the pre-industrial. Reached a peak about 5,000 years ago and started descending because of the orbital changes back towards the next ice age. It moved away from that path as we began massive deforestation, rice production, cultivating with animals, husbandry, cows and sheep and chickens and so on. Then we found fossil energy and the temperature starts to go up and has gone up about 0.8 degree above the pre-industrial benchmark and probably about 1 or 1.2 degrees above where it would have been apart from human activity. The blue line is the Holocene. That has ended. The red line is the Anthropocene – it has already begun.

We are no longer in close to equilibrium slow change – we are in far from equilibrium rapid change. And the change is happening about 300 times faster than at any point in the fossil records. Wow!

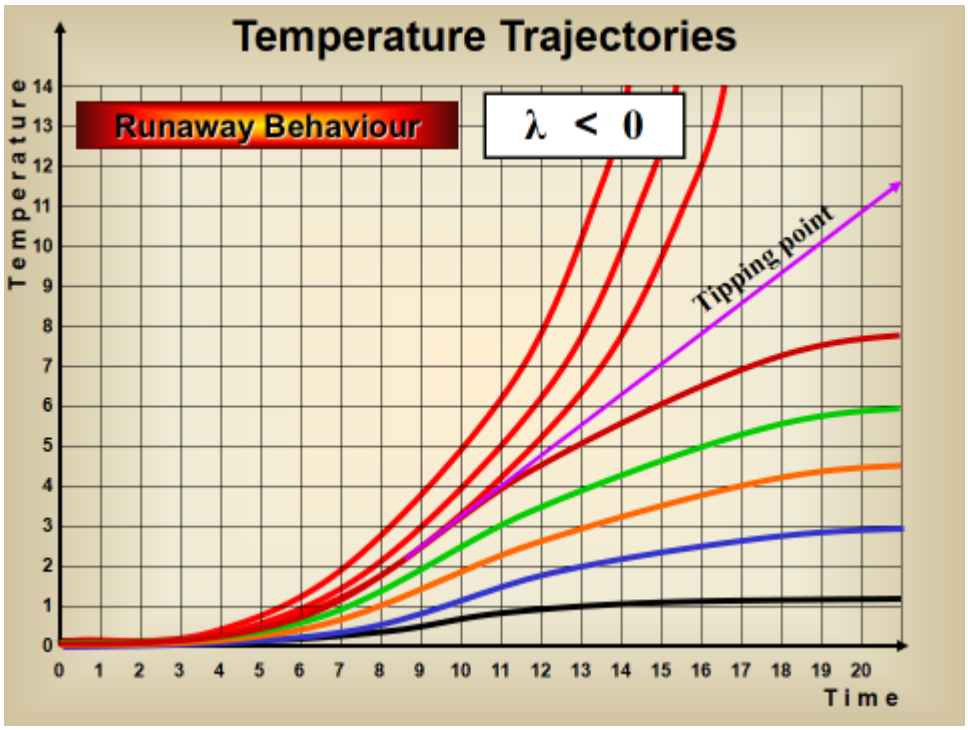
Beyond the Stable State: Boundary Conditions of Self-amplification in the Global Climate System.

That pushes us beyond the stable state and raises new risks in the global problematique. In fact it pushes us quite close to the threshold of self-amplification or what we call runaway behaviour. This was (and I surprise myself at having water at this point again!), this was John Schellnhuber's threshold of "absolutely scary" stuff wasn't it? Let's look back here.

The earth system sensitivity is this red line in stable slow change positions. In the current situation there are factors that are moving sensitivity closer and closer to the critical threshold. The outcome temperature would go higher and higher, and indeed if the Feedback Factor exceeds the Radiative Damping Coefficient, the system moves us into runaway behaviour.

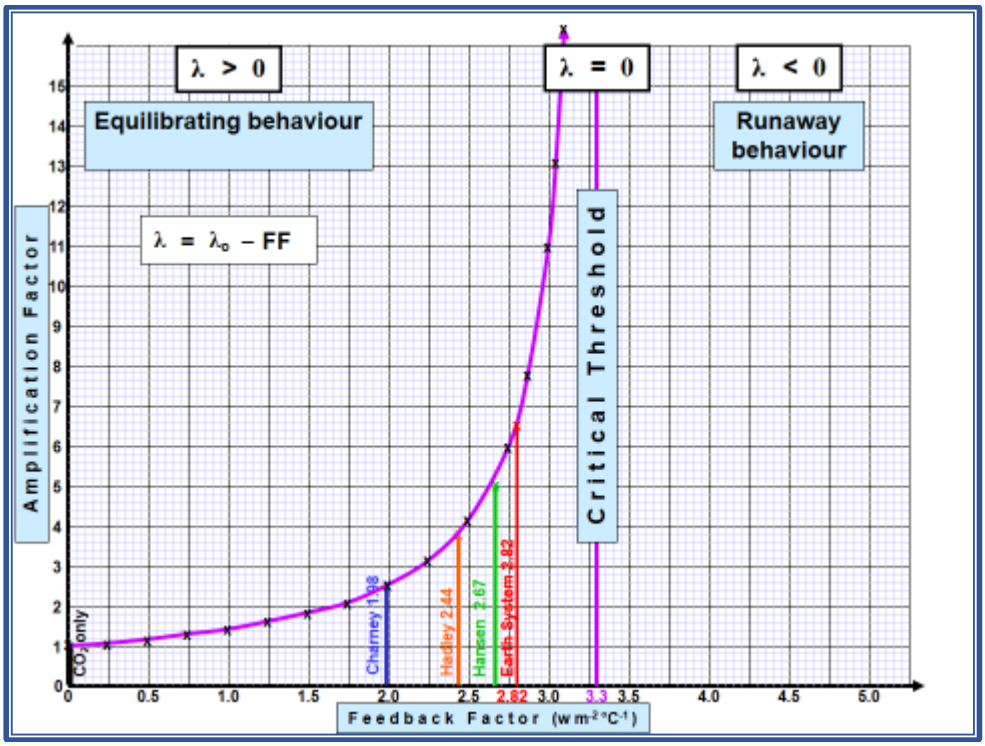


Carbon dioxide on its own reaches an equilibrium. Fast feedbacks, carbon feedbacks, ice sheet, earth system as a whole, and then we are being pushed beyond that into higher temperature formats. To the left of the critical threshold the gap between the damping system and the accelerating system is positive – in other words the brakes are stronger than the accelerators and the climate change comes to a halt.

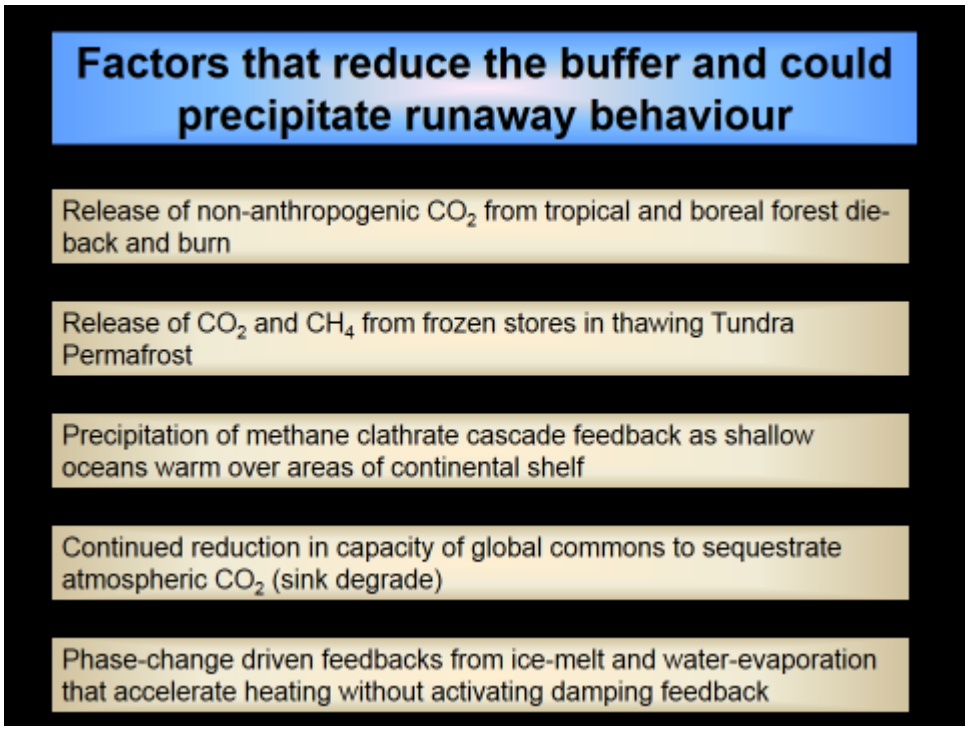


At the critical threshold the braking system and the accelerating system are identically strong, and climate change just goes on and on and on at a constant rate, as shown in this diagram with the tipping point representing constant change.

To the right of the critical threshold, the accelerating factors are stronger than the braking system, and climate change gets faster and faster and faster under its own momentum. That is the area of runaway change, illustrated by those curves.

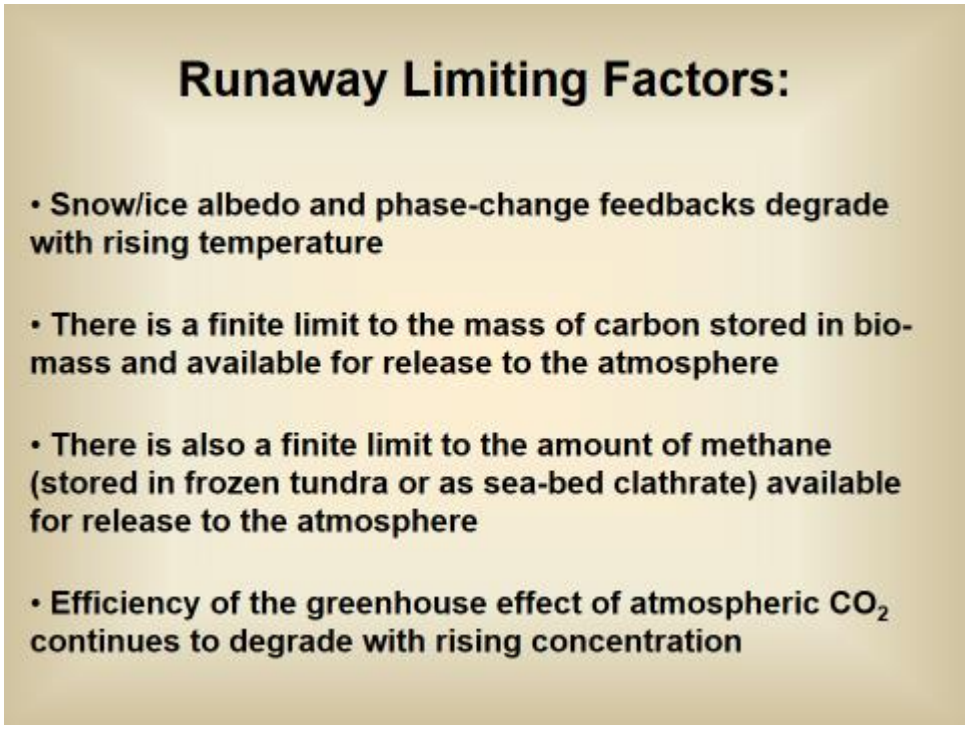


Now then, what are the **factors at work beyond the stable state that are moving us beyond the Earth System Sensitivity** – as if that wasn't bad enough – into this more dangerous zone and pushing us towards the critical threshold or beyond it? Well here is a summary of some of them.



- Very fast change leads to die back and burn in the great forests – whether tropical or northern.
- Carbon dioxide and methane are released from the tundra permafrost.
- The release of clathrates – the methane crystals – from the shallow warm oceans on the continental shelves. As the ice is withdrawn, warm water is fed down to there. We already have significant feedback methane coming out from those sources. Those of you who have seen my work on the Arctic will know that effect.
- The faster we go the worse the sinks become in absorbing carbon dioxide from the atmosphere so more stays up there.
- Finally, are phase-change feedbacks in conditions of rapid change. The changes from ice to water, and from water to water vapour, both change the heating of the system without changing the temperature, so they by-pass the braking system but increase the accelerator.

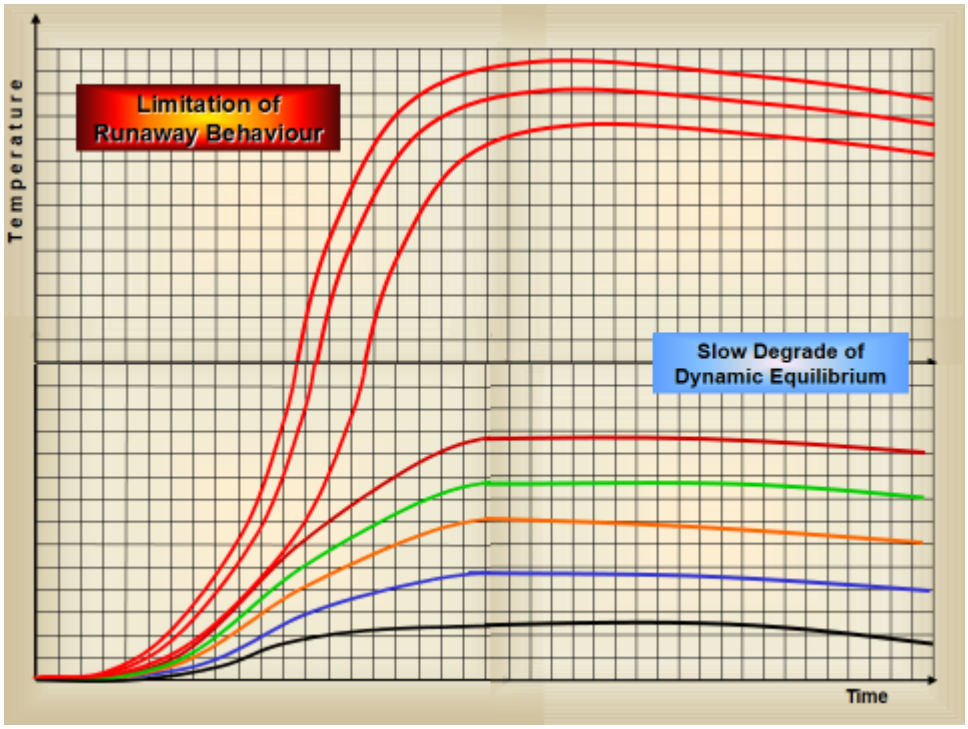
Those are some of the factors that push us towards runaway, if not actually over the threshold.



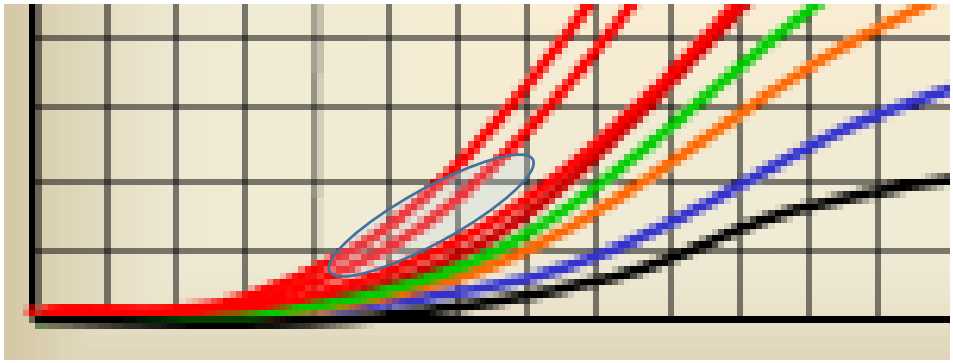
Now no runaway system in any system goes on for ever and there are of course **self-limiting (or runaway damping) factors:**

- There is a limit to the snow and ice albedo feedback, because as the snow all goes that stops.
- There is a limit to the amount of carbon that can be burnt and put out.
- There is a limit to the amount of methane that would be released.
- And in any case with high concentrations of CO_2 the efficiency of CO_2 as a greenhouse gas degrades.

This summary diagram illustrates the various possibilities facing us:



We have the earth system sensitivity leading to some kind of equilibrium but we know it is going to be worse than that, and maybe up into the runaway period. To the left of the horizontal axis we have an area of decadal to century change, moving over to thousands and then ten thousands of years as the concentrations of CO_2 are taken down and sequestered by rock formation and sediments in the ocean. Slowly the system returns to base. It is, however, the next few decades that constitute the crisis period that we face. It is for this that the development of the management of the commons and the decision-making processes are absolutely crucial.



I am going to focus right down in this bottom left hand corner because we are presently in this area. We have some increase in temperature and the computer models portray it as on the blue line. We now know we are tracking on the red line and going above it. So we are somewhere in this domain here.

The solutions that we provide must not be determined by the conservative set of our computer modelling but by the reality of the way the earth system behaves and particularly under the conditions beyond the stable state in which we find ourselves. So the set of solutions that we provide must be commensurate with the problems we face.

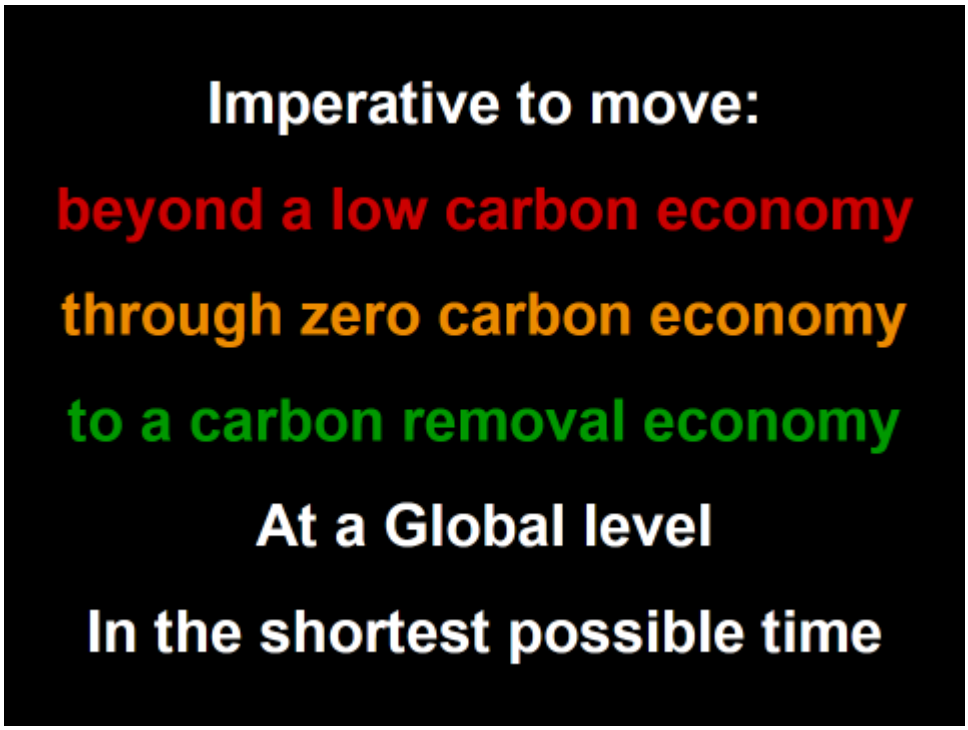
Responding to the State of Planetary Emergency.

So we recognise that there is already A State of Planetary Emergency. And I have about 4 minutes worth of presentation remaining. As we started a little late, so if I may I will take my full time.

I think we need to globalise those laconic words from Jim Lovell on Apollo 13, do you remember, "Houston, we have a problem".

In today's world: "Planet Earth we have a problem" and we have to solve it. And just as Gene Kranz's leadership function was so critical to the success of the survival in Apollo 13, so failure in dealing with this problem is not an option for our species. Whatever it takes we need to get there.

So in **moving towards an effective strategy for climate stabilisation**, we have to move beyond the low carbon economy currently postulated as a solution by our inadequate global climate models.



It is imperative we go through the zero carbon economy, to the carbon draw-down – (a carbon removal) – economy. We have to do so at a global level in the shortest possible time before the temperature rise takes over and drives the feedback system out of control. We do have a window of opportunity but it is quite small.

Yvo De Boer speaking to the business leaders at one of the big UNFCCC COP meetings said 'What we have to do is to turn round the super-tanker of the global economy'. Well, these juggernauts take about 20 miles to turn round! They are controlled by one brain – the master up in the bridge here with a very small crew. But the master is under very strict orders to deliver the oil to its destination. Turning one of those round is not only physically difficult, it is going to be blocked by the vested interests, the profiteering and the political systems that depend on the profits of the vested interests that control the voyage. It is not just an issue of turning a little tip on the rudder and turning it round.

I want to offer you a different solution, and that is the deconstruction of the super-tankers of our institutional life into a form of massively parallel processing, with interactive learning, and emergent solutions of complexity. That is the transformation from super-tanker to shoal. I am quite certain that the polycentric solutions provided as one of the inputs to this conference have a lot to do with this. Shoals – you know shoals respond very quickly don't they to stress.

They notice threat and change. They can reform.

So the learning activity of concerted complexity allows emergent problem-solving in real time. We have the solutions, we have the capacities, the question is are we able to put them into effect?

Well that is pretty well the end of your ordeal with this new technology. I just want to say this. Over the last few weeks we have been celebrating the life and work of Martin Luther King and remembering his dream speech in Washington. Now, Martin Luther King was not the only one to have a dream, and I too have a dream and I would like to share that with you.

I have a dream: that humanity will break out of its state of denial and find the courage to face the harsh realities of now.

I have a dream: that we will rise up and overthrow the collusional power of political and economic vested interests.

I have a dream: that we will acknowledge the life-destroying gravity of our addiction to the dark energy of yesterday, to kick the habit of our fossil dependency, and to succeed in the task of system de-toxification.

I have a dream: that we will repudiate the myth of eternal growth, and learn to live sustainably within the limits of our finite world.

> **That we will find a way to stabilise the climate of planet earth before temperatures rise too high.**
>
> **That we will find a way to abort the extinction event of the Anthropocene before it grows to catastrophic proportions.**

I have a dream: that as a species we will look back on the current crisis and celebrate the solutions we were able to put in place and say with pride "that was humanity's finest hour!".

[applause]

Thank you so much I am going to take a couple of minutes break for a breather and leave you to just chat with your colleagues around the table and get your questions in and to react to what I know has been an extraordinarily difficult time of listening to a presentation with a new technology that is also dealing with very complex material. Thank you for being so patient and being such a wonderful audience.

*** * * * * * * ****

The Question and Answer session chaired by Jon Legg.

Jon Legg (on David's return): David we were instructed not to applaud but I have already excused all of us including myself because of your brilliant presentation. While you were having a break I explained that I do have two questions submitted by someone who has studied this material and if you are ready may I ask the first question.

DW: By all means go ahead and my moderator at this end will try and type them into the chat line at the bottom and at least the few people in the front will get to read it. Eventually I think the technology should make it bigger than that so that everybody can read it, but for the moment this will help me to pick up the gist of the question. Let's fire ahead with question 1.

Question 1.

Jon Legg: So David here is the first question. **The 5th Assessment Report of the IPCC, (that is the Inter-Governmental Panel on Climate Change), is due to be published at the end of next week. How does your work relate to its conclusions?**

DW: The Inter-Governmental Panel is one of the most extraordinary and comprehensive surveys of published material in any scientific discipline that has ever been conducted. Its material, when it is published, is about 2 years out of date and that is inevitable in the fact that it only reviews peer-reviewed material and that has been perhaps a year in the editing and publishing side and then it closes its books about a year before publishing its report. So when it comes out at the end of next week, probably on Friday I think in Stockholm, the material will reflect 2 years' ago leading edge science. Much of the stuff that I have brought to you today has been published since then. My own material just missed the window of publication for that. There is a paper that has just been produced in the current issue of the Quarterly Journal of the Royal Meteorological Society which is a review of climate sensitivity in the Anthropocene which is absolutely supporting the analysis we have done, although I think we are probably about a year and a half ahead of that article. Looking at the necessity not simply to let our strategies be based on the current fast feedback evaluation from our computer modelling community, but to include carbon vegetative feedbacks, ice sheet dynamics feedbacks, many other feedbacks between climate change and the system and to treat the Earth System Sensitivity as **the** factor that determines our strategic policy making. So I think in summary, to answer that question, the IPCC report, in so far as it goes, is absolutely solid. However in terms of whether it is fit for purpose as a ground for strategic policy-making, the answer is **'no, it is not fit for purpose'** for the reasons that I have outlined. It is a foundation, but we need to work with an understanding of the problematique that we face, that is to do with

the reality of the system in which we live, not a conservative computer model of that reality that doesn't do justice to the crisis. Thank you very much.

Question 2.

Jon Legg: Thank you David. The second question is from someone who knows a bit about your background. Here is the question: **In addition to your work in the natural sciences you have a background in Theology and Psychology. Do you have any insights concerning the origin and power of the universal myth of unlimited growth that is driving our civilisation to destruction?**

DW: I am reminded by the question, just to give me a moment to think, of another quote from 'Bankrupting Nature' and I think it is on page 4. 'Our Society has long been built on the myth of endless growth. Nature's cupboard is perceived as infinitely large … The myth is powerful and very difficult to dislodge'. Then, on the next page, 'Our economic system is built on the myth of endless material growth. No environmental legislation in the world can rein in an economic system that has endless material growth as its starting point'.

Well, yes, there is a lot of work been done on the origins of our need to maintain growth. There is a lot of that on my Meridian Programme web-site and I working currently with people in Germany and in the States to take this understanding further. Let's put it this way. At what stage in our development did we have unlimited resources, room to grow, an environment that absorbed our pollution without any responsibility on our part? The more we expose ourselves to this current situation the more we seem to be driven back into an almost foetal trance, a kind of view of our environment as if we were still unborn. We behave as if Gaia, the great mother, will go on looking after us: will hold us in an infinitely elastic womb that can expand forever, will provide all we need in terms of resources without depletion, will absorb everything we produce in terms of entropy and waste product, without us having to do anything. These are the myths of foetal behaviour that we are carrying forward with fatal impact into our adult (so-called) homo sapiens (but not very) life on earth. We are treating the environment as if we are still unborn. As we reach full term in Gaia and reach the limits to growth, the limits to absorption, to pollution absorption, and transgress the boundaries of planetary safety, then we face the next stage in our development and for most of us that is the battle of all mothers, or the mother of all battles - the movement out of a safe environment, that we have idealised, into one in which we have to take responsibility for the environment in which we live. That is the boundary. I think the answer here is that the myth has power because it resonates with some very, very deep experiences. Sustaining growth defends us from the anxieties we feel as we reach the limits to growth in our own birth process. We are terrified of what happens next, and we idealise our early environment as if it is some kind of utopia to be held onto at all costs. So there is psychology here and that drives economics, it drives politics, it drives religion, it drives war, it is an enormous driver of our whole civilisation. There is a lot more on that. I won't take more of your time because we are pushing time boundaries. Let's have another question.

Question 3.

Jon Legg: Next question is: **What can be done today to tell our governments that we have reached a state of emergency?** The second question to that is: **What is the time window minimum to maximum?**

DW: Reaching critical mass is important. There is I think a theory of inadequacy in the science community. "If only we put the facts out better, government would take notice of them!" and that is another big myth. The control of our understanding of climate change. I am going to

quote from Jeremy Grantham, known to some of you I am sure. "Recognition of the facts is delayed by the frankly brilliant propaganda and obfuscation delivered by energy interests that virtually own the US Congress" – we won't mention the Australian government, we certainly shouldn't mention the Canadian government or the UK, and to talk about Saudi Arabia and other energy countries is probably out of order – Vested interests are managing political process, they are controlling media and they make political change extremely difficult. So what can we do? Just trying to get the facts to government doesn't change what government does, because government is controlled basically by vested interests. I think we have to move to a mass movement of educated, transforming people, connected to each other globally, something the way that 350 dot org is working, but much more viral. We need to get to the point where the value system and the activity and the responsibility of the population as a whole repudiates the power of the vested interests. We need to get to the point where political power cannot be elected unless it is paying crucial attention to the realities that we face and is espousing and enacting legislation and policies that deal with those problems, rather than that block the capacity to deal with them. I think the answer lies in mobilising mass human commitment, across the globe, across cultures and we have the technology to do that now. Watch this space – applied complexity can topple the pyramids of power.

In terms of time window, that is difficult. We have a little bit of grace in that the particulates coming out from Chinese and Indian power supply are masking some of the effects of carbon dioxide, a lot of the heating is being mixed into the deep ocean and the temperature isn't going up very fast. That means the feedback loops aren't being activated at the moment across the planet as a whole, but they are in the arctic. We see the arctic as the canary in the coal mine of global climate. Don't try and resuscitate the canary but do pay attention and get out of the coal mine! Time-wise the earth is very inert and responds to heating slowly, so we have a window of perhaps 5 or 6 decades to get the solution completed – not just started – in other words to have drawn down vast amounts of carbon dioxide from the atmosphere that are already there and are driving the system out of control. To reduce concentrations, not reduce emissions. Yes, we have to reduce emissions to zero and beyond but we need to reduce concentrations to get a solution on the ground. So by 2050, 2060, 2070, concentrations need to have come down to around 330 parts per million. So 60 years to get the solution on the ground. In terms of what time window do we have – we have to act now to begin that process because we do have to overcome the constraints, the blockages, to clear – and I think Canada is the right place for this – to clear the log-jam, to release the power of human potential for problem solving on the planet that we know as home. I can't be more precise than that, it is a difficult question. Thank you. What is your time frame and how are we doing.

Question 4.

Jon Legg: I will call upon Roberto Peccei about 5 minutes before the hour so we have 7 minutes left and I have 2 questions in my hand. The first one is: **Your early work was in social systems. Can you suggest ways to affect social behaviour in terms of ethical, religious, etc. not to replace international agreement, but to anticipate and complement changes towards crisis avertion?**

DW: Yes, there are I think significant things that we can do in this way. I see "how can we affect social behaviour, not to replace international endeavours, but to complement it and give it sanction?" It is absolutely crucial that the population as a whole grasps the solemnity and severity of the crisis in which we find ourselves. That is an issue of communication and at the moment the communication channels are dominated by the vested interests. So we have a communication block to clear. In terms of social settings, people change their values and their behaviours in small groups of relationships in which they trust each other. And I think the

innovation that we have been looking at (and people around the world are suggesting) is not the mass movement of Twitter and the social media, but a dynamic replicating cellular structure for humanity, as a holding structure within which transition can then be fostered. So perhaps meeting up with 3 or 4 people in your neighbourhood, in your organisation, in your school, in your company, whatever it is, beginning to make a small cell committed to transforming, transforming your own lives, transforming what you can do, take responsibility in areas in which you can own. As that begins to move, you are connecting with other cells, each cell replicating, looking for new members, dividing, opening up, developing connections through the media, developing web connections and learning systems around the world, becoming shoal. Shoal systems have the capacity to transform top-down pyramid systems and topple them into change. So I think the insight from social research is saying we need virally replicating, dynamic cellular patterns, that can reach a tripling-in-six-months' growth rate, and, within 3 or 4 years of starting, can overwhelm the rigidities and the disinformation campaigns that we are facing. They can develop change processes that can sweep the powers that stop change out of the way, like a tsunami of transformative behaviour. That I think is where the hope for the future lies. Yes there will be political issues around that, yes there will be legislation, but the real dominance is commitment to solving the problem and taking responsibility at a popular level. If you just make laws, everybody tries to play the laws and get round them as much as possible. Where you have responsible commitment everybody has got their back into it and puts their shoulder to the wheel to make the change happen themselves, with their colleagues, in ways that are networked and cumulative and can reach a tipping point or phase change in human consciousness, human behaviour, human commitment within the time frame that we have available.

Question 5.

Jon Legg: This is the last question and then there will be a request or two for me to make. This question has to do with the role that the Club of Rome can take. Here is the question: **What is the best role and set of immediate activities that the Club of Rome can play to help turn things around?**

DW: I am deeply reminded of a student of theology who faced an examination and the question in the exam was 'Would you write a critique of the theology of Second Isaiah?' And his response was 'Who am I to critique the theology of Second Isaiah? Here, rather is a list of the Kings of Israel' – He failed. I think I am going to fail this one! The Club of Rome is one of the most extraordinary institutions on the planet. You have a network of expertise in a wide variety of disciplines and backgrounds. You have an independence which is second to none. You have a concern from your start with answering the issues of the global problematique and supporting solutions to it. But historically you have not been an active, participating, campaigning, change-driving organisation. And I think there are some profound questions now that you will be facing, I guess within this conference, about the role of the Club of Rome as it evolves into tomorrow's world, dealing with today's problems and solutions, and whether you can take up a leadership role in the transformation or whether your role should be more limited as a more independent think-tank. I don't think I am the right person to be answering those questions, but you have the responsibilities, you have the capacity to address those in the remaining time of your conference and I look forward very much to being a part of what comes out of that and of working as closely with you as I possibly can in these coming months and years. It has been a privilege journeying with you over these last 8 years and I have watched your emergence, your reorganisation, your re-positioning of yourselves globally. You are in a position now to take up a leadership role at this crucial time. But please don't do it as a managerial one. Remember the issues of catalysis of complexity, not management and legislation of the

commons. I think that is about all I can do, but thank you so much for such a creative set of questions, and I am sure we have raised far more than we could address in the time.

[applause]

Jon Legg: Before I call upon Roberto Peccei to thank David Wasdell, I would like to make a request on behalf of whoever put this suggestion in. David could you please send us the text of your "dream". I understand we have really in case of emergency, perhaps even recorded something of your presentation, but I don't believe we have this, so this has been called upon. The final comment is, and I think this is addressed as a rhetorical question, but it would recall David your knowledge of presentation and bringing complex issues into play, and the suggestion is: **To publicise climate change why not put up a giant climate change clock in some prominent site?**

Vote of Thanks by Roberto Peccei.

Roberto Peccei: Hello David, first of all thanks very much for the really splendid lecture, I think you posed the right questions. I think not enough people understand about feedbacks and that they amplify much more than people expect. So placing yourself beyond what the IPCC says is more likely to be the case, I think this the most important message.

I think that the other thing I got from your talk was that wonderful, wonderful point, in that you compared a super-tanker to a school of fish and a super-tanker is rigid, it cannot turn. The school of fish can do that very rapidly. Now it is difficult to get a school of fish as large as a super-tanker so that is a problem of the sea! Nevertheless the idea that we change course is most important and I think that, in line with you, you really need to mobilise. It is not enough to have talking heads and discussions, you need people on the street. You need young people - after all it is their future - we are putting them into an enormous mess. And if they just realise the mess they are in they should all be in the street to say things have to change.

I think the message that I get from here is that we must change course. We must decarbonise the energy system much more rapidly than we are doing. There are enormous vested interests. I think de-coupling on the terms outlined yesterday by Ernst and others, is of course important

there. So many things that I can think of that need to be done in the next 50 years, and what we must do to go in that direction.

You are right, we are in an emergency. We are all ambling along in our usual way and we don't realise we do have to change many things and very rapidly. So I am very happy that you gave us a wakeup call. I was expecting that in this conference you would focus more on the arctic and the canaries. But you talk about systems, I really like systems, and I actually understand them and I agree with you, although I am not sure that you can get towards singularity where the system breaks down, but that is a technical point. Anyway thank you very much for an inspiring talk. Thank you very much also for showing that we don't have to meet all in hotel rooms, we can be in the comfort of home! Perhaps we should do this more often. Thank you.

[applause]

DW: Just a quick response to Roberto. Thank you so much for that, and I remember meeting you also 8 years ago. In terms of the recording, the whole presentation and questions have been recorded and I think they will probably be available on the CACOR web-site and the Club of Rome web-site and indeed on our own on Apollo-Gaia. The text of what I put through as the dream will also be made available to you.

I leave you with one last thought and that is that we are engaged in the most appalling act of child abuse ever. We are taking the planet and stripping resources from the unborn children for generation after generation after generation. This has to stop and I look forward very much to the journey ahead as we all move from contemplation to action and effective problem-solving. Thank you so much it has been a joy working with you.

[applause]

End of Presentation.

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In September 2013, the Annual Conference of the Club of Rome was hosted in Ottawa
by the Canadian Chapter of the Club of Rome.
Further information about the Club of Rome can be found here: http://www.clubofrome.org/.
The web-site of the Canadian Chapter of the Club of Rome is: http://cacor.ca/