Climate Dynamics:

Facing the Harsh Realities of Now

Climate Sensitivity, Target Temperature & the Carbon Budget:

Guidelines for Strategic Action

By

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Preface

As a completely independent systems analyst I find myself in a unique position. With no institutional, political or economic strings attached, it is possible for me to draw attention to some of the fundamental flaws in the scientific foundation of the strategic proposals at the heart of the Paris negotiations. This presentation carries no institutional authority other than that derived from the rigour and integrity of the analysis on which it is based.

Last Spring I received an invitation to lead a two-hour seminar on Climate Change for the Alternative Business Club (ABC) of Hitchin, some 35 miles north of London. It came from the Founder and MD of the Global Leaders Academy who was organising the event. It faced me with something of a dilemma. The proposed date was 8th July which clashed with the major scientific conference "Our Common Future under Climate Change" being held in Paris in preparation for COP21. It also coincided with the tenth anniversary of the start of my work on climate feedback dynamics which eventually led to the launch of the Apollo-Gaia Project itself.

The implications of our radical new analysis of climate dynamics posed a massively disruptive intervention to the consensus position on climate mitigation. It also required a complete revision of the international negotiating process leading up to the COP21, together with a transformation of the global strategic approach in response to the developing climate crisis. The question was "How best to communicate the material?" I had two choices. The first was to deliver a brief academic paper to a small group of fellow scientists in one of the many parallel sessions of the Paris conference, knowing full well that the content would be contained and buried, confined within the defensive walls of academia, with no access to the concluding communiqué, the text of which had already been finalised before the conference started. The other choice was to provide a dynamic one-hour presentation to a group of deeply concerned citizens who had power and responsibility to act both in their local community and also through their executive positions in the business world. Then to revise and release the material for viral circulation. The decision was a "no-brainer"!

So it was that on 8th July I found myself in the Adam Room of Hitchin Priory, with the challenge to step out beyond the ghetto of academic jargon, to reach out to the real world of the business community, and to communicate profoundly complex science in a way that could transcend disciplinary and cultural boundaries. A press photographer turned up. The event was recorded and transcribed. The presentation was subjected to seven further stages of stringent revision and re-recording, using a wide range of critical feedback. The dynamics of an intimate seminar have been captured. The style of non-technical spoken English has been preserved. Critical

scientific content is presented in visual format. Web-based output is in the dual media of fully illustrated PDF and a high definition AV recording with specially designed triple-screen format. The Table of Contents gives parallel reference to pagination of the PDF and accurate timing of the Video Presentation.

I had been asked to give some background about the Apollo-Gaia Project, and to ensure that anyone with only a sketchy grasp of climate change would be brought up to speed right at the start. Although the first four sections are designed to do just that, they also lay the basic foundations on which the rest of the presentation rests.

Understanding the dynamics of multi-dimensional complex systems requires collaboration between both visual and verbal centres of the brain, what I have described as a "bicameral" approach. Whole-brain stimulation is sustained throughout the presentation by the continual interplay between graphical illustration and textual explanation.

Coping with the emotional response to the implications of the analysis is another world altogether. If emotional intelligence is not engaged, then intellectual grasp of the content is seriously diminished. Cognitive clarity requires open acknowledgement of the affective response and the resources to work through the emotional issues that inevitably emerge. Some of these are absolutely appropriate reactions to the "harsh reality of now". Others are triggered from deep within the unconscious. When projected onto the world around us, they can distort our view of reality to such an extent that effective action becomes well-nigh impossible. Deconstruction of projected fears, healthy resolution of emotional response, deep understanding of the complex issues involved, and collective engagement with the process of transformation, are the characteristics of realistic hope that open the door to the best achievable future for life on our planetary home.

Hemispheres in harmony: The bicameral video recording was released at 12.00 noon (GMT), on the Greenwich Meridian, during the Autumn/Spring Equinox (depending on your point of view!). The date also coincided with Eid ul Adha, Yom Kippur, and the celebration of my 20th wedding anniversary. The final editing of the PDF was delayed till the 5th October so that we could take account of the completed set of INDCs (Intended Nationally Determined Contributions) and the release of the text of the Draft Agreement prepared ahead of the COP21. Earlier publication felt premature. Further delay was judged irresponsible.

David Wasdell **Apollo-Gaia Project** **5th October 2015**

Errata: *Great care was taken to keep the audio track in line with the finished text. However, even with the support of an auto-cue, three mistakes were subsequently identified, for which my apologies are duly offered:*

1: At (00:20:41) "1.4 wm^{-2}" should have been "4.1 wm^{-2}"
2: At (00:59:28) "14.6 metres" should have been "14.26 metres"
3: At (01:05:26) "Sebastien Laurent" should have been "Laurent Fabius"

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Climate Sensitivity, Target Temperature and the Carbon Budget: Guidelines for Strategic Action

Executive Summary

The value of Climate Sensitivity is the fundamental parameter governing all strategic policymaking in response to Climate Change. This presentation summarises 10 years of work under the auspices of the Apollo-Gaia Project, dedicated to providing the most robust answer to the question: **"By how much does the Earth System amplify the effects of anthropogenic emissions of greenhouse gasses?"**

Current computer estimates of Climate Sensitivity are shown to be dangerously low. They are based on inadequate treatment of the amplifying feedback system that multiplies the effect of human disturbance of atmospheric composition. Detailed analysis of historical planetary response to change in concentration of carbon dioxide, reveals an eight-fold amplification of CO_2 forcing (in contrast to the three-fold amplification predicted by the IPCC climate modelling computer ensemble). Applying the corrected value of Climate Sensitivity multiplies previously predicted temperature rise by more than 2½ times in response to any given change in CO_2 concentration.

One immediate consequence is the **collapse of the "available carbon budget"** and the recognition that all future emissions add to the overshoot of atmospheric greenhouse gasses. Major reduction in the present stock of CO_{2e} is an imperative element in the limiting of increase in global temperature to 2°C. Moreover, advances in understanding of implicit sea-level rise and the dynamic response of global climate to small changes in average surface temperature, demonstrate conclusively that **the 2°C target temperature limit is set far too high**. It has to be reduced to below 1°C if we are to avoid catastrophic climate change. Implications of the new analysis are spelled out for the set of emissions reduction pledges currently offered prior to COP21, as well as to the persistent high emissions scenario of "business as usual".

Recognition of the **dynamic inertia of the global system** highlights the major time-lag between cause and effect, between human intervention and full manifestation of consequences. While this is significant in the case of temperature change, it is even more apparent with respect to rise in sea level, which is itself an extremely inert response to observed change in temperature. Introduction of **the concept of "Implicit Change"** collapses the time dimension and allows policymakers to develop strategies that are coherent with the total consequences of human action, rather than in response to minor changes in observed behaviour of the global climate. Planetary inertia also provides a time window of opportunity in which to achieve effective strategic intervention – perhaps the only remaining ground of realistic hope for the achievement of climate stabilisation at a level consistent with the terms of the UNFCCC.

Guidelines for Strategic Action

Strategy can no longer be driven by what is considered politically or economically feasible, but by the harsh reality of planetary dynamics. Response will have to be collective, collaborative and global. The current one-dimensional approach of emissions reduction and establishment of a "low-carbon economy" is completely inadequate. Effective strategy demands three concurrent lines of approach:

1: Stop making the problem worse.

Eliminate all activity that increases the energy imbalance of the Planet, or that profits therefrom.

2: Solve the problem we already have.

Engage an aggressive and effective carbon draw-down program to reduce the current concentration of greenhouse gasses.

3: Reduce target temperature increase to less than 1°C.

Contain disruption of climate behaviour, limit rise in sea-level, abort the extinction event and minimise risk of feedback-driven runaway change.

Concluding Caveat

The value of Climate Sensitivity, on which this presentation is based, was derived from historical conditions in which change was slow, close to equilibrium and in response to which natural systems had time to adapt. Those conditions no longer apply. Anthropogenic change is at least 100 times faster than at any time in the Paleo record. The system has been driven far from equilibrium and smooth natural adaptation is no longer possible. In this situation many factors combine to drive a higher and increasing value for Climate Sensitivity. That will inevitably require even more urgent and stringent strategic intervention than has been outlined above.

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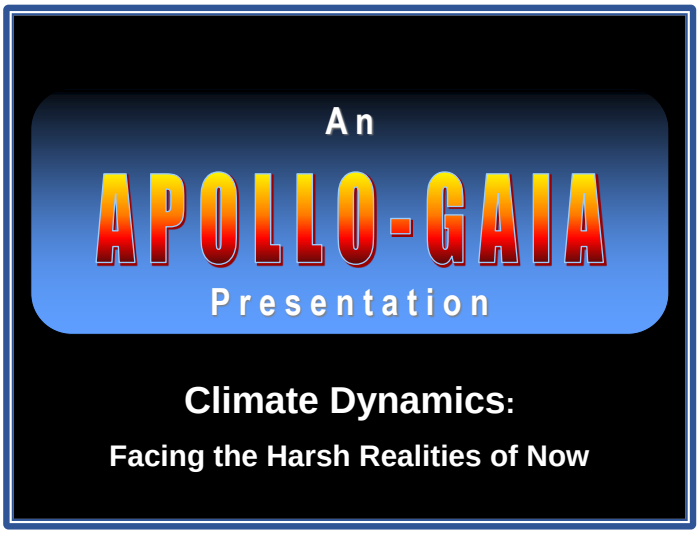
David Wasdell **Apollo-Gaia Project** **23rd September 2015**

Climate Dynamics: Facing the Harsh Realities of Now

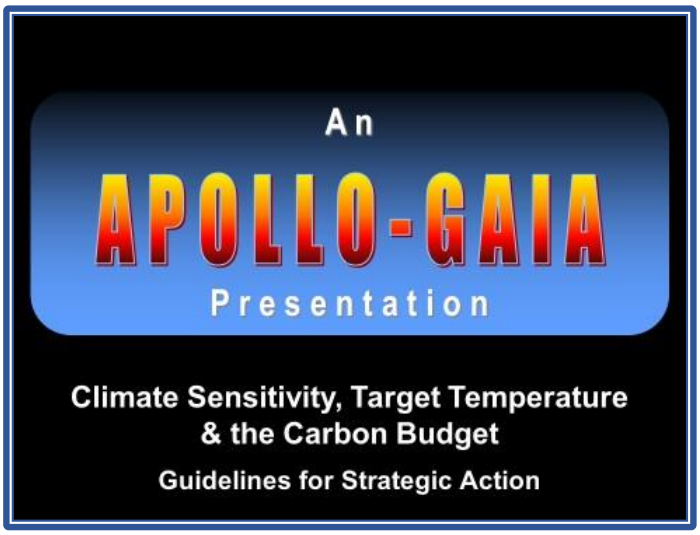


Background and Introduction. It was just over ten years ago (on 8th July 2005) that I initiated what eventually became "The Apollo-Gaia Project". It was designed to bring the most competent available international expertise to bear on the fundamental question **"By how much does the climate system as a whole amplify the effects of changes in atmospheric composition resulting from our combustion of fossil hydrocarbons?"** That is the question of Climate Sensitivity. If the planetary system is very sensitive then we are in deep trouble. If it is not very sensitive at all then there really isn't a problem.

We were eventually forced to the conclusion that we could not answer that fundamental question by building computer models involving more and more complexity, (but which still do not include all the issues, and which come up with more and more uncertainty). Instead we turned to the actual history of the earth as the direct source of information. Using that approach, we found that we could derive more robust results with reduced levels of uncertainty. Our conclusions are game-changers in the understanding of the response we need to make in the contemporary situation. They have the potential to break the log-jam of the current international negotiations, and initiate a more effective strategic approach to the crisis of Climate Change.

In this Apollo-Gaia Presentation, I want to reach out and touch base with you personally, to build a bridge from the extraordinary world in which I have been working for the last 10 years, across to the everyday working world in which you play such an important part.

The main title reflects the discipline of System Dynamics which lies at the heart of our approach. It courageously rejects alarmism, breaks free of denial and refuses to endorse unrealistic hope. The invitation is to engage with "the harsh realities of now".



As a sub-title we are taking **Climate Sensitivity** [by how much does the planet as a system amplify the effects of human activity], **Target Temperature** [what is the maximum rise in global temperature that will still enable us to avoid dangerous climate change, and how can we achieve it], and the **Carbon Budget** [how much extra emissions, if any, can we dump into the sky-fill site without overwhelming the system's behaviour]. Finally, we develop some **Guidelines for Strategic Action**. So that is my title and my subject.

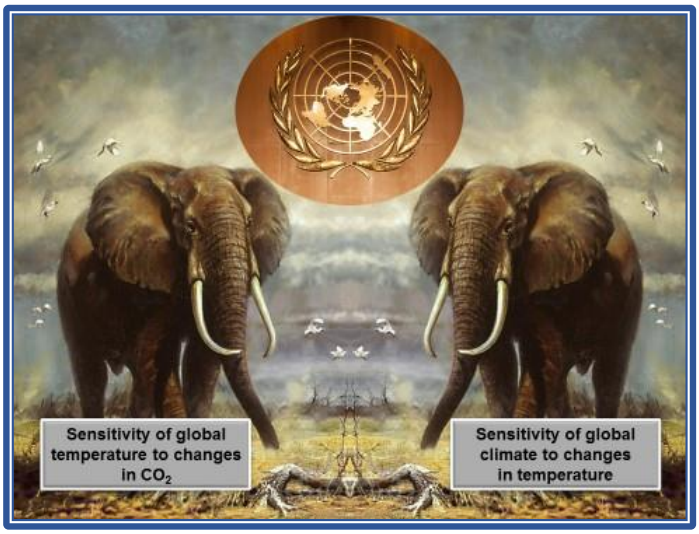
We will start **thinking globally** – I am not dealing with local, tiny issues. I am dealing with global behaviours, global dynamics, seeing the system as a whole.

The Planet acts a little bit like your own body. I mean in response to temperature. If your temperature goes up by three or four degrees you are getting into life-threatening stress. Five degrees you are probably dead, three-and-a-half you may be going into delirium. If your temperature drops by about two or three degrees, you are suffering hypothermia. You have a very narrow temperature scale within which to operate. Your body is very sensitive to small changes in temperature. So is the Planet. Just five degrees marks the difference between a mile and a half of ice over the Birmingham Bull Ring and the kind of traffic jams we have on

Spaghetti Junction today. Five degrees, that is all. So in that sense, global sensitivity is extremely high.

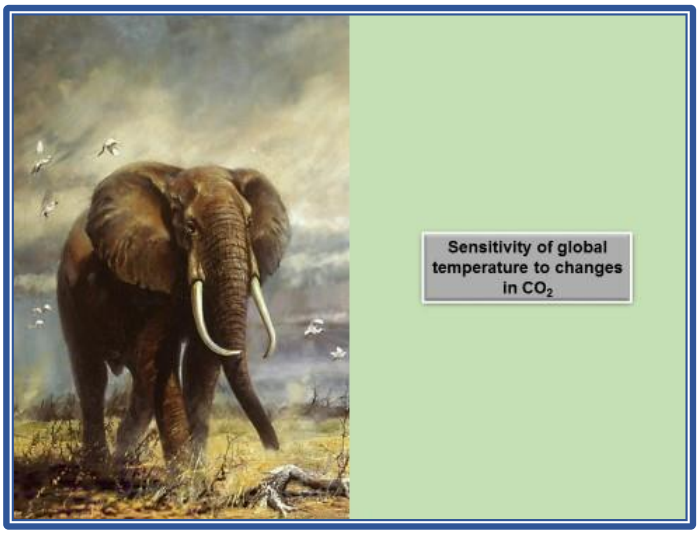
From a different perspective, if you catch flu your temperature goes up. If you have streptococcal meningitis it will go up a lot further and faster. So there is sensitivity of temperature to pathogen behaviour, and there is also sensitivity of the body to change in temperature. Two different sorts of sensitivity and that is what I want to look at here.

Earth System Sensitivity is the elephant in the room of climate change – it is what we don't look at because it is so fundamental that all the rest follows. In fact – a lot of this material was developed for a presentation after the Ban Ki-Moon Climate Summit in New York in September 2014. I said at that point that there were two rogue elephants rampaging through the corridors of impotence in the United Nations.

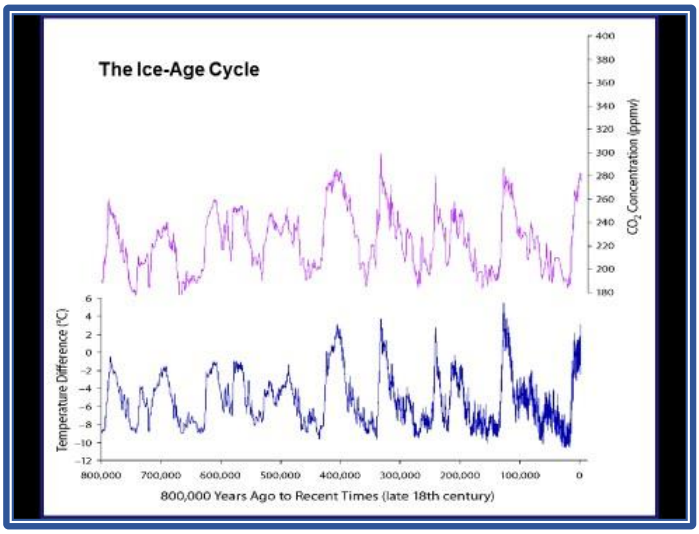


The first Elephant represents the sensitivity of global temperature to changes in the atmospheric concentration of CO_2. That is the "by how much does it amplify" question. The second Elephant deals with the sensitivity of the global climate to small changes in average surface temperature. Two elephants, two different sorts of sensitivity.

During this first major section, I am going to focus on the left-hand elephant. **The sensitivity of global temperature to changes in atmospheric concentration of CO_2.**



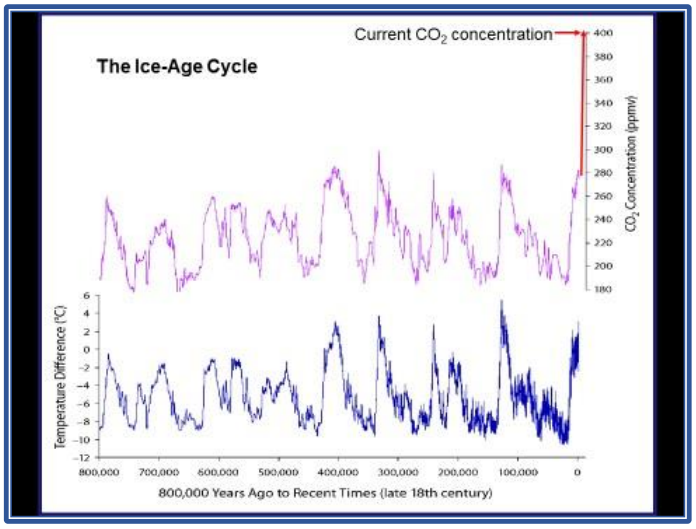
As a first step we will look at **the relationship between temperature and CO_2 concentration during the Ice-Age cycle**. Information is taken from tiny bubbles of air trapped for many thousands of years in Antarctic ice.



This slide presents data covering some 800,000 years of Earth's history. You will notice that the temperature change has gone warm, ice, warm, ice, warm, ice, warm, ice, warm, ice, warm, ice, warm, ice, warm. You will also notice that the shape of the graph of carbon dioxide matches the shape of the temperature graph. It is a bit like the coastline of Africa matching that of America isn't it? They correlate. In fact the atmospheric concentration of carbon dioxide is the "control knob" on our global climate.

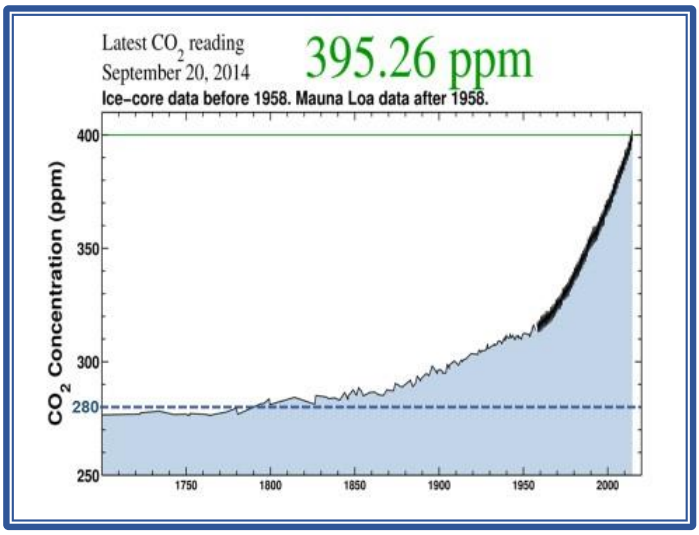
Now I am going to focus on the top right area of the graph and superimpose the change in atmospheric concentration of CO_2 during our recent history since the start of the Industrial

Revolution. 400 parts per million is where it is actually at today. The climate has never changed like that before. So what has been happening here?



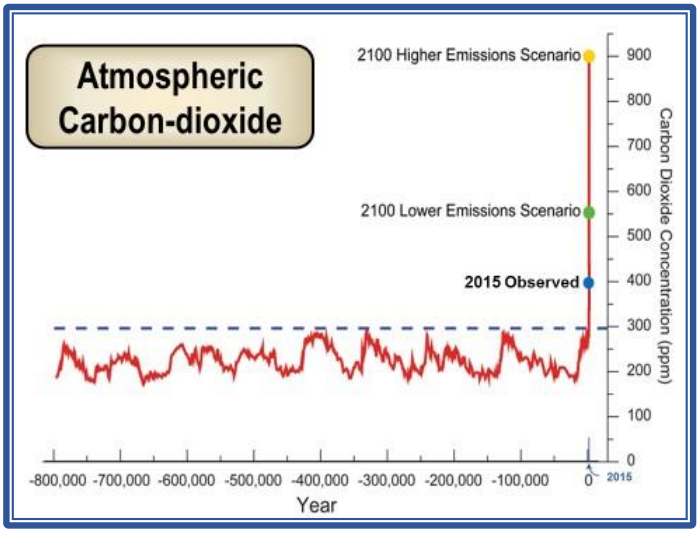
Oh and by the way, this took off like a rocket! You have seen – of course you have seen – a rocket taking off on the television if not in person! It starts very, very slowly and it accelerates faster and faster. Started very slowly about 250 years ago and accelerated and accelerated. Most of the change has happened in the last 50 years. Now, today, at this point, we are going faster and accelerating more sharply than at any point heretofore.

Let's expand that section a little more. Here is that 250 year period laid out.



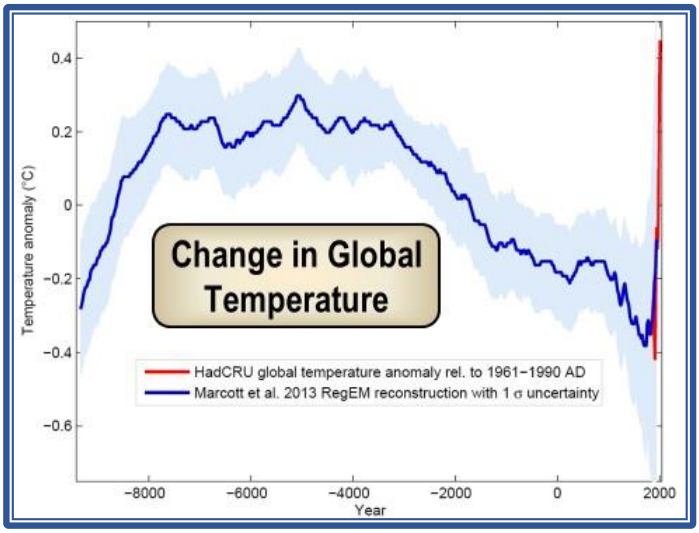
We came in before the industrial revolution, at around 280 parts per million. That has been the peak CO_2 concentration in most of the inter-glacial warm periods. And then, towards the end of the 18th century, those wretched British started digging up coal. They did that more and more, and burnt it and used the steam to drive manufacturing machinery. Then they used the steam engines for mobiles, and the innovation went international. Then oil was added to the mix. Oil we can use for mobile transport. There was a bit of a hiatus during the Second World War and then emissions really took off, driven particularly by coal-fired electricity generation

and a massive expansion in the use of oil. We will shortly be looking at the effects on global temperature driven by this change from the stable, pre-industrial base-line, to the industrial accelerator which is going up faster and faster and faster. However, in this next slide we look first at some of the possible levels of CO_2 concentration that could well be achieved during the rest of this century.



Today we are here at 400 ppm. The best promises on the table for Paris, the big climate conference next December, look like taking us way beyond 550 ppm, going to more like 700 ppm when they are implemented. That is the best answer on the table. But continuing to do what we are actually doing ("business as usual") takes it way beyond that up towards 800 or even 900 ppm by the end of the century. There is nothing in the history of the planet anywhere near this kind of phenomenon. The great extinction event of the Paleocence-Eocene Thermal Maximum, (c. 56 million years ago) was 300 times slower than this and the changes in CO_2 concentration were way below what we are driving today. So do you begin to see what we are looking at?

Now **what has actually happened to temperature?**

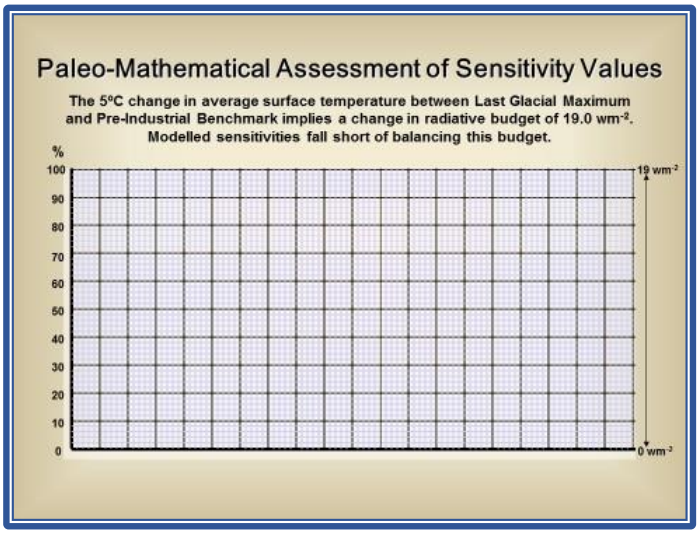


This slide shows what happened to global temperature over 12,000 years as we came out of the last ice age. It rose steadily till c. 9,500 years ago, reached a peak, plateaued, rose to a higher maximum and then started to descend towards the next ice age, until those wretched Brits started to dig up the coal. Now we have changed the average surface temperature of the planet by about 0.85 of a degree Centigrade. That is all that is. And you dare to tell me that there is no evidence for human activity in climate change! You don't get that kind of abrupt marker simply from natural variation! This is an extraordinary intervention. This replicating infestation, with accelerating energy use and increasing output of waste gasses from the combustion of fossil hydrocarbons, has driven 0.85 of a degree of change in the last century and a bit. Then this year, in 2015, we have a major "El Nino" event in the Pacific Ocean which is expected to drive average global surface temperature up by another 0.15°C.

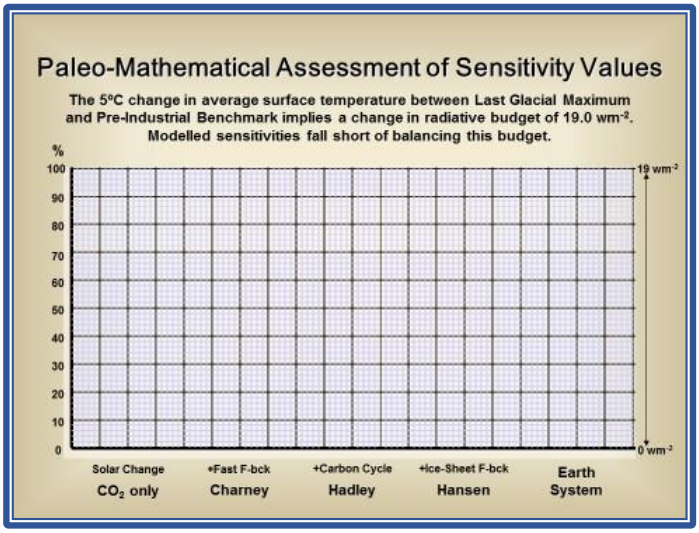
The earth is incredibly inert. It is a huge kettle of water. We are applying a small amount of heating, 1 or 2 watts per square metre. But summed over the whole surface of the earth that comes to a massive amount of energy. The time lag between cause and effect, between the heating and the final change in temperature, is vast. So this explosion of the heating, driven by change in the concentration of carbon dioxide, has run way ahead of the eventual temperature change. As a result, the currently observed change in temperature represents only about $1/6^{th}$ of the eventual expected increase in temperature resulting from changes we have already made to the atmosphere. If this is $1/6^{th}$ of the change that would occur if we let it go to equilibrium, then how far up beyond this screen is it going to go?

In this next major section, we are going to use 20,000 years of history to **evaluate different approaches to the relationship between CO_2 concentration and temperature**.

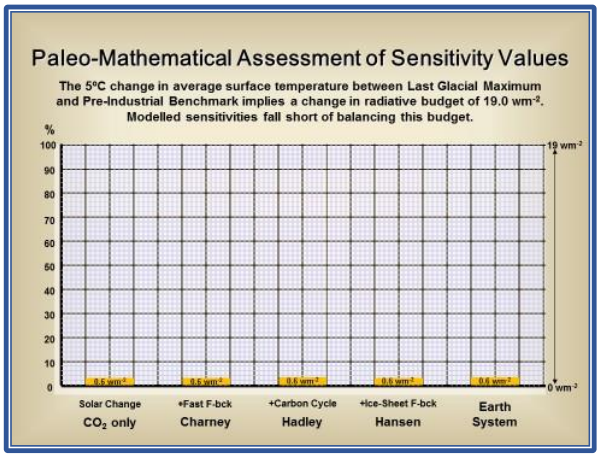
In order to maintain the energy balance of the Earth, the average surface temperature of the planet has to change by 1°C to compensate for each 3.8 watts per square metre of radiant energy blocked by change in the greenhouse effect. So if temperature has changed by 5°C between the depth of the last ice-age and the pre-industrial benchmark, it means that 19 (3.8 x 5) watts per square metre has been blocked because of the change in the greenhouse effect and the reflectivity of the planet during that period. In this next slide, we explore this in percentage terms (up the left side) or as contribution to the total of $19wm^{-2}$ (up the right hand side).

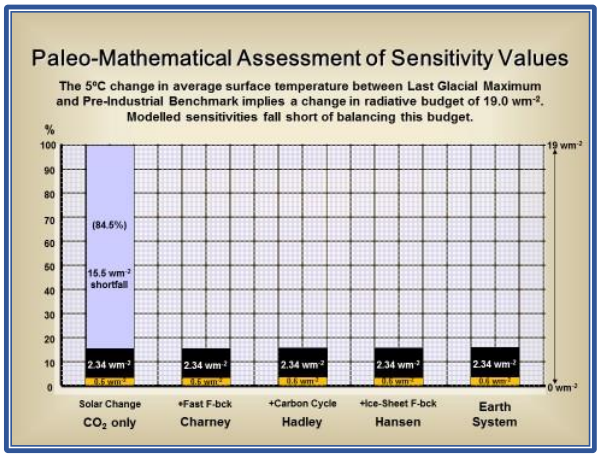


So what are the elements that give rise to this change? I am going to introduce them in layers, starting with change in solar energy, then adding the contribution of CO_2 on its own. In the next layer we will add the effects of the "fast feedbacks" (the "Charney" sensitivity). That will be followed by the carbon-cycle feedbacks (Hadley), the ice-sheet dynamics (Hansen), and finally the full Earth System Sensitivity including all amplifying processes.

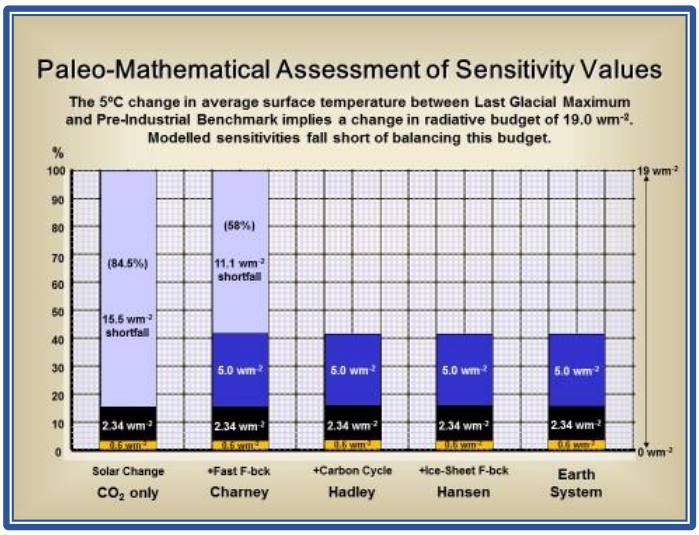


To start with, there is a change of just over ½ watt per square metre in the solar energy received because of **change in the eccentricity of the earth's orbit** around the sun. Change in the concentration of carbon dioxide contributed about 2.3 watts per square metre during that period. The earth system amplifies the effect of carbon dioxide, so if you are just looking at the contribution from carbon dioxide on its own, we have to account for another 84%.

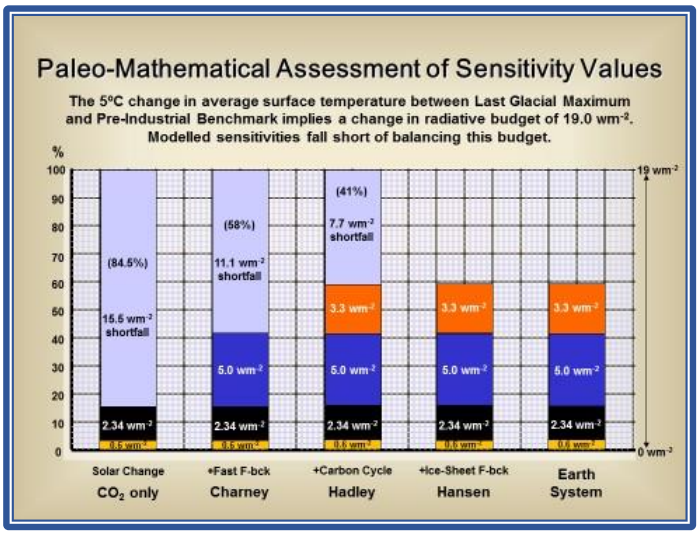




Next we put in the effects of the fast feedback response (the "Charney" sensitivity): firstly atmospheric water vapour (a powerful greenhouse gas) increases with rising temperature, secondly, cloud-behaviour changes and increases the feedback, and thirdly, the area of floating sea ice decreases with rising temperature so reducing the reflection of solar energy. These come into action as soon as the temperature starts to change, which is why they are called "fast feedbacks", though the resulting heating is very slow. They added about $5wm^{-2}$ during this period, leaving 58% still unaccounted for.

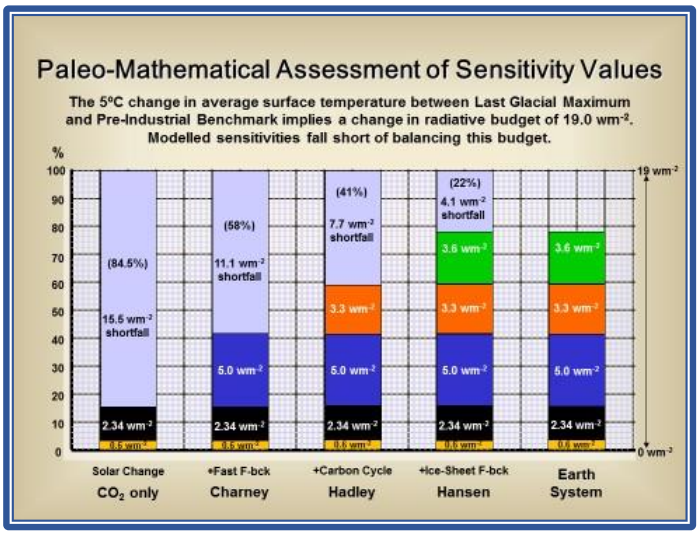


The current set of climate models, the one used as the basis for the Fifth Assessment Report of the IPCC, deals only with these fast feedbacks. Workgroups 2 and 3 of that Report, together with all the subsequent analyses prepared in the run-up to the Paris Climate Conference, all share the same methodological dependency. They all use an understanding of climate feedback dynamics that falls short of reality by nearly 60%, but persists in being inappropriately used as the basis of the international negotiations in Paris.

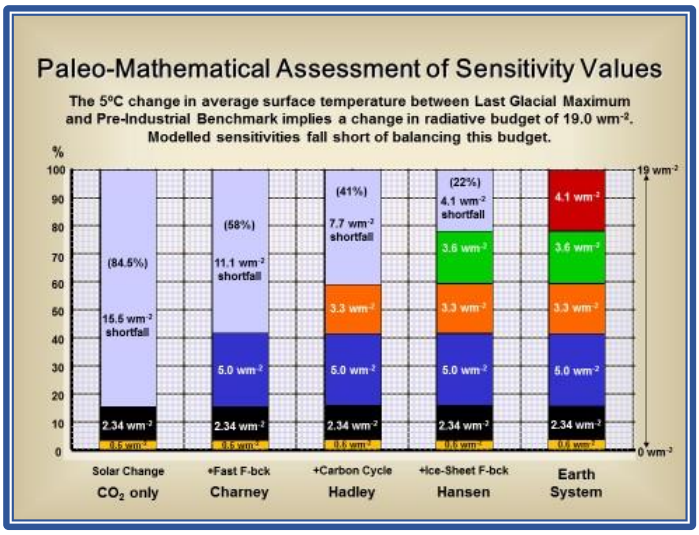


Some of the more sophisticated super-computer models (like that of the UK "Hadley" centre) also include some of the effects of the carbon cycle feedbacks which add around another 3.3wm^{-2}. We are still 41% short of the 19wm^{-2} required to balance the energy budget of the Planet.

The carbon-cycle feedbacks are not taken into account in the IPCC advice to Policymakers. This situation reflects a long-standing policy in the work of the IPCC which tends to focus on the output from the most basic computer models, while the more sophisticated ones are seen as "outliers" and tend to be ignored! No evaluation, judgement, or ranking of the competence of the various climate models is undertaken. The outputs from the good, the bad, and the crude, all tend to be given the same weight.



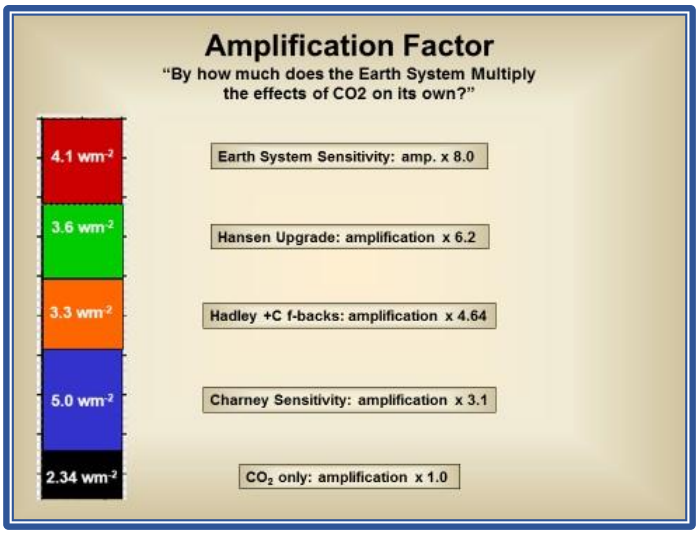
Using non-modelled historical data, James Hansen has included the long-term ice dynamics – the changing reflection from the big land-based ice sheets. That adds another 3.6wm^{-2}. But even Hansen's work is still some 22% short of the target.



The dynamics of the planet as a whole, with all its feedbacks and all their interactions, known and un-known, adds a final 4.1wm^{-2} to the total, so completing the change of 19 watts per square metre between the depths of the ice age and the pre-industrial bench-mark. That is the figure we need to be working with in making strategic policies. It is the ground of what we have come to term the full **"Earth System Sensitivity"**.

However, as I noted above, the IPCC continues to limit its strategic policy advice to the outcome of computer models that are only dealing with the fast feedbacks. That is in spite of the number of articles in the academic press pointing out the inadequacy of the approach. There is a rapidly growing understanding that these are incredibly conservative models. They continue to understate the problem massively. As in cartography the map is not the territory, so also in the world of computer simulation, it is important to bear in mind that the model is not the reality!

We are now in a position to answer that fundamental question with which we began: "By how much does the earth system as a whole amplify the effect of changes in atmospheric composition resulting from our combustion of fossil hydrocarbons?" The **value of the Amplification Factor** will be built up step by step and then related to the wider question of "Climate Sensitivity"



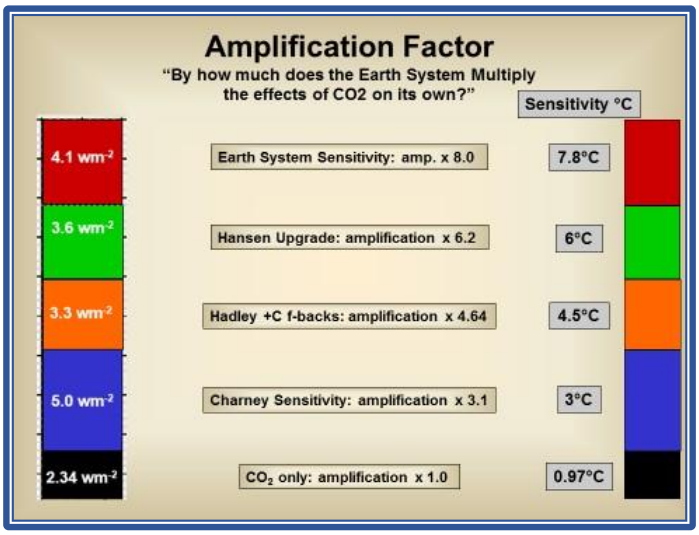
Using the stack of contributions to the global radiative budget between the last glacial maximum and the pre-industrial benchmark, we first introduce the effects of change in CO_2 concentration on its own. No systemic amplification is involved and the value is, by definition, 1.0.

Next we add the contribution from the fast feedbacks, (the "Charney Sensitivity" of the IPCC computer modelling ensemble). The value of the associated Feedback Factor stands at 3.1. Adding in the carbon-cycle feedbacks increases the Amplification Factor to 4.6, while including the feedback from the dynamics of the great land-based ice sheets increases the Amplification Factor to 6.2.

Completing the amplifying effect of all the feedback processes of the whole earth system provides a value of 8.0 for the Amplification Factor. In other words **the Earth System as a whole amplifies the contribution from change in the atmospheric concentration of CO_2 by a factor of 8.0**, a little over 2.5 times the value used by the IPCC in its strategic advice to Policymakers.

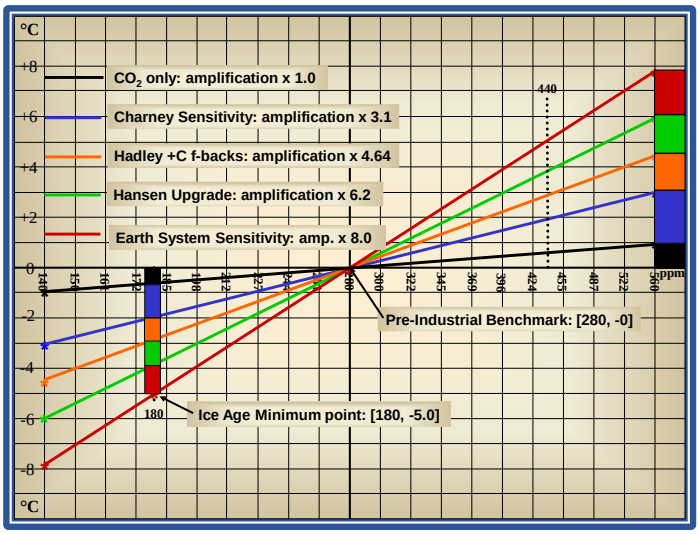
Moving from the specific example of change since the last ice-age, we can derive the **value of the more generalised "Climate Sensitivity"**, the equilibrium change in average surface temperature of the planet following a doubling of the concentration of atmospheric CO_2.

The temperature change required to compensate for the effect of doubling concentration of CO_2 on its own is calculated to be 0.97°C. Climate sensitivity when only fast feedbacks are taken into consideration stands at 3°C. Including the effects of the carbon-cycle feedbacks raises the value of Climate Sensitivity to 4.5°C. Adding the contribution from the ice-sheet dynamics correlates with a 6°C value for Climate Sensitivity.



While the Sensitivity value representing the equilibrium dynamics of the Earth System as a whole stands at 7.8°C. Though please note that this figure is derived from slow and close to equilibrium conditions of change in the Quaternary period. It may be too low in the current conditions of the Anthropocene.

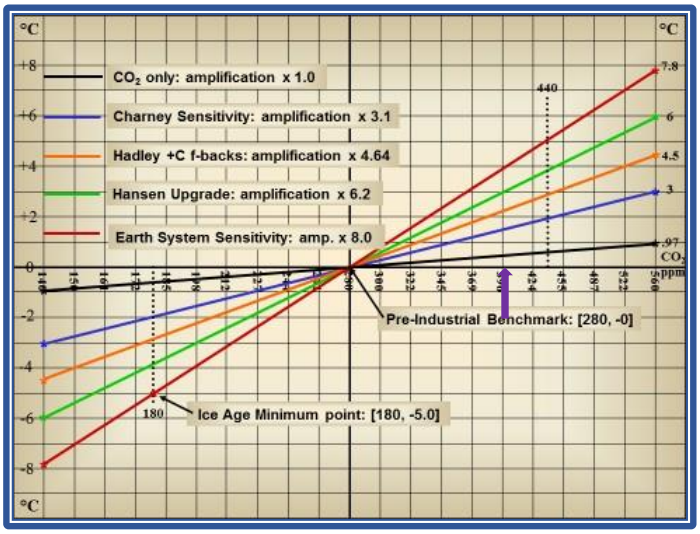
In order to show in more detail, how the equilibrium temperature adjusts in response to changes in concentration of atmospheric CO_2, I am going to **introduce the "Graphic Simulator"**. The carbon dioxide forcing, the fast feedbacks, the carbon cycle feedbacks, the ice-sheet dynamics and the full earth system sensitivity, are all mapped onto a different scale, like this:



The CO_2 concentration is on a "log scale" along the central axis (to provide a constant greenhouse effect for each doubling in CO_2 concentration). In the mid-point is the pre-industrial benchmark, 280 ppm. We will take the temperature at that point as the basic guideline with changes above or below. The CO_2 concentration at the depth of the last ice-age was 180 ppm, so it had only changed by 100 ppm before we started burning fossil hydrocarbons for our energy. Change in CO_2 concentration only contributed a small amount to the temperature change. The fast feedbacks contributed more, as did the carbon feedbacks, and

the ice-sheet feedbacks. The methane feedbacks, together with all the other bits and pieces that make up the full Earth System Sensitivity, contributed the rest.

Removing the coloured columns you will note that the values of Climate Sensitivity (temperature change expected after a doubling of concentration of atmospheric CO_2) are presented to the right of the upper quadrant.

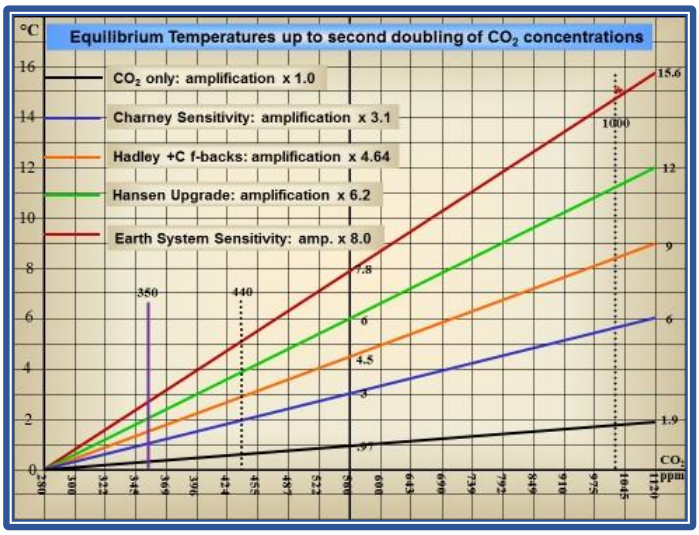


Now if you are working with computer models using only the fast feedbacks, you would predict that 2°C would be achieved at around 440 ppm. But if you are using the Earth System Sensitivity (look at the red line), then at 440 ppm we would be looking at more like 5°C of change. The way the earth system behaves in reality, the temperature is going to go up by 5°C. However, as I keep reminding you, the computer simulation, inadequate and partial though it may be, is what is still being fed into the process of strategic policy-making on the assumption that the temperature change will only be 2°C for a concentration of 440 ppm of CO_2.

At present the CO_2 concentration stands at 400 ppm. I have marked it with a purple arrow on the graph. If it is thought to be safe to go up to 440 ppm, then we have a good budget to play with. There is still plenty of room in the sky-fill site. However, if we don't use the inadequate computer models, and instead apply the real Earth System Sensitivity, then 2°C was hit way back around 334 ppm. We have already overspent the budget by a large amount! Getting the picture?

In order to explore the future, I need to expand the image to cover the next doubling of CO_2.

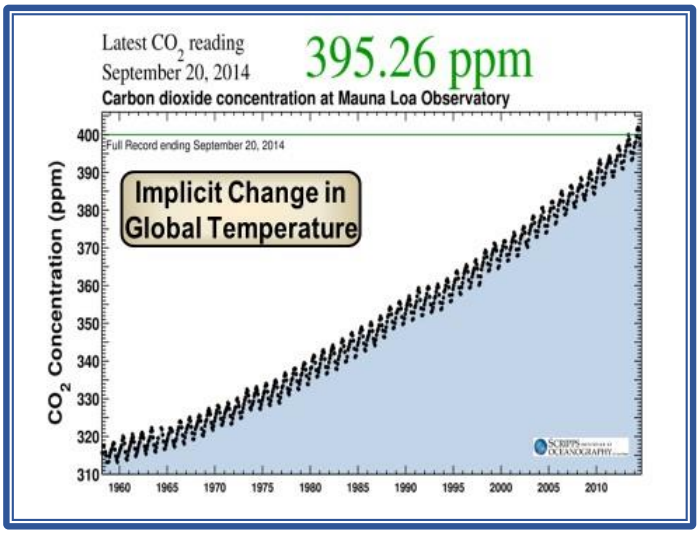
The quadrant from the industrial benchmark to the first doubling is now in the bottom left corner. National promises ("INDCs") concerning reduction in CO_2 emissions, have been tabled ahead of the COP21 in Paris. Those promises look like pushing us to about 700 ppm (if they are implemented, and there is no guarantee about that whatsoever!). Business as usual is driving us up towards 800 or 900 ppm up here. If we cannot improve the level of promised emissions reduction, then "We might hit 4°C" predicts the Intergovernmental Panel on Climate Change.



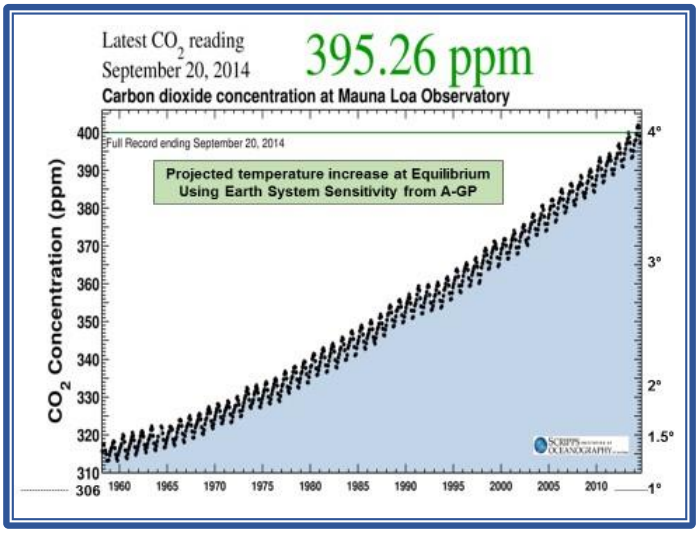
Just examine the way the earth system behaves at the level of 700 ppm. We are not looking at something around 4°C on the blue line, but an increase of more like 10°C on the red line. That is twice the temperature shift between the ice ages and the pre-industrial benchmark. If we are not able to constrain the current "business as usual" behaviour, then the temperature rise increases to more like 12°C, (and two or three times that amount in the Arctic!) Good bye all the ice on earth. Welcome to something like 90 feet of sea level rise, or even more when all the Greenland ice-cap and the whole of the Antarctic ice sheet melts. Civilisation would have collapsed and we would have evacuated London well before then!

In this next section I introduce **the concept of "Implicit Temperature Change"**. I will be relating it to the past increase in concentration of atmospheric CO_2 as it changes over time. Then, once we have passed the point of present concentrations, we will relate implicit temperature change to the total accumulated levels of future carbon emissions.

First I reintroduce the graph of rising CO_2 concentrations based on measurements made since 1958 at the Mauna Loa Observatory in Hawaii. The measurements are taken at high altitude, in a location well away from major sources of emission. They give a good representation of average global concentration.

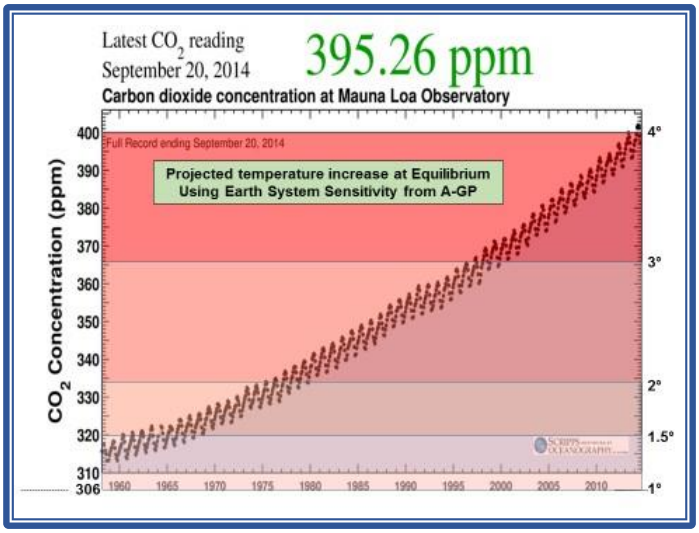


I am going to look at the eventual equilibrium temperature implicit at different stages of this curve. We are addressing the question: **"What is the eventual change in temperature to be expected as a result of any specific level of rise in the concentration of atmospheric carbon dioxide?"** We take into account the fact that the earth system multiplies the effects of carbon dioxide by a factor of 8. That is based on the full Earth System Sensitivity derived over the last 10 years' work of the Apollo-Gaia Project. The temperature scale is shown up the right-hand side to show what implicit increase is to be expected at different stages of the CO_2 concentration, when all the feedbacks have worked their way through the system.



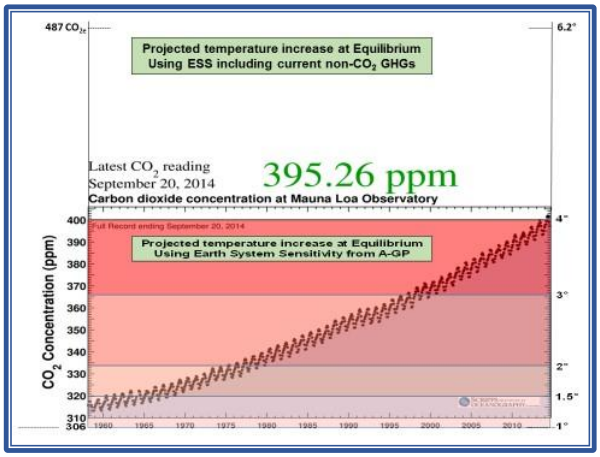
Would you notice that 1 degree was already implicit in the system when the date was about 1956. An increase of 1.5°C was implicit by around 1965. 2°C was implicit by about1978. So 2°C was already in the pipeline towards the end of the 1970s. Today we are under the illusion that reducing our emissions will still keep us under 2°C!

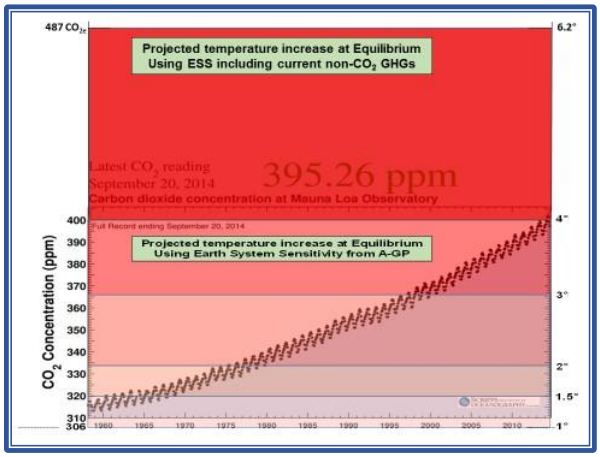
An implicit increase of 3°C was passed around 1998. That was six years after the great Earth Summit in Rio that initiated the United Nations Framework Convention on Climate Change. By then we were already committed to an increase of 3°C which is way above what they later described as a "safe ceiling".



And now today, at 400 ppm, we have an implicit increase of about 4°C as a result of current concentrations of CO_2.

But we have also emitted nitrous oxide, ozone, methane and CFCs. If you add the effects of all those non-CO_2 greenhouse gasses together I have to reduce this scale in order to get them in.





There are about 487 ppm carbon dioxide equivalent already in the atmosphere. The implicit temperature increase from that is now about 6.2°C when it has all worked through to equilibrium. (Contrast that with the increase of 1.5°C which is what the computer models are predicting.) That leads us into a discussion of the **collapse of the Carbon Budget**.

The budget approach was introduced just prior to the 2009 Copenhagen Conference by a big think tank in Germany, the WGBU. It was chaired by Professor John Schellnhüber, who was one of my initial colleagues at the start of the Apollo-Gaia Project. In his introduction to their work he wrote: "this Report is a compromise between what is scientifically necessary and what is politically and economically feasible". This report is a compromise between what is scientifically necessary – what the actual situation demands – and what can be tolerated politically and economically. Now when key scientists put out reports that have already made

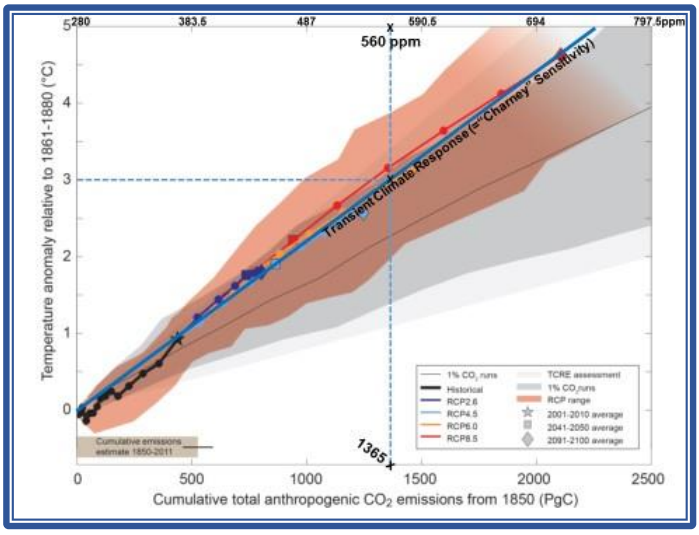
that compromise, so that what they report to the policy-makers is already an appeasement document in terms of what the vested interests will allow, then, in my opinion, they have lost their authority as scientists. History sits in judgement on the scientific community. Our task is to hold the reality, the reality-testing for the global society, even if it hurts, even if we get death threats, even if our funding is taken away, and our academic position is called in question. We have to hold that reality and resist the pressure to go into appeasement mode.

That report introduced the Carbon Budget as the basis of negotiation for the planetary future. What did they mean? Let me explain it like this: If we estimate that the temperature impact of what we have already emitted is x°C. But we need to keep the increase to not more than 2°C. Then we estimate that between x°C and 2°C there is still significant space in the sky-fill site into which we can dump more of the waste products from the combustion of hydrocarbon fuels. That is the budget. How much more can we dump into the sky-fill site and still be safe?

Once this "available carbon budget" is established, then you see we inevitably have one almighty punch up in the international community. "We have the right to emit", "No, **we** have the right to emit", "this is not equitable or just", "we want differentiated responsibilities", "look at the history of who has put out what", "look at our needs, we are developing countries", and "we depend for our survival on the income from fossil industries, you can't take that away from us", "look at the sea level rise, we have lost our livelihood", and so on. This massive group of completely conflicted interests is trying to wrangle over how to spend an assumed budget.

So how **do** you calculate the "available carbon budget"? Is there still any available space in the sky-fill site? And if so, how much and under what conditions? That is what this section is all about.

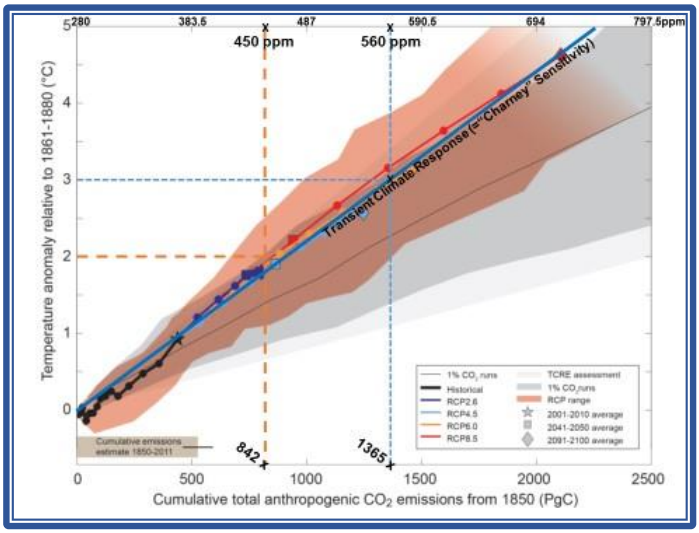
Let me introduce the instrument that was used to create the key graphic in the Summary for Policymakers of the Scientific Workgroup of the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. It provides the basis for the IPCC calculation of the available carbon budget. Its purpose is to establish the relationship between total cumulative human emissions of carbon dioxide and the expected temperature response. I think it is a very complicated diagram, so let me go through it with you.



Along the bottom axis, the total cumulative human emissions is marked in thousands of millions of tonnes of carbon. Where we are to date is the 2011 shaded estimate extended to about 580 GtC to represent total emissions by 2015.

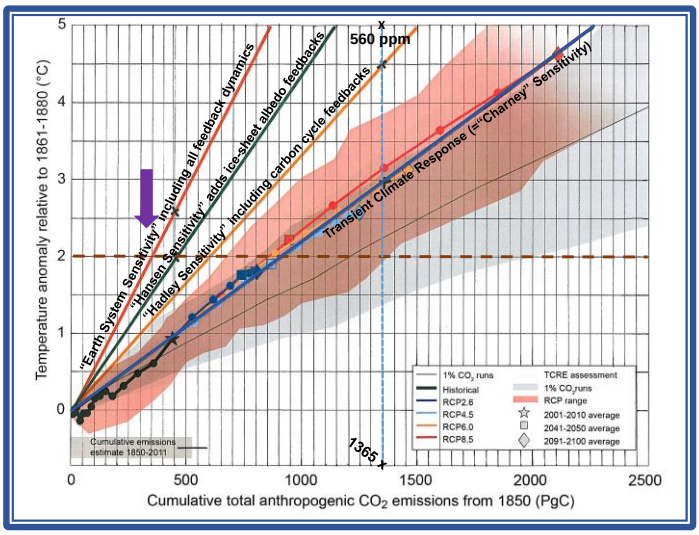
Across the top I have put in atmospheric concentration of CO_2 in parts per million. It starts from the pre-industrial bench-mark of 280 ppm, and then increases across to the right. British start to burn coal and so on. Today we are at 400 ppm. The first doubling of CO_2 concentration would take us to 560 ppm from which I have dropped a vertical line to the equivalent 1365 GtC point. The conservative computer models, using only the fast feedbacks, predict that we would expect an increase in temperature of about 3°C in response to this first doubling of CO_2 concentration. If you draw a straight line from the origin through that point of intersection you have the slope of the transient climate response. It is identical to the Charney sensitivity, using only the very fast feedbacks and ignoring all the rest. That was the blue block on our previous slides, remember? They are basically showing that the temperature change is proportional to the total cumulative emissions (with an Amplification Factor of only 3.1) – a straight line.

Next let us look at the 2°C marker – there it is. We put the 2 degree marker-line across and then drop it down where it intersects with the 450 ppm line. That correlates with cumulative emissions of some 842 thousand million tonnes of carbon, so there is still some space from where we are to date (580 GtC) until we reach that (842 GtC). In other words, there is apparently an "available carbon budget" for future emissions of around 262 GtC.



In his public briefing, the co-chair of Workgroup I, (the scientific section of the Intergovernmental Panel on Climate Change Fifth Assessment Report), introduced this diagram from the Summary for Policymakers as: "a better metric than climate sensitivity" for the projection of future policy. So I challenged him because **the available budget changes dramatically as soon as we start looking at other values of Climate Sensitivity**.

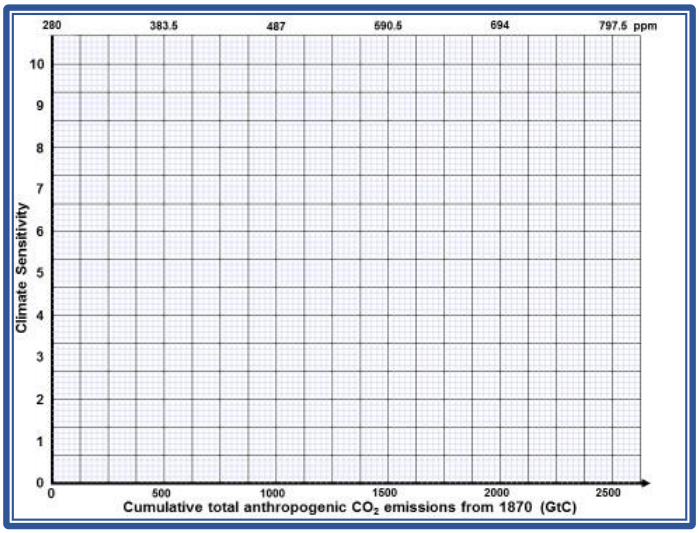
Let me illustrate the point in this next slide. The blue line is the one they are using in the IPCC Report. If we add in, as we should, the carbon feedbacks, it becomes steeper and the 2 degree line is cut further to the left. If we add in, as we should, the ice dynamic feedbacks, then it gets even steeper still and the 2 degree line is cut even further to the left.



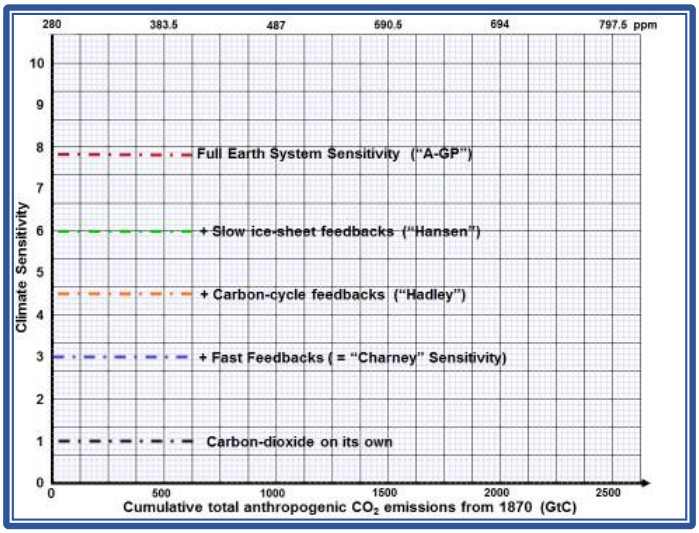
If we add in, as we should, the full Earth System Sensitivity and use that as the basis for our strategy, then 2 degrees is passed way back in our history (see purple arrow marker), not somewhere in the future with still space to play. So sensitivity is fundamental to the existence or otherwise of an available carbon budget.

So let's explore in detail the **relationship between climate sensitivity and the available carbon budget**. This takes us well beyond the IPCC advice to Policymakers.

Here I am taking exactly the same scale along the bottom, the cumulative anthropogenic CO_2 emissions. Atmospheric CO_2 concentration is retained in ppm along the top. However, up the vertical axis I am going to plot not temperature but Climate Sensitivity itself. They are different. Here are the numbers ranging from zero (no temperature response to change in CO_2 concentrations) right up to a sensitivity value of 10°C following a doubling of atmospheric CO_2.

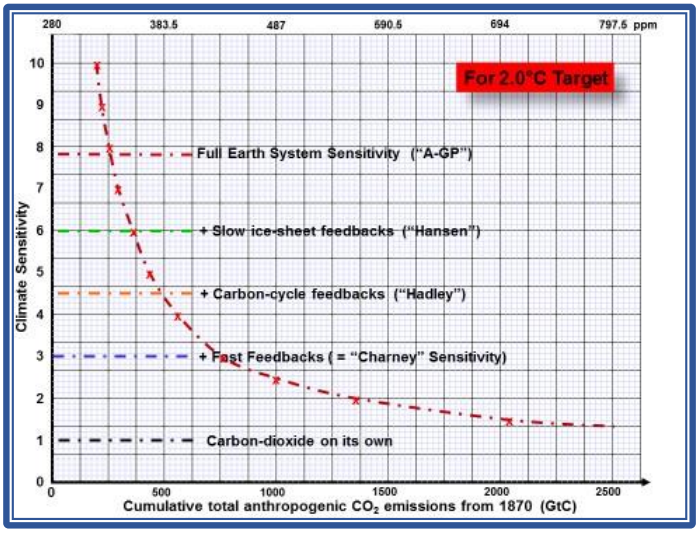


Then we insert the sensitivity values relating to the various approaches to the subject. 0.97°C for a doubling of CO_2 on its own, ignoring all feedbacks. 3°C taking account of only the fast feedbacks. 4.5°C when we add in the effects of the carbon cycle feedbacks.



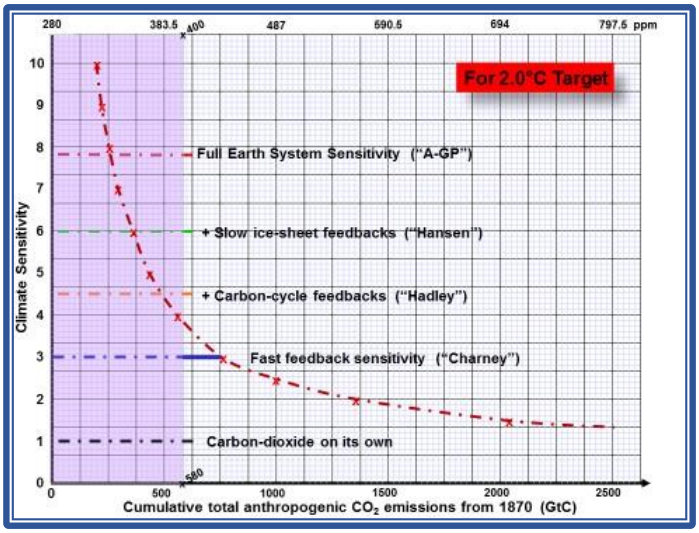
6°C when we include change in albedo from the great land-based ice-sheets. **Finally 7.8°C** gives the global change in average surface temperature when equilibrium is reached in response to a doubling of CO_2 concentration, **based on the full Earth System Sensitivity**.

Now let's explore the potential of this new illustration. First I have drawn the 2°C contour line on the temperature hill. (The temperature axis points out into the room at right angles to the screen.) Above and to the right of the contour line the temperature is higher than 2°C. Below and to the left of the contour line the temperature is lower than 2°C.



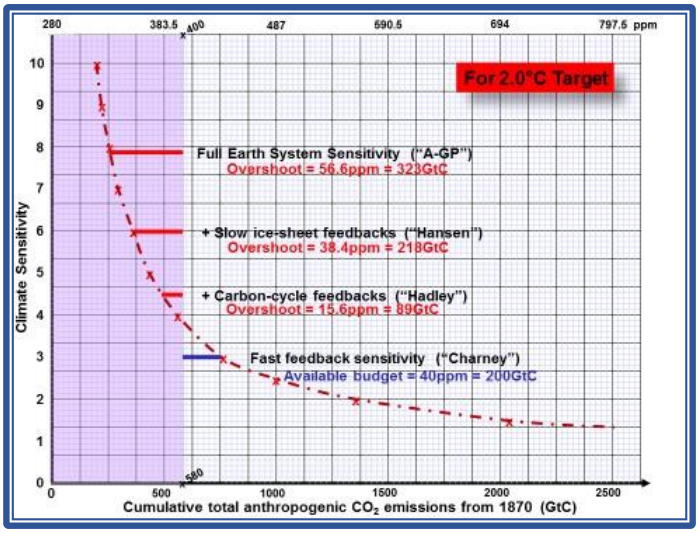
Now clearly, if the sensitivity of the system is very low we can emit vast amounts of carbon and never climb up to the 2 degree contour line. On the other hand if the sensitivity is very high then even small amounts of emitted carbon will take us up, across and above the 2 degree boundary path.

Next we add in the light purple shaded area to represent what we have already emitted to date. Examine the fast feedbacks line, the "Charney" sensitivity line. Using this understanding of sensitivity, 2°C is hit where the blue line meets the contour path that marks the boundary beyond which temperature would rise beyond the 2°C guideline.



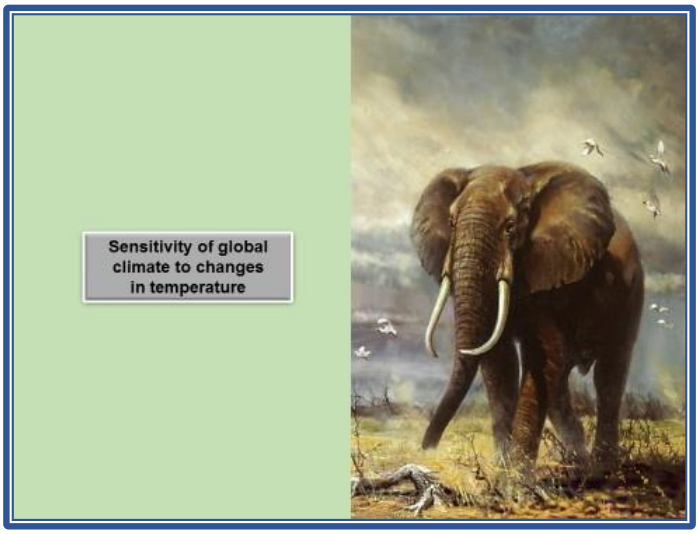
The edge of the purple shading marks the amount we have emitted to date. So the solid blue line represents the available carbon budget, the amount we can go on emitting, (adding to the sky-fill site) before we cross the 2°C boundary. It gives us an available carbon budget of around 200 GtC. (Rising to some 250 GtC if we are prepared to take a 50% risk of overshooting the target!)

However, if we add in the carbon cycle feedbacks (as we should), if we add in the ice-sheet dynamics (as we should), if we go to full Earth System Sensitivity (as indeed we must), then in each case we have already overshot the 2°C marker. We are in debt. Rather than facing a positive budget represented by the length of the solid blue line, we are overdrawn by the length of the solid red lines. You think you have a positive balance to spend in the budget but you haven't. You are bankrupt. Sadly, the Planet doesn't have a central bank to write off the debt or guarantee a bail-out! This is just the harsh reality of the way the Earth system works.



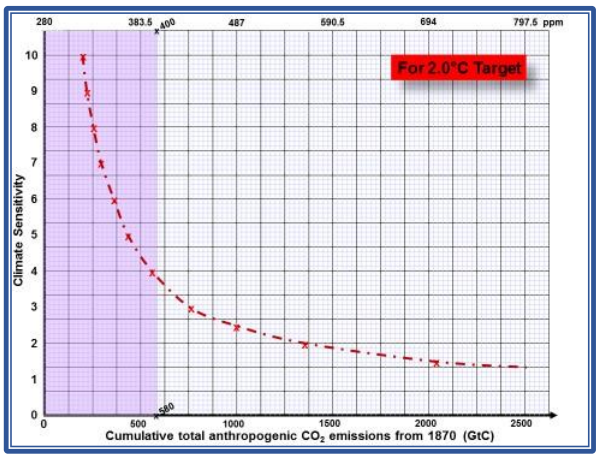
Let's put some numbers on this. Those basing their policy advice on the IPCC are talking about humanity having a budget of 200-250 gigatons of carbon still to be emitted before we risk overstepping the 2°C guideline. No we haven't! That budget has already collapsed with the carbon cycle feedbacks, let alone the ice-sheet dynamics, let alone the full Earth System Sensitivity. **We have already overshot the 2 degree boundary by some 323 thousand million tonnes of emitted carbon.**

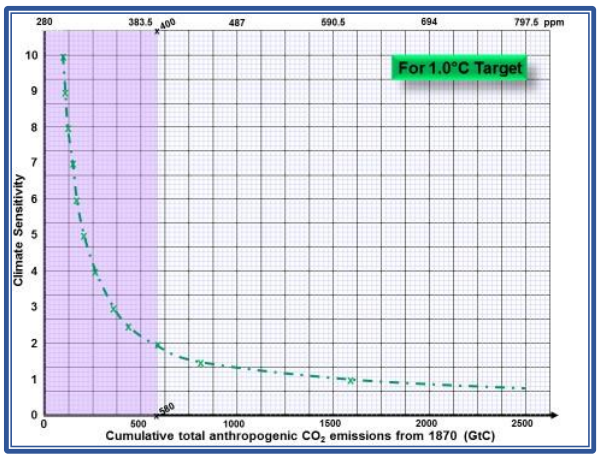
And then the other rampaging elephant comes into view. This is the one that says that **the global climate system is incredibly sensitive to changes in temperature.**



In the 1990s, in what was essentially a political judgement, it was decided that "2°C looks as if it will be a reasonably safe target to set as the maximum permitted rise in average global surface temperature". There was not much scientific evidence for it, and some of the evidence they did cite was actually wrong. Today we have only increased the average surface temperature of the planet by 0.85°C but we are already seeing all sorts of dangerous disruption to the global climate. I won't go into the details, you know them well enough.

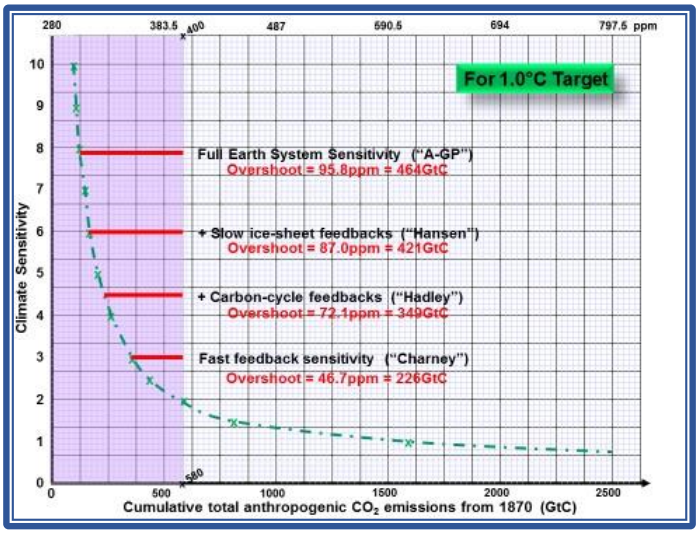
Back in the 1980s and early 1990s, (and again more recently) James Hansen and other scientists were saying "we daren't go above a 1°C rise, it would be catastrophic." But politically and economically it was judged to be more appropriate to put 2°C as the target ceiling.



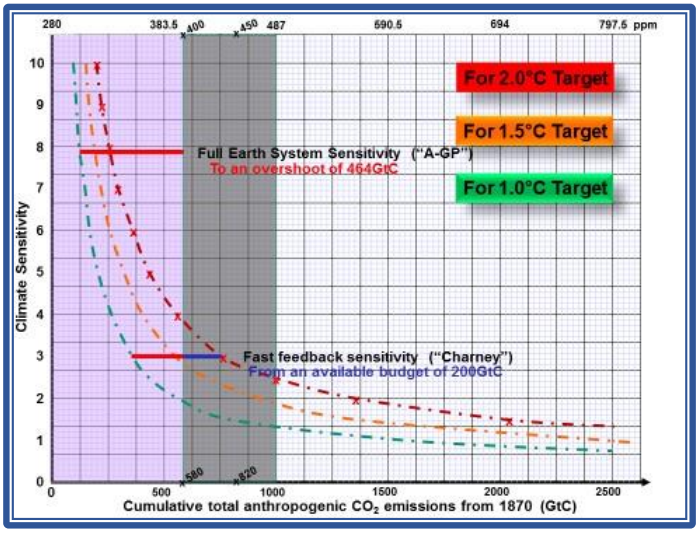


Now this elephant, this elephant has a very wise eye. He is saying, "Excuse me, the extreme sensitivity of climate to changes in temperature means that we have to **reduce the target from 2°C to no more than 1°C, and even that carries significant dangerous risk**".

Did you see what happened to that contour line? The red line is the 2°C contour line. The green contour line for 1°C is much lower down the hill. It is tighter in to the axes.

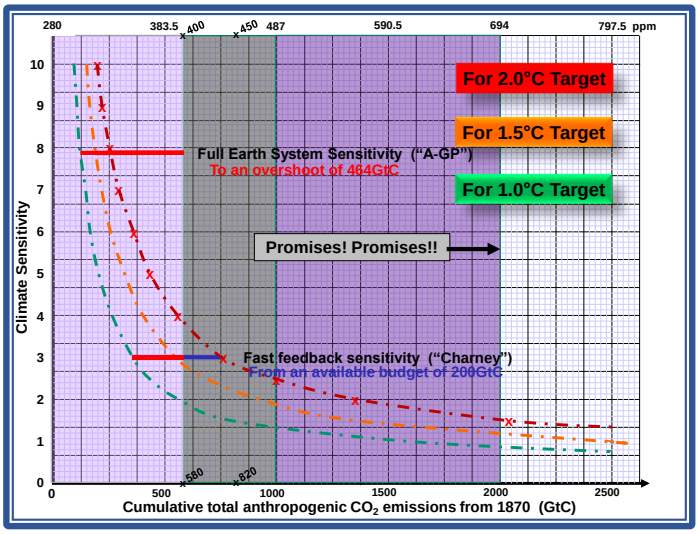


Even using the "Charney" fast feedback sensitivity, it is quite clear that we have already overshot the 1°C boundary by some 226 gigatons of emitted carbon. So even the computer models say there is no available carbon budget for a 1°C target. However, the full Earth System Sensitivity (which should now replace the "Charney" sensitivity) indicates that we have overshot the new target by about 464 gigatons of total emitted carbon.

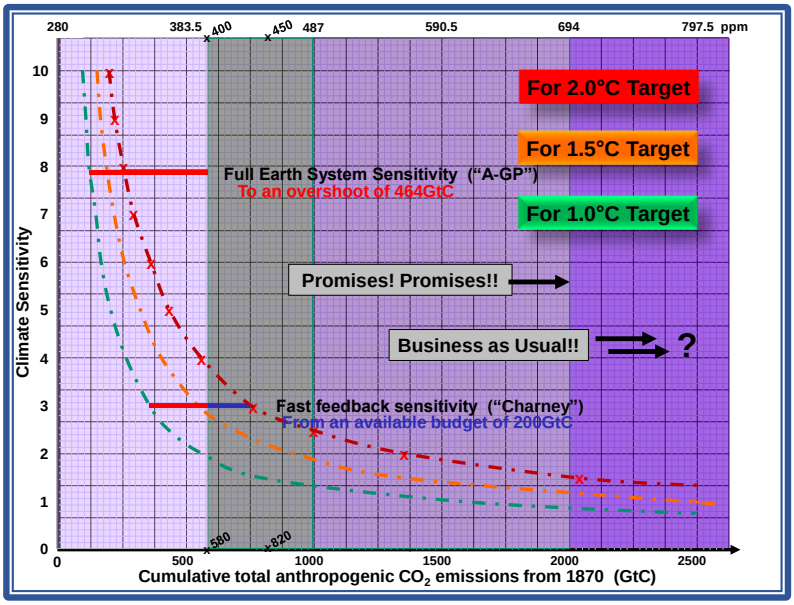


Up to this point we have taken no account of the non-carbon-dioxide greenhouse gasses. So now I put them back in here represented by the grey shading. Even using the 2°C target and the appalling understatement of our computer models, we have overshot that. Using the Earth System Sensitivity, their inclusion expands the overdraft of 464 GtC by a further 520 gigatonnes of carbon equivalent.

In this next and final section we turn our attention to the **strategic negotiations facing the international community** as it prepares for the major UNFCCC climate conference to be held next December in Paris (COP21). Updating the "Charney" sensitivity to the value of the full Earth System Sensitivity has profound implications for strategic policymaking and so for the whole international negotiating process. You will remember that most countries have already submitted their intended proposals (INDCs) for limiting or reducing their greenhouse gas emissions in an attempt to keep temperature rise below 2°C.



Initial evaluation of the outcome of these tabled promises indicates that they are likely to take us to a cumulative total of anthropogenic emissions of about 2,000 thousand million tonnes of emitted carbon in gaseous form by the end of the century. That would push the atmospheric concentration of CO_2 up to around 700 ppm, as represented by the darker purple shading.

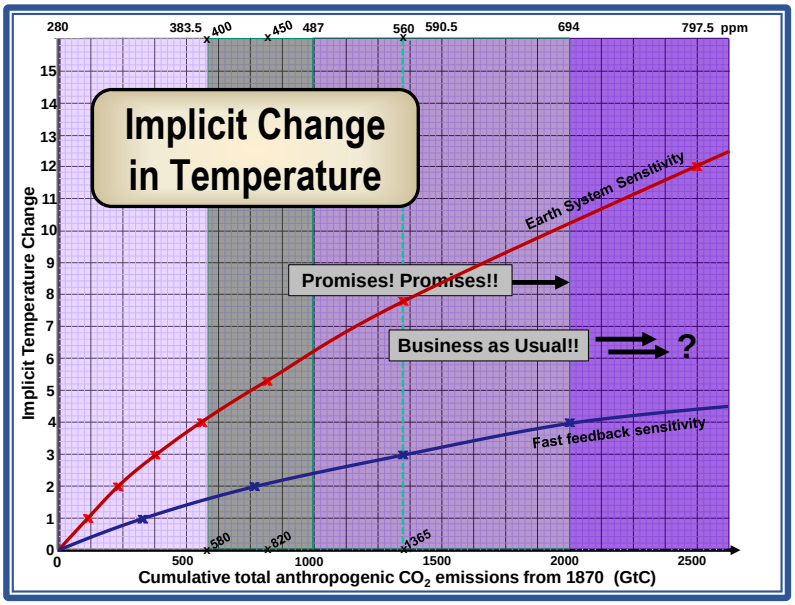


Meanwhile the "business as usual" path, on which we are currently embarked (very dark purple), is going to drive us even further than that, threatening to top the 2,500 GtC and overshoot the 800 ppm level of CO_2 concentration. The international negotiating process

currently concentrates on the attempt to restrain business as usual and limit it to the level of the commitments already made. Then there is the massive task of raising the level of ambition of those promises in order to bring them more in line with the suggested available carbon budget as suggested by the IPCC.

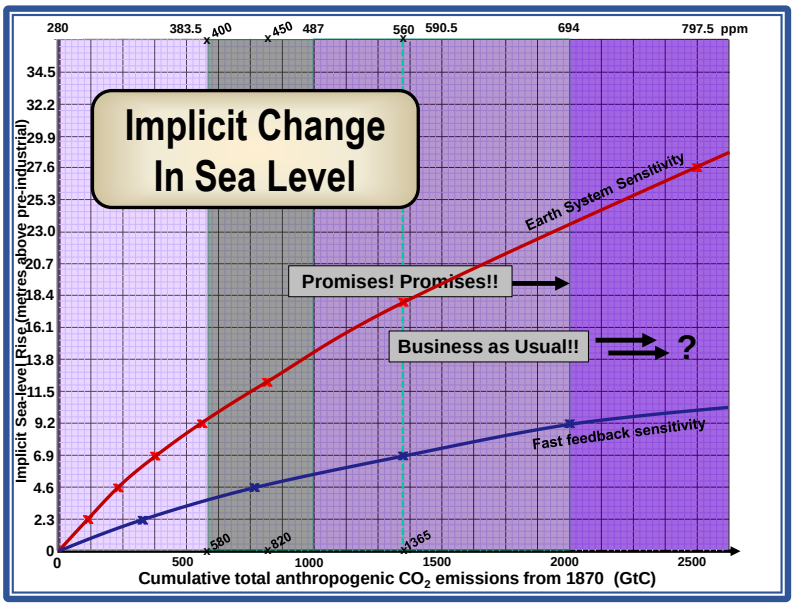
Next let me introduce the **two fundamental parameters of global change** that are driven by the cumulative total anthropogenic emissions of carbon dioxide. They are, **firstly, the implicit change in average global surface temperature,** and, **secondly, the implicit change in average global sea-level.** The term "implicit" encapsulates the eventual change in the system for which the given total amount of emissions would be responsible.

This next slide therefore demonstrates the **implicit change in global temperature correlated with total cumulative emissions**. The red line shows the temperature profile predicted by the full Earth System Sensitivity, while in contrast, the lower blue line indicates the temperature change indicated if sensitivity is limited to the fast feedback response underlying the conservative computer model ensemble on which current strategy is erroneously based.



(By the way, as I noted a few minutes ago, the value of the Earth System Sensitivity itself may still be too conservative. It is derived from planetary behaviour during slow and near-equilibrium change during the Quaternary period (alternate ice-ages and inter-glacials). Its future value is expected to rise due to degrade in the carbon sinks, enhanced biomass die-back, and methane release, all of which are driven by the pace of change and far-from-equilibrium conditions of the Anthropocene, the Age dominated by human behaviour.)

We now turn to the **second fundamental parameter, namely implicit change in sea level**. A series of recent studies provides a reasonably robust "rule of thumb" that predicts a minimum of 2.3 metres of eventual change in global sea level for each 1°C change in average global surface temperature. This next slide keeps the basic form of the illustration, but replaces the temperature scale by one representing change in sea-level. It multiplies the temperature scale by 2.3.



If the current implicit change in global surface temperature stands at 6.2°C, then the current implicit change in sea level stands at 14.26 metres, of which only 20 cm has been observed to date. That leaves over 14 metres still to come.

As I have noted before, the inertia of the earth system is massive. Observed effects lag far behind applied causes. The behaviour is very apparent when we note that the implicit temperature change caused by current cumulative emissions stands at 6.2°C. Observed temperature change, however, has only registered 0.85°C. Explicit (observed) change therefore stands at only 13.7% of implicit change. **Over 86% of the implicit temperature change is still in the pipe-line.**

Sea level change is subject to double inertia in the system. In terms of temperature, the observed effects lag massively behind the applied cause. In terms of sea level, the observed temperature change itself acts as cause, and the change in sea level lags massively behind that driver. So observed change in sea level lags massively behind observed change in temperature, which in turn lags massively behind implicit change in temperature. That is itself driven by the fundamental cause of system change, namely total cumulative anthropogenic emissions.

Quantitatively, observed temperature change of 0.85°C implies sea level rise of 2.0 metres, of which only 20 cm (i.e.10%) has been observed. But 0.85°C is itself only 13.7% of currently implicit temperature change, so the observed rise in global sea level of just 20 cm represents only 1.4% of the current implicit change in global sea level. Some 98.6% of implicit rise in sea level is still in the pipe-line.

It is imperative that the implicit changes are taken as the basis for current decision-making. We have to stand at the bar of history and say "We knew the implicit change resulting from what we are doing to the planet was this. We had only observed a tiny amount of it, but we knew this lot was coming and was inherent in what we had done." Do we dare to stand at the bar of history and say that we knew that these levels of temperature change, these levels of sea-

level change, were going to be the outcome of our strategic decision-making, yet refused to take them into account? How dare we?!

Historically **the pace of ice-melt** (and therefore of change in sea level) has danced in tune with multi-millennial time-scales reflecting astronomical changes in the orbital shape and the tilt and wobble of the earth's axis of rotation. Today the pace of ice-melt is driven by rapid increase in global temperature and we have no historical precedent by which to predict its timing. It is likely to be exponential and much more rapid than current models suggest.

Implicit benchmarks for COP21. If cumulative total emissions could not be reduced below the level to which the current set of promises would lead, then the implicit increase in average global surface temperature would be just over 10°C (not 4°C as predicted by the IPCC). That would be reflected in an implicit rise in global sea level of just over 23 metres.

If it proved impossible to constrain business as usual to the set of promises, then the implicit rise in global average surface temperature would increase to around 12.5°C, and the rise in sea-level would be almost 30 metres. It should be remembered that these benchmarks ignore the effects of non-CO_2 greenhouse gasses (currently accounting for an additional 54% over and above the effect of CO_2 on its own.) They are also likely to be set too low in the conditions of rapid change and far-from-equilibrium behaviour of the Anthropocene. The task of leadership in this context is awesome.

In this picture, Laurent Fabius, the French President of the COP21 conference (to be held in Paris later this year), is flanked by Manuel Pulgar-Vidal, the Peruvian President of COP20 (which was held in Lima last December), and by Ban Ki-moon, the Secretary-General of the UN. Individually and collectively they have positions of great authority but very little actual power. The institutional structures that they represent are rendered impotent by the very processes and protocols which define them and constrain them.

In his closing remarks at the end of the Climate Summit held in New York in September last year, Ban Ki-moon reiterated the "international commitment to achieve a meaningful and universal agreement in Paris in 2015". He noted "the commitment to limit increase in global

temperature to no more than 2 degrees by cutting emissions". Every report and every paper being prepared and presented ahead of the Paris Conference echoes this three-fold mantra of:

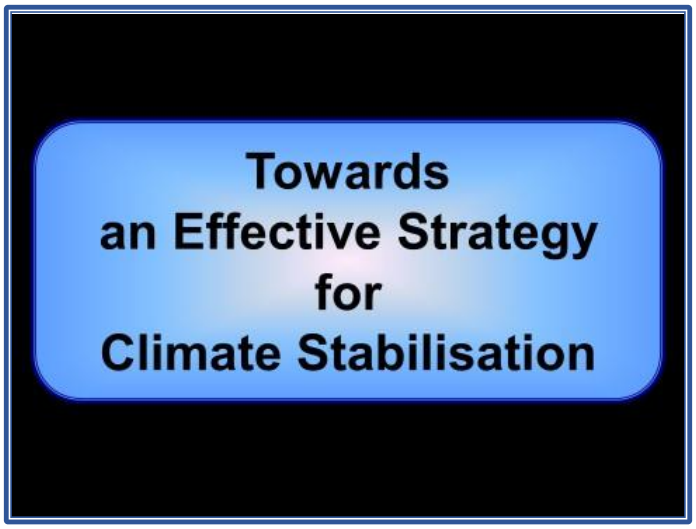
- The 2°C ceiling
- The budget approach to negotiations
- The strategy of goal-achievement by the reduction of carbon emissions.

The pressure to collude with this party line is phenomenal.

Any agreement reached in Paris on these terms would be a strategic disaster, committing humanity to a course of action that would guarantee catastrophic climate change with all the unmanageable consequences that would involve.

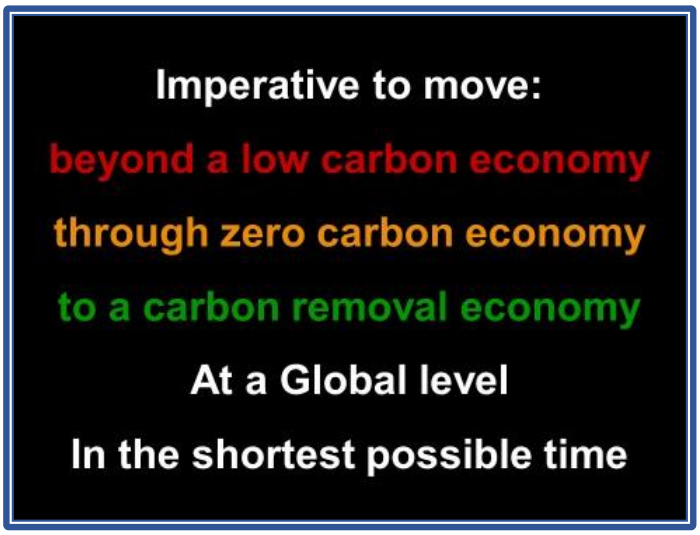
There is also profound pressure to determine strategic response by reference to currently observed changes in the global climate system. That is a grossly inadequate approach when dealing with any complex system subject to the kind of massive time delays between cause and effect that we have already noted. **Strategic response must be ordered by the scale of implicit change in system behaviour rather than by reaction to the minor symptoms already presenting themselves for observation.**

Towards an effective strategy for Climate Stabilisation.



It is now abundantly clear that limiting temperature change to 2°C cannot be achieved by emissions reductions on their own. There is no available carbon budget. It is already massively overspent, even for the 2°C target. Moreover the 2°C target has been set far too high and must be reduced from 2°C through 1½°C to 1°C in order to avoid dangerous climate change and therefore to conform with the globally agreed terms of the United Nations Framework Convention on Climate Change.

Emissions reduction is a necessary but not sufficient step towards climate stabilisation. In addition it is now imperative to draw down much of the stock of emitted greenhouse gasses already in the atmosphere.



It is therefore essential to move beyond the reduced emissions of a low-carbon economy, to pass through and beyond the zero-carbon economy and then to achieve a substantial carbon draw-down economy at a global level and within the shortest possible time-frame. **This demands moving beyond the current one-dimensional strategy of emissions reduction to an integrated two-dimensional strategy that also includes stock reduction.**

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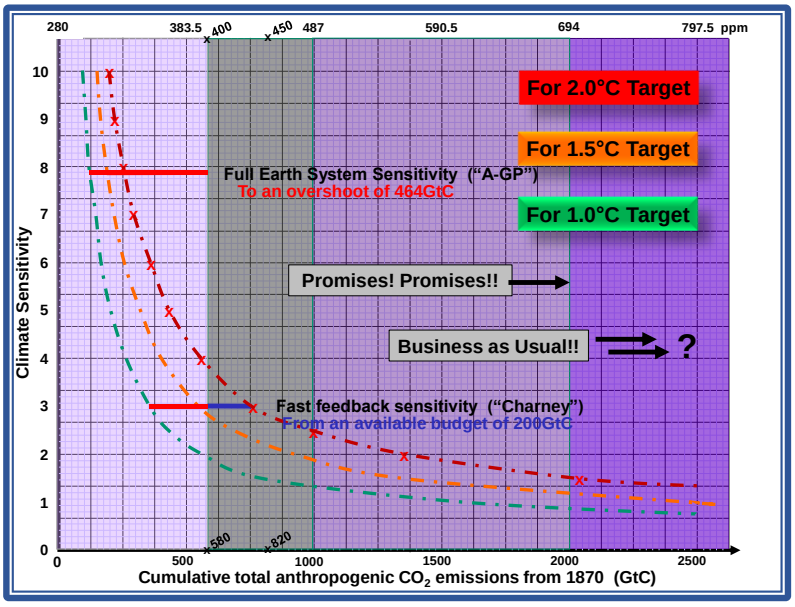
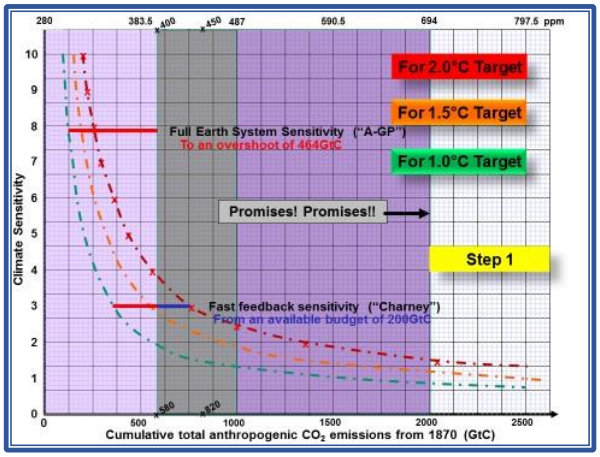
The collective journey towards climate stabilisation involves five global steps

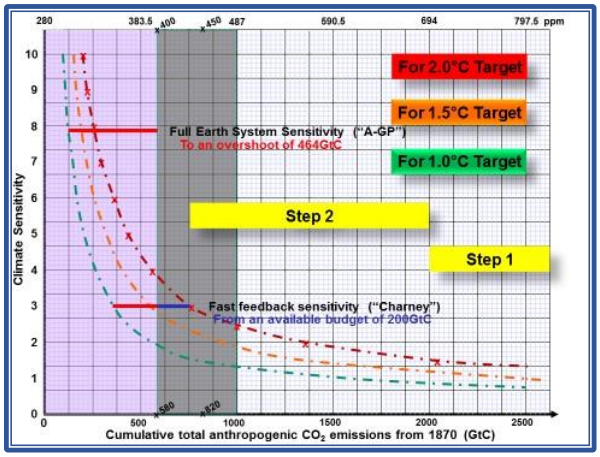
beyond the harsh reality of our current situation:



Step one: involves the constraint of our current "business as usual" behaviour to the set of promises tabled internationally for COP21 in Paris.

Step two requires increase in the ambitions of the tabled set of promises until they match the demands of the IPCC "available carbon budget".

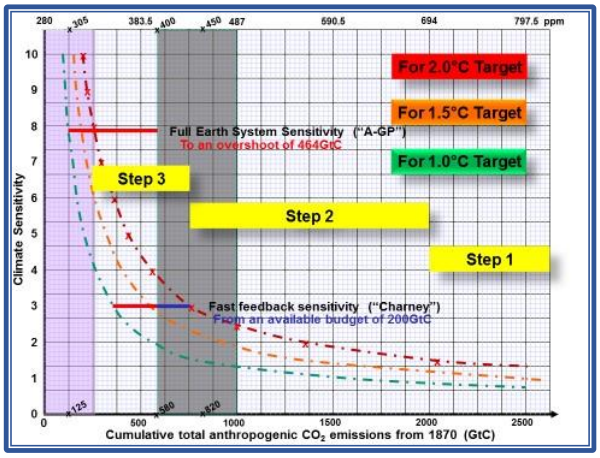


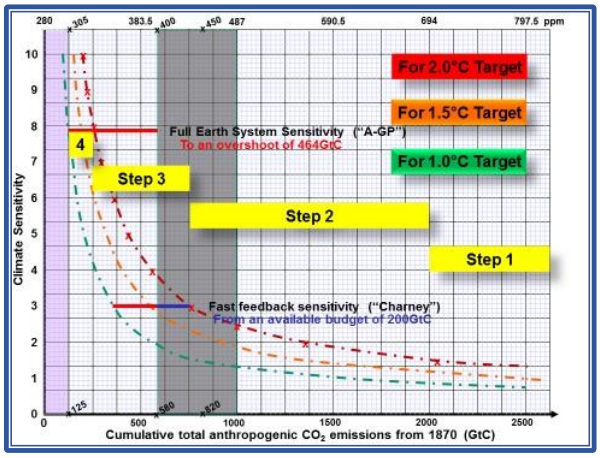


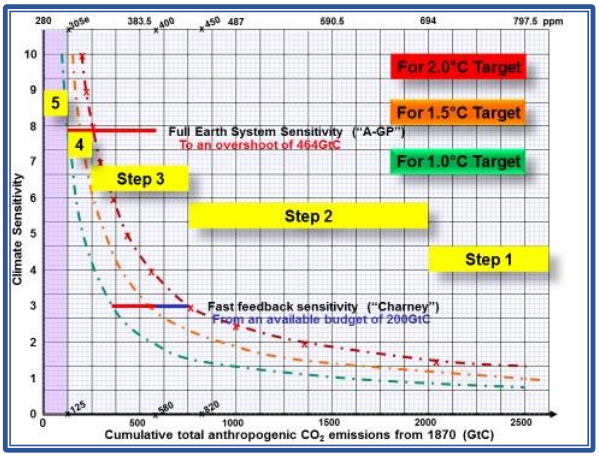
Three further steps would then be required before the global climate could be deemed to be on track for stabilisation at a level that would minimise our exposure to dangerous climate change:

Step three would be the essential replacement of the inadequate computer-derived value for climate sensitivity by the figure for the full Earth System Sensitivity.

Step four reduces the target ceiling temperature from its current setting of not more than 2°C above the pre-industrial bench-mark down to a target increase of just 1°C or less.







The fifth and final step would be the strategic removal of the forcing from all the non-CO_2 greenhouse gasses (or their compensation in extra reduction of the allowed level of CO_2 emissions). In other words the transformation from a maximum concentration of 305ppm of atmospheric CO_2 on its own, to a ceiling of not more than 305ppm of CO_{2e} and its maintenance however the atmospheric composition changes over time.

So we have 5 massive steps between where we are now and where we need to be. However, standing firmly in the path, dominating all the official pronouncements, governing the terms of every official report being tabled ahead of the COP21, and embedded at the heart of the Draft Agreement (Article 2.2), is the policy-directing illusion of the 2°C target, the falsely assumed budget of available carbon emissions (based on the low value of climate sensitivity) and the myth that reduction in emissions on its own can achieve those objectives.

Meanwhile we face a **massive amount of resistance** to staying in touch with the reality of the global climate and bringing our political and economic decision making into line with that reality.

Not least we have to confront the power of addictive enslavement to fossil fuel as the energy source of our global civilisation. We tend to ignore the collateral damage. It is not just about changing our energy mix. It is not just making political decisions. There are massive profits being made from the extraction, refining, marketing and use of fossil hydrocarbons, whether they be coal, oil, gas, fracking or tar-sands. They make the world go round. They make the money that drives the global economy. Remember that, in addition to large multi-national companies, there are some very large national economies that are totally dependent on their income from fossil energy for economic survival, for social stability, for religious coherence, and for the maintenance of political and military power. Resistance to change also extends deep into the social and collective unconscious. That profound motivation for resisting change compounds the power of the more rationalistic political and economic forces outlined above.

The resistance to the implementation of any strategy required to avoid dangerous climate change is massive. **Never, in the course of human history, have so many been trapped in economic bondage to so few.**

So this is a call for global transformation.

It is time to say NO to the dark and toxic energy of the underworld. It is time to say YES to the pure and sustainable energy of light. Photo-dynamics can out-power, out-pace and out-resource any amount of energy we can get from fossil sources. It is time to break free from our bondage to the past. It is time to embrace the freedom of the Sun. It is time to usher in the dawn of Solar Society.

The transition from fossil dependency to solar dependency is an extraordinary shift for our species. It can be compared to the introduction of photosynthesis in the evolution of plants, which could then take solar energy to transform basic chemicals into more complex molecules. Today we are able to take solar energy and transform it directly into electricity, power, heat, and light. That provides the basis for a metamorphosis. We are not caught in the death throes

of civilisation, merely the demise of an inappropriate mode of civilisation. We are experiencing the birth pangs of a new form of humanity.

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Looking forward to a time beyond the trauma of birth, I have a dream:

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

My friends that is the dream. Our task is to make the dream come true.

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David Wasdell Apollo-Gaia Project 23rd September 2015