The Club of Rome

International Conference
on
Managing the Interconnected Challenges of Climate Change, Energy Security and Water

6th and 7th November 2008

Presentation on

Feedback Dynamics and the Acceleration of Climate Change

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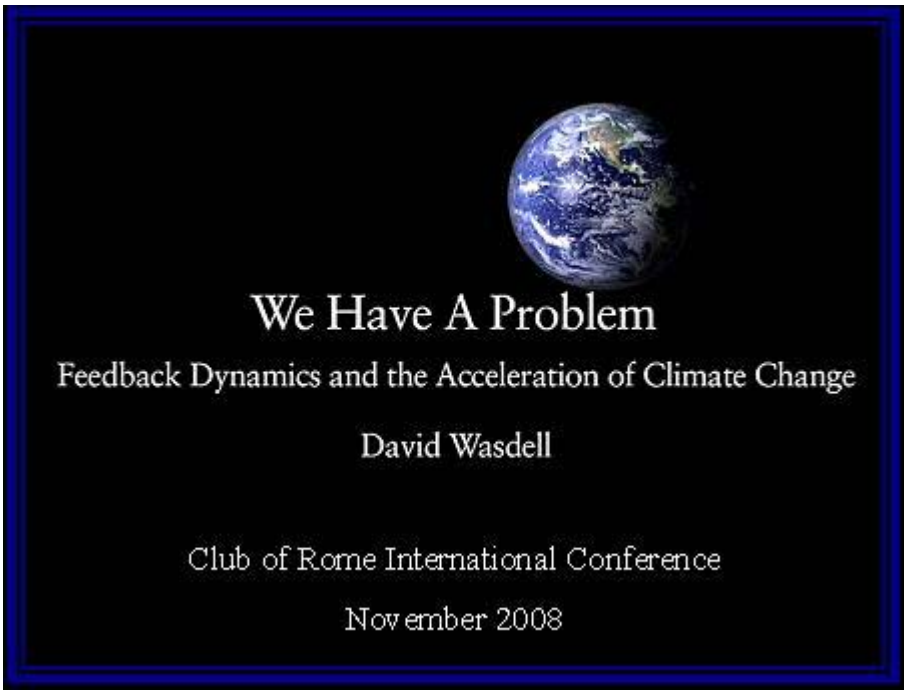

It is three-and-a-half years since the original analysis of the Feedback Dynamics of Climate change was shared with HRH El Hassan bin Talal, the then President of the Club of Rome. He subsequently invited me to introduce the material at the next meeting of the Club in Norfolk, Virginia, and since then there has been an unrelenting process of testing, challenge

and revision of the analysis. It is a privilege to have the opportunity to share the current version with you at this International Conference of the Club of Rome.

During the next few minutes I will offer an introductory overview of the material. A much more detailed treatment is provided in chapters 1 and 5 of the Westminster Briefing in your resource pack. There you will also find a couple of dvds, one is a PAL version for European display, the other is in the more universally available Apple Quicktime format. They give you access to the full-length presentation given last June at the Tällberg Forum, and have been made available by the Tällberg Foundation Team.

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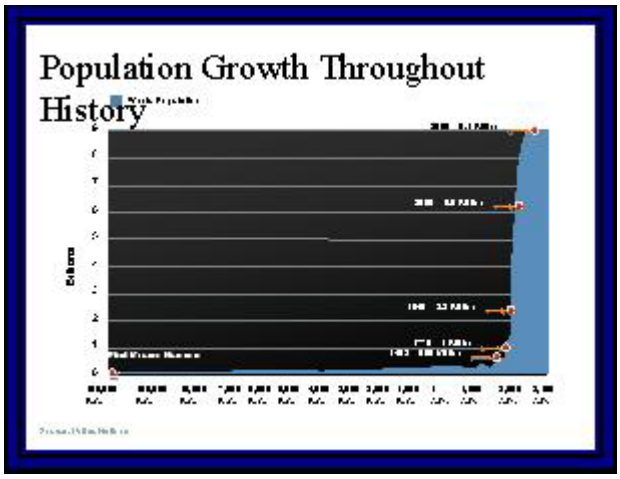
In Brief: This presentation introduces a conceptual, top-down, systems-dynamics approach to modelling the whole earth system as a single global entity. It builds upon, but stands in sharp contrast to, the bottom-up, integrational approach adopted in familiar climate modelling.

Analysis of the feedback dynamics in climate change alerts us to the existence of a "tipping point" in the whole earth system (not to be confused with the set of sub-system, energy re-distribution tipping points identified by John Schellnhüber, Tim Lenton et al). Topological presentation offers a landscape with two complex equilibrium zones. One is the current stability of the Holocene epoch, its dynamics grounded in the conditions of the Pleistocene, with oscillations between cold glacial and warmer inter-glacial periods. The other zone, entered via a slope of runaway climate change, is the higher-temperature solution of the Anthropocene Extinction Event.

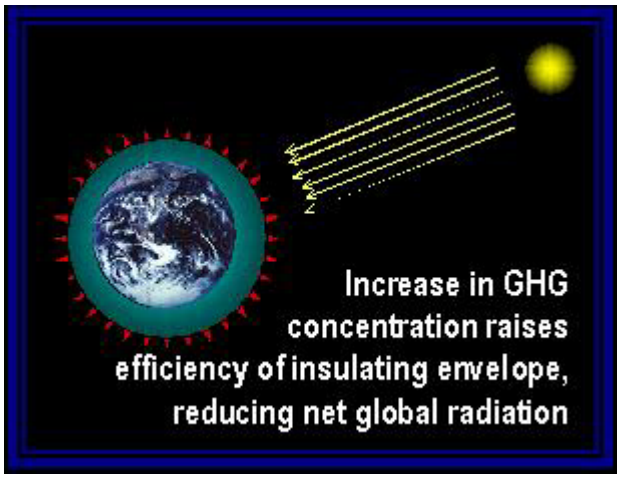
Current observation of accelerated climate change indicates that the natural watershed between the basins has already been passed, and acceleration towards the second solution is underway. Contemporary civilisation faces the choice between continuing the current path towards unstoppable catastrophe, or, as a matter of global emergency, introducing powerful negative feedback processes able to halt the runaway climate change and return the planet to a viable and sustainable equilibrium.



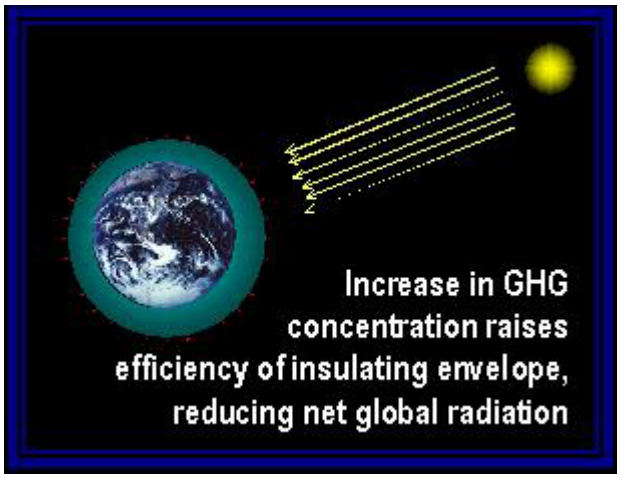
We start with the fundamental driver of the whole set of complex interconnected challenges that together constitute the core of the contemporary global problematique.

Instead of living sustainably on the annual harvest of the biosphere, one species of the Gaian biota has challenged every limit to growth. It has learned to mine the fossil remains of solar energy from the planet's geological past, to consume the capital assets on which the harvest depends in the present, and to mortgage the income of generations as yet unborn. It is a debt-based enterprise that is headed for bubble and crash on an unprecedented scale. Under these conditions, no natural population stabilises at its peak value. The assumption that the human population is immune and will somehow stabilise at some 9.6 billion toward the end of this century, is a fantasy of arrogant hubris born of collective denial.

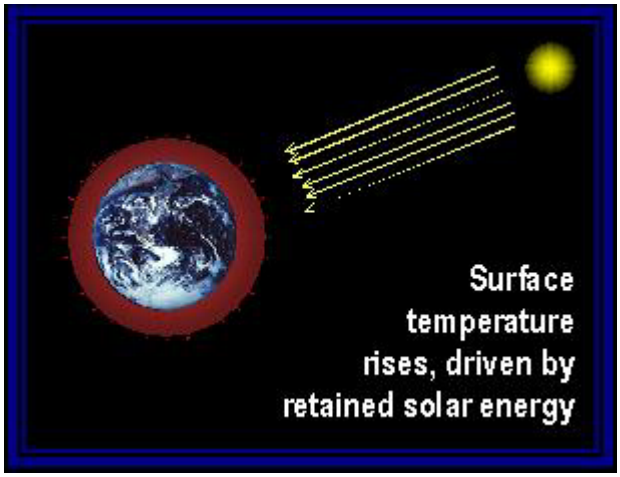
As part of its collateral damage, this species has also overwhelmed the pollution-absorbing capacity of the global commons. Inadvertently it has dumped into the atmosphere, the gaseous combustion-products generated by its hyper-exponential use of fossil fuel, the outgassing of limestone in the production of building materials, the carbon-dioxide released from burning bio-mass in the process of deforestation, together with a set of other gaseous compounds that together drive the greenhouse effect.



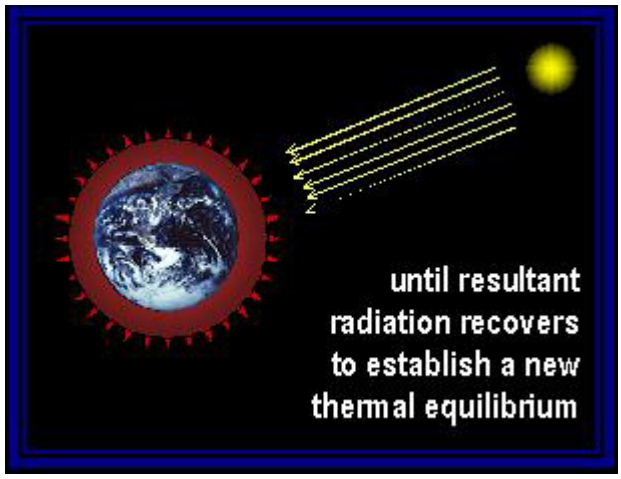
The result has disturbed the energy balance between the earth and its environment,



Driving the value of radiative forcing away from its near-zero value of dynamic equilibrium, and increasing the energy stored in the surface layers of land, water, ice and air.

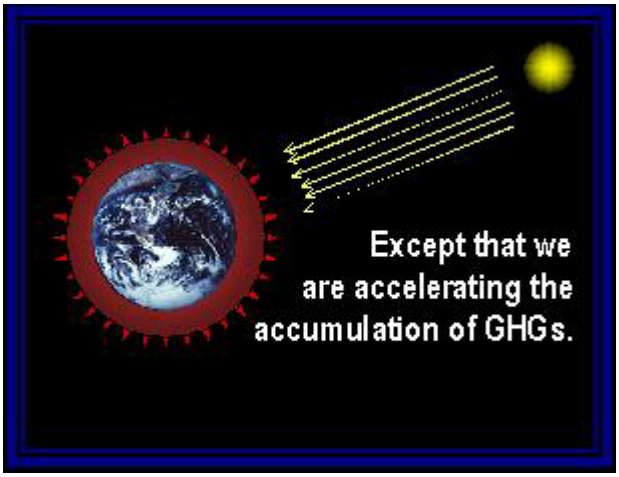


The heat energy slowly initiates a process of global warming, and average temperature rises. The classical understanding of climate change postulates that provided the concentration of greenhouse gasses can be stabilised at some given level,

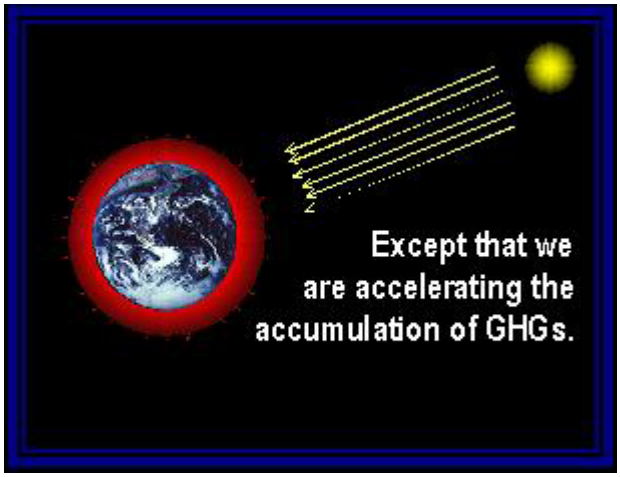


Temperature will rise to a new equilibrium value at which incoming solar energy is once again balanced by outgoing radiation. That classical understanding is the foundation of all current negotiations for the mitigation of climate change. It is the basis of the Kyoto protocol, of the Bali roadmap, of the Conference of the Parties at Poznan, of the approach to Copenhagen 2009 and the attempt to reach global agreements reaching beyond Kyoto.

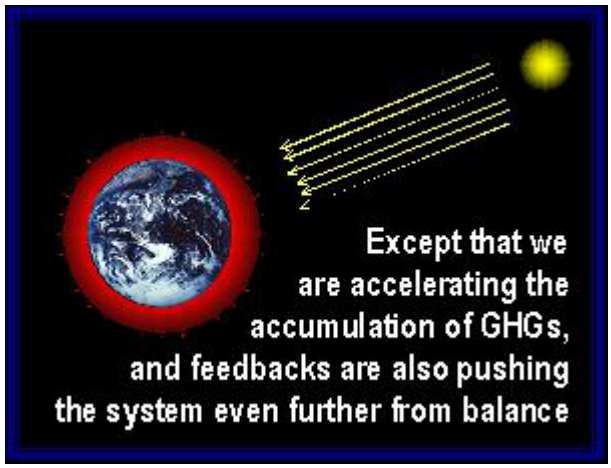
That basis is now fatally flawed on two fundamental counts:



Firstly, we are accelerating the accumulation of atmospheric greenhouse gasses faster than envisaged even in the worst case "business as usual" scenario of the IPCC.

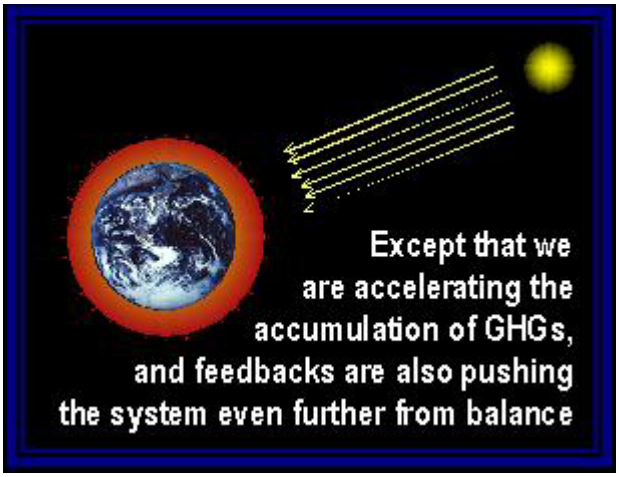


That is increasing radiative forcing and accelerating many parameters of climate change.



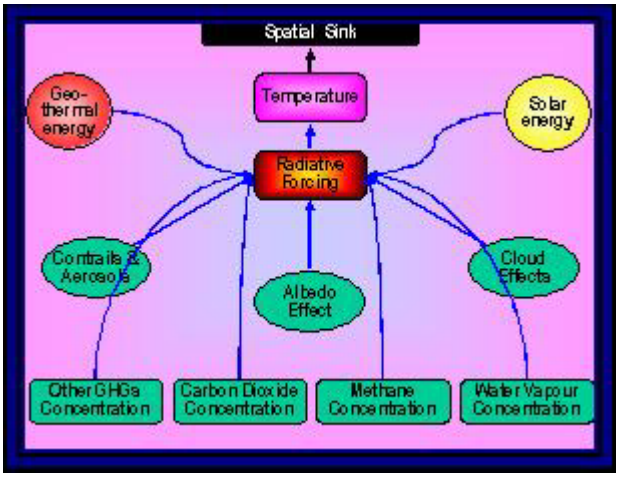
Secondly, and far more significantly, we have mobilised a set of positive feedbacks, that is

driving the system further and further out of equilibrium The anthropogenic shunt to the energy system has triggered a complex amplifying response that would already appear to have initiated runaway climate change.



It has the potential to accelerate that process into an unstoppable trajectory that would inexorably lead into the hot-earth scenario of the Anthropocene Extinction Event.

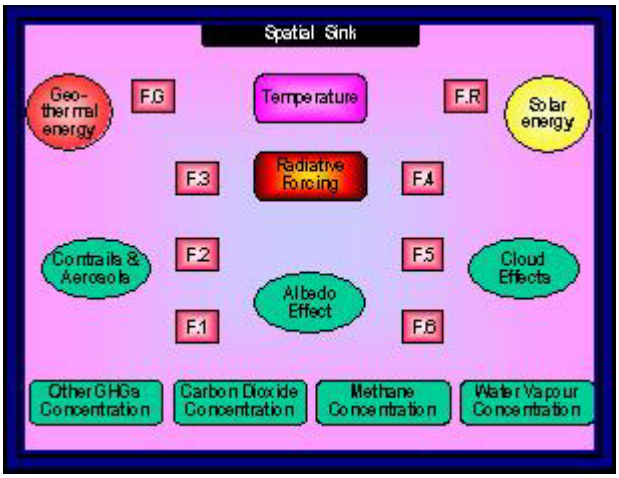
Next I want to share with you the elements of the systems dynamics analysis that gives solid ground for that last assertion.



We start with the set of drivers that control the value of radiative forcing.

Some of the energy at the surface of the earth is generated by geo-thermal heating. It is very small in comparison to radiant solar energy. The concentrations of carbon-dioxide, methane, water vapour and other greenhouse gasses modify the atmosphere's capacity to transmit infra-red radiation back out into the spatial sink. They are joined by the combined effects of contrails, aerosols, clouds and surface reflectivity or Albedo.

To this we can now add the

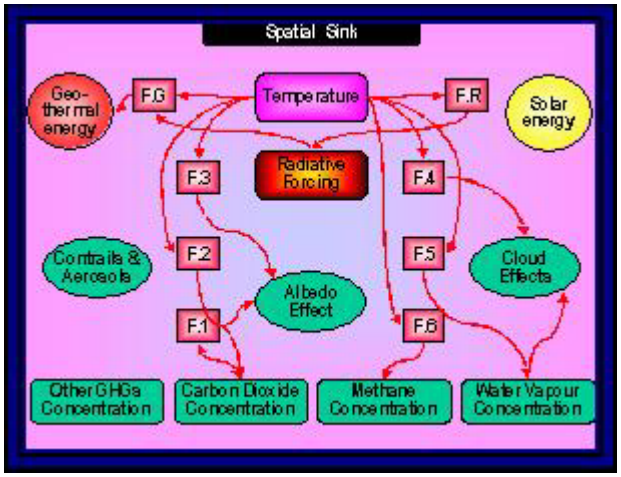


Clusters or categories of feedback mechanisms that have been brought into play by anthropogenic activity.

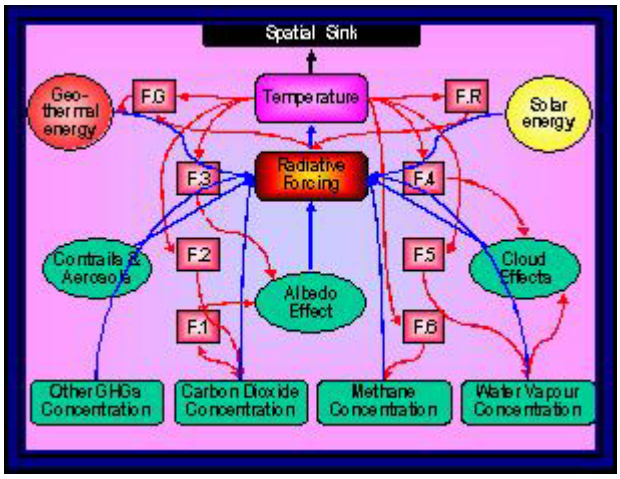
Feedbacks associated with geothermal energy (**F.G**) are very slow and small. They can safely be ignored for the rest of this analysis.

The radiant feedback (**F.R**) is the major negative or damping mechanism in the system. As temperature rises, more energy is radiated back into space, so lowering radiative forcing. If the combined effect of all positive feedbacks is less than this value, the system tends safely towards equilibrium. If the combined effects of all positive feedbacks outweigh the power of all negative or damping mechanisms, then the system is in a condition of accelerating or runaway change.

Cluster **F.1** is driven by rising concentration of atmospheric carbon-dioxide. Categories **F.2** through **F.6** are driven by rising temperature. Each cluster operates on a specific driver of radiative forcing like this:

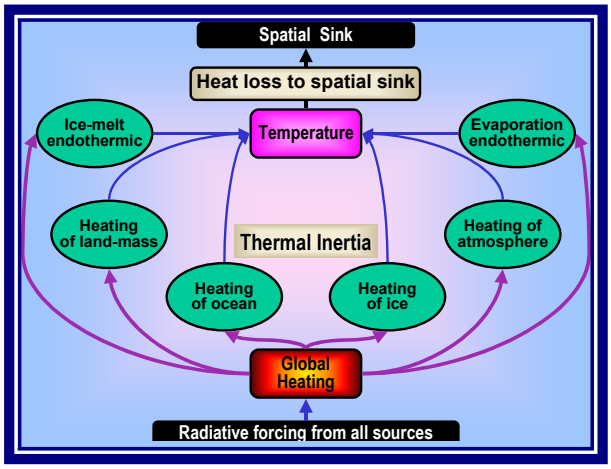


The feedbacks modify the behaviour of the drivers:

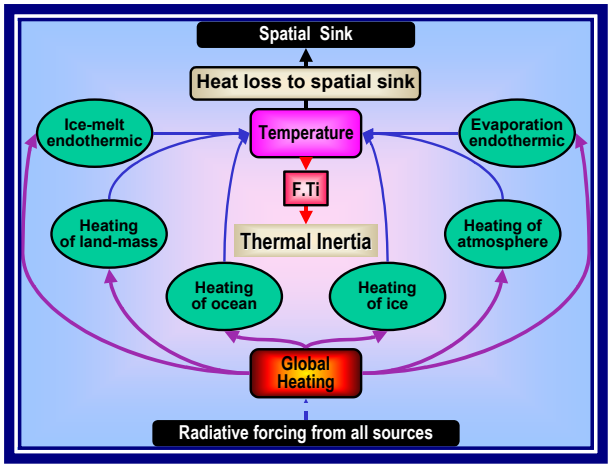


Which in turn changes the value of radiative forcing. Over time the increased heating drives up temperature, so reinforcing the accelerating power of each temperature-dependent feedback mechanism.

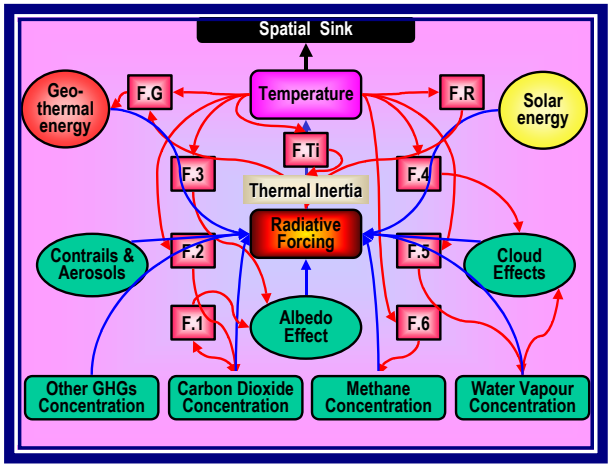
The relationship between radiative forcing (global **heating**) and rising temperature (global **warming**) is moderated by the thermal inertia of the whole earth system.



So net radiative forcing from all sources constitutes the heat engine that drives climate change. The energy is taken up in the heating of land and oceans, ice and air. It is also absorbed in the endothermic phase changes of ice to water, and of water to water-vapour. The rate of change of temperature (rather than the absolute increase in the value of temperature) together with the rate of increase of ice-melt and the rate of increase in the atmospheric concentration of water-vapour, all indicate increase in the power of radiative forcing.



There is one further feedback cluster (**F.Ti**) associated with thermal inertia. The hotter it gets, the lower the thermal inertia, and the faster the temperature rises. Now we can place the thermal inertia subsystem together with its feedback cluster into the main diagram:



So completing the structure of the complex feedback system. For reference, the details of all the various mechanisms are spelled out in Chapter 1 of the Westminster Briefing in your resource pack, where you will also find a slightly more recent update in lecture form on the Tällberg Forum DVD.

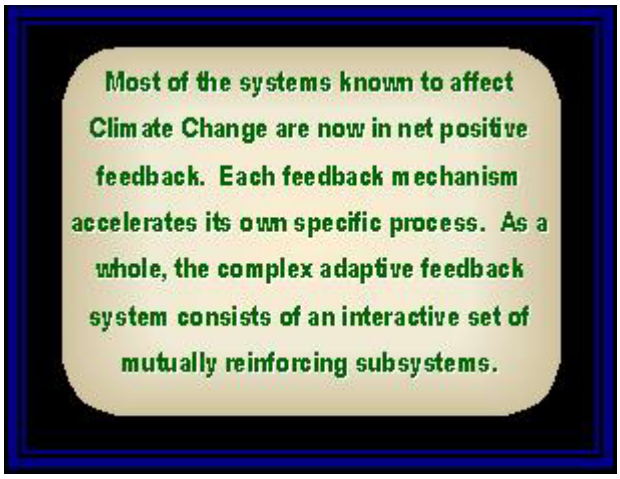
Some 30 feedbacks have now been identified. Some are strong, others weaker. Some feedbacks are fast acting, others respond more slowly. At this point I will simply note some of the most significant mechanisms:

Increased temperature and concentration of atmospheric CO_2 **degrade the natural carbon sinks**, so accelerating the rate of accumulation of atmospheric CO_2. The process is exacerbated by anthropogenic deforestation and by natural **climate-driven die-back and burning of tropical and boreal forests**. This latter can also add massive amounts of CO_2 to the atmospheric stock and is another potentially powerful and fast-acting feedback.

Rising temperature drives increase in tropospheric **water-vapour concentration**, a very powerful and fast-acting feedback that adds about 1wm^{-2} to the value of radiative forcing, per 1ºC rise in temperature.

Decreased area and duration of sea ice and snow cover are driven by rising temperature and high radiative forcing. Resultant **decrease in Albedo** leads to greater retention of solar energy and rising radiative forcing. There are several knock-on effects to do with increased atmospheric water vapour, rapidation of thawing of Tundra permafrost and release of methane from frozen deposits.

Concentration of atmospheric methane has just started to rise, driven partly by saturation of the supply of hydroxyl ions required for its breakdown, but mostly because of the rapid rise in release from thawing permafrost areas and from clathrate deposits on the bed of the continental shelf areas north of Canada and Siberia. Late summer observation in 2008 of methane chimneys off the Siberian coast may indicate initial penetration of fossil ice layers on the sea-bed by warming shallow water in the area, allowing release of methane held in store from before the last ice-age. The **temperature-driven methane feedback** is one of the most powerful mechanisms. It was previously thought to be subject to long slow cascade behaviour, but may be much faster acting than anticipated.



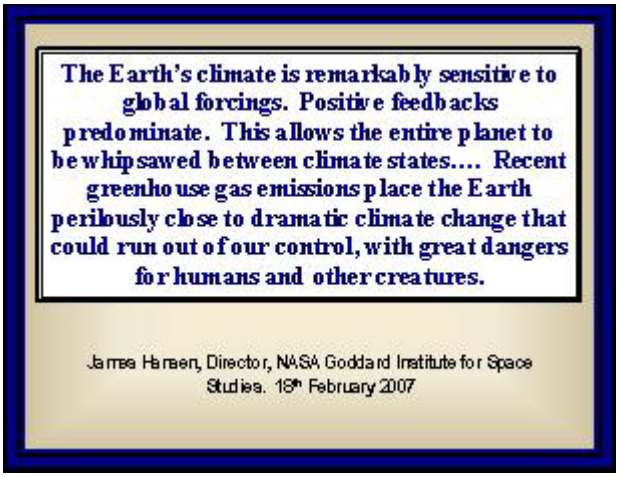
Let me summarise the position. Most of the systems known to affect climate change are now in net positive feedback. Each feedback mechanism accelerates its own process.

Current observation indicates that many parameters are now accelerating much faster than predicted by the ensemble of climate models on which the latest IPCC Assessment report was based.

But **most importantly**, as a whole, the complex adaptive feedback system consists of an interactive set of mutually reinforcing subsystems

This second-order feedback system therefore accelerates the rate of climate change. The output from every single feedback mechanism accelerates the behaviour of every other feedback mechanism in the system, rendering the whole process dynamically unstable.

18 months after I developed this analysis, James Hansen circulated the first draft of his paper, **"Target Atmospheric CO_2: Where Should Humanity Aim?"** eventually published in Spring 2008, in which he wrote:



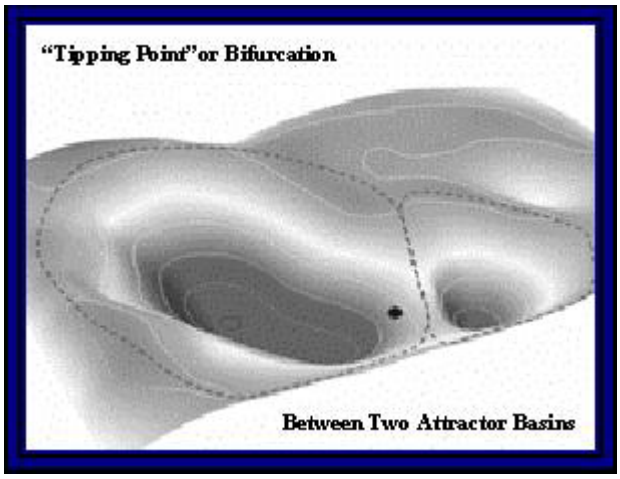
He concluded that the atmospheric concentration of CO_2 **"will need to be reduced from its current 385 ppm to at most 350 ppm"**. His largest uncertainty in the target arose from changes in (non-anthropogenic) CO_2 forcings and other forcings and feedbacks.

As we take into account those extra forcings and feedbacks and, in particular, as we recognise the compounding power of the second order dynamic, it becomes clear that the imperative task of preventing unstoppable runaway climate change will demand an intervention strategy even more stringent than that proposed by James Hansen.

In the next section we move beyond the consideration of the acceleration of climate change and explore the dynamics of moving:

Beyond the tipping point in the global system as a whole. It is a threshold or watershed that marks the onset of the pathway towards the Anthropocene Extinction Event.

Firstly we must clarify what is meant by:

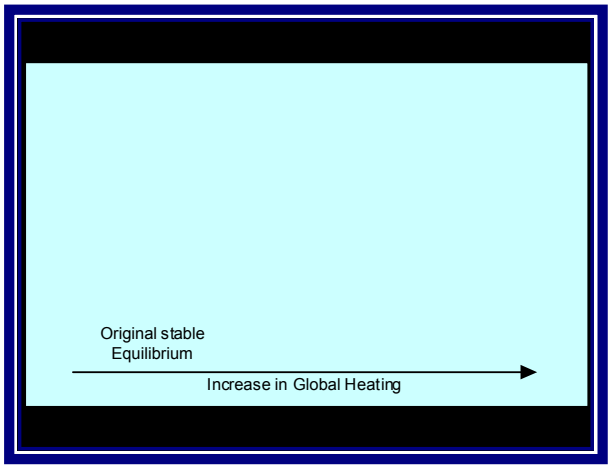


a "tipping point" in the behaviour of complex systems. The landscape illustration is taken from work by the Australian, Brian Walker, one of the founder members of the Resilience Alliance. Let the left-hand basin represent the variable, near-equilibrium, but contained dynamics of the glacial/interglacial period. It is separated by the watershed or tipping point from the hot-earth scenario of the right-hand basin. There is no record of excursion into the second basin in the near-equilibrium conditions of the Gaian bio/geoshpere.

Only the five great extinction events of geological history have pushed the system far away from equilibrium, passed the tipping point, and into the hot-earth scenario. On each occasion there has been a large initial shunt in the concentration of atmospheric CO_2, precipitated by massive volcanic activity, prolonged and extensive lava flow or catastrophic asteroidal impact. Each disturbance has then been amplified by powerful feedback dynamics not active in the near-equilibrium state. The events have typically resulted in the loss of about 90% of life on earth. It can take tens of thousands of years for the system to re-stabilise, and a couple of millions of years for the biota to evolve and re-populate the planet.

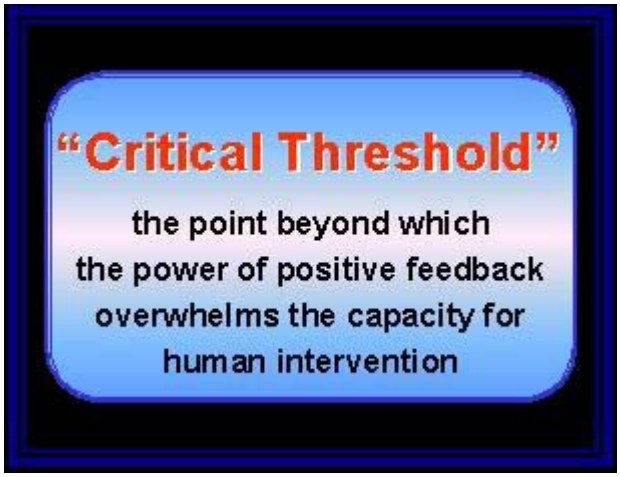
The anthropogenic intervention in the Gaian system is now of the same order as the initial shunt in radiative forcing that triggered each of the five great extinction events of the past.

In order to explore the issue further, let us take a line of cross-section through the watershed between the basins, like this:



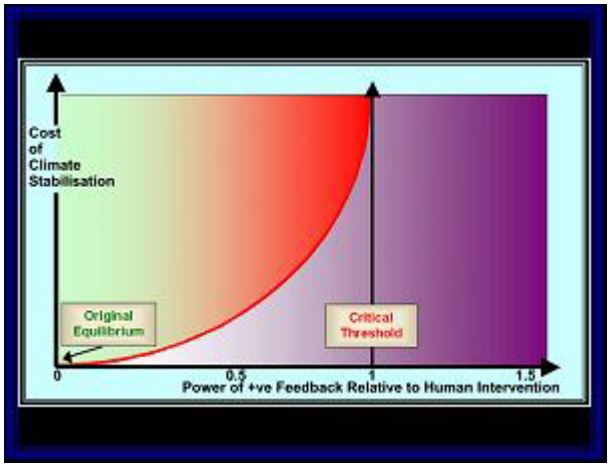
As the power of radiative forcing rises, the system behaviour is pushed up the slope until the net effect of positive feedback just balances the containing dynamics of negative feedback. This is the tipping point of unstable equilibrium. Beyond that point amplifying feedback increasingly overwhelms the damping factors and the system moves past the watershed into a pattern of accelerating runaway heating. Anthropogenic drivers are, of course, still active at this stage.

Next I want to introduce the concept of "Critical Threshold". Somewhere on the down slope we cross the boundary between stoppable and unstoppable runaway heating.



This is the point beyond which the power of positive feedback overwhelms the capacity for human intervention. Even if we take our drivers down to zero and put the brakes on as hard as we can, beyond this point the positive feedback goes on increasing the value of radiative forcing. The extinction event runs its inexorable course.

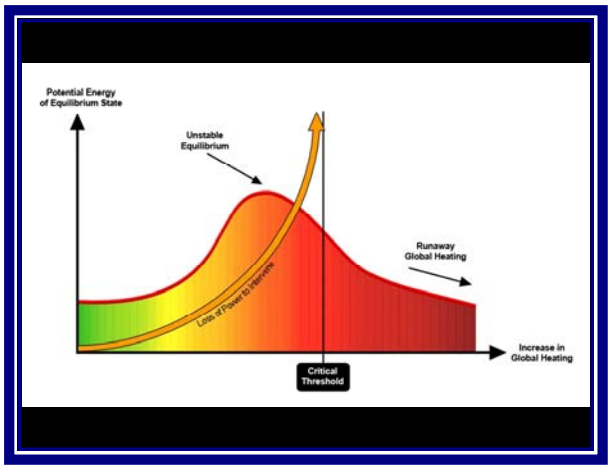
In economic terms, costs of mitigation do not increase slowly (even if exponentially as in the Stern Report), but reach a threshold beyond which no amount of investment can possibly solve the problem.



Like this. The critical threshold is the point of no-return (the tipping point) in the coupled climate-human system. **The closer we come to the critical threshold, the more massive and costly the required intervention becomes.** As John Schellnhüber commented: "This turns the cost-benefit analysis of climate mitigation on its head".

The recent implosion of the global finance markets offers us a real time exemplar simulation of the behaviour of a complex system with low resilience and powerful, close-coupled positive feedback mechanisms in the light of which we are better able to comprehend the similar but slower acting dynamics of global climate. It also exposes the possibility that the surplus wealth in the global economy, required as investment to manage the mitigation transition, is highly vulnerable. Economic turbulence and decaying resources narrow the window before we engage the critical threshold and lose control of the process of runaway climate change.

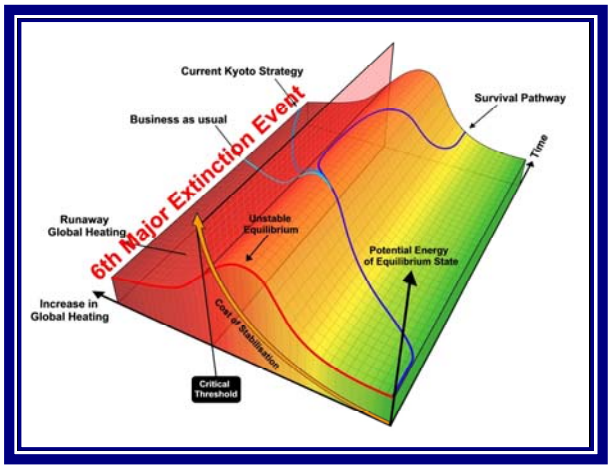
Now we can combine the critical threshold with the original diagram of climate dynamics:



The critical threshold represents the closing of the window of opportunity during which human initiatives to generate negative (system damping) interventions are still able to halt global heating and return the system to a stable, life-sustaining equilibrium.

Current strategies assume no limit to the time-scale within which it is still possible to intervene effectively. They also ignore any degrade in the ability of emissions-reduction to

control the rate of global heating however high it becomes. In so doing they gravely underestimate the power of the second-order positive feedback. **These are false assumptions that are placing the future of our civilisation and its holding environment in extreme danger.**



Let us now introduce the dimension of time from left to right along the front horizontal axis. The lines of the previous diagram are now stretched out as surfaces within the volume of the resultant three dimensional space.

The tipping point, or watershed, is now represented by the ridge stretching from left to right. Near to the front face is the green valley area of historically stable equilibrium. The surface rises from the valley through the inflection line, where the positive feedback loops begin to influence the system. It then climbs on up to the unstable equilibrium at the summit of the ridge where the positive and negative feedback processes just cancel each other out. Over the hill the positive feedback loops are dominant and drive runaway global heating and the resultant climate change.

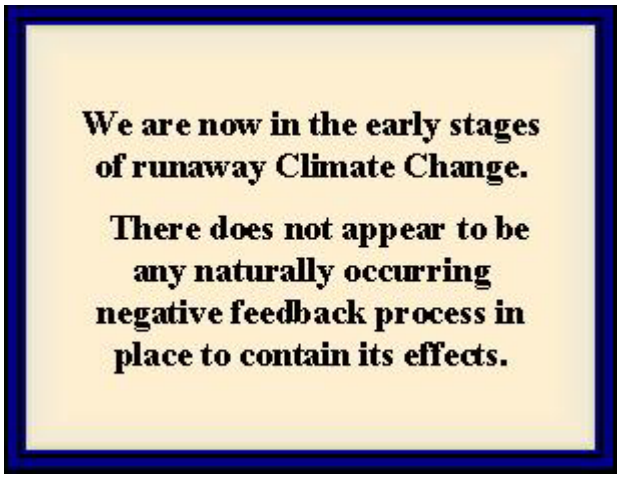
The vertical wall of the critical threshold reaches up through the downward slope on the far side of the ridge. It contains the area within which human intervention is still able to return the system to a stable equilibrium. As the wall is approached the power of this intervention decreases rapidly, and the reduction in emissions required to stabilise the system becomes massive and increasingly costly.

The **"business-as-usual" path** stretches downwards on the steepening slope, passes through the wall of the critical threshold and descends ever-further into the vale of positive feedback, the landscape of unstoppable runaway climate change.

The Current Kyoto strategy, aims at slow reduction in the volume of emissions, but does not reduce GHG concentration. Global heating continues to increase, though at a somewhat reduced rate. Positive feedback processes (particularly the temperature sensitive ones) are not de-activated but slightly damped. The projected path deviates slightly to the right. The descent is slowed, but continues downwards, away from the ridge and on past the critical threshold into the domain of unstoppable runaway climate change.

The Survival Pathway is the only intervention that can halt the descent, turn it along a contour-line and then make it climb slowly back up and over the ridge. It requires a strategy of sustained reduction in GHG concentration, stabilising and reducing the rate of global heating and initiating a period of global cooling. That scenario would have to be held in place whatever positive feedback loops were activated in the long period before the rise in global temperature was halted, reversed and brought into a constant stable equilibrium. It would then have to sustained until the potential instability of the methane clathrate cascade had been effectively contained. The sharper and faster the intervention is effected, the more hope we have of averting an otherwise inevitable climate catastrophe of our own making, the Anthropocene Extinction Event.

We cannot afford any further delay in effective action. Any procrastination increasingly risks global bankruptcy in financing the needed intervention, and massive human suffering in carrying it through to completion. It also threatens our ability to regain control before the system is overwhelmed by the positive feedback loops and drifts inexorably into runaway global warming. To allow the powerful vested interests of the social, economic and political systems to continue to hijack the world and hold it to ransom for the sake of short term profit, political power, and national protectionism, would be an act of collective suicide.



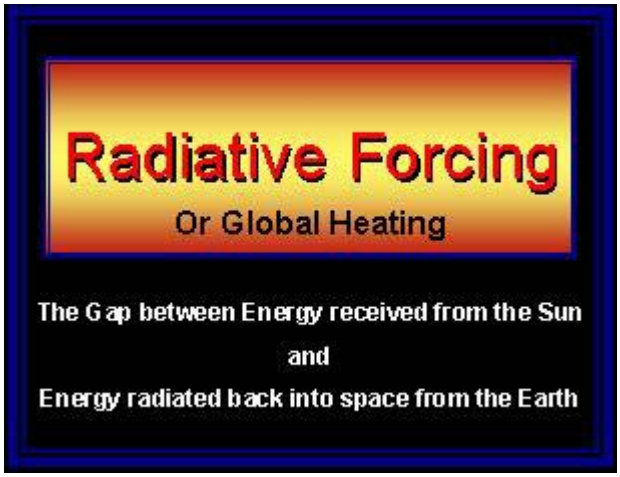
So, to summarise

It is neither hyperbole, nor alarmist exaggeration to say that

We are now facing a state of planetary emergency. That appears to be the stark reality of the situation in which we now find ourselves. It is no longer a question of maintaining economic growth, or equitable patterns of sustainable development (whatever that means!). The issue now has become one of survival at all costs.

We are living in slow motion through the early stages of a massive asteroidal impact, and the asteroid is us. The critical difference between the asteroid and the human impact lies in the realm of observation, analysis, communication and resultant action and behavioural change. The asteroid is not a learning system. We are. We have the capacity to initiate massive, fast-acting, negative feedback dynamics, which are still capable of averting the imminent extinction event. The fundamental question concerns our ability to mobilise that ability within the narrow window of opportunity still open to us.

In terms of risk management, we now have what is called a "fat tailed distribution" of probability against consequences. Very high impact events normally have a very low probability of occurring within the foreseeable future. In this case we have an event with massive consequence whose probability is not only high, but rising rapidly. However you interpret the precautionary principle, the situation now calls for urgent and effective action on a global scale.

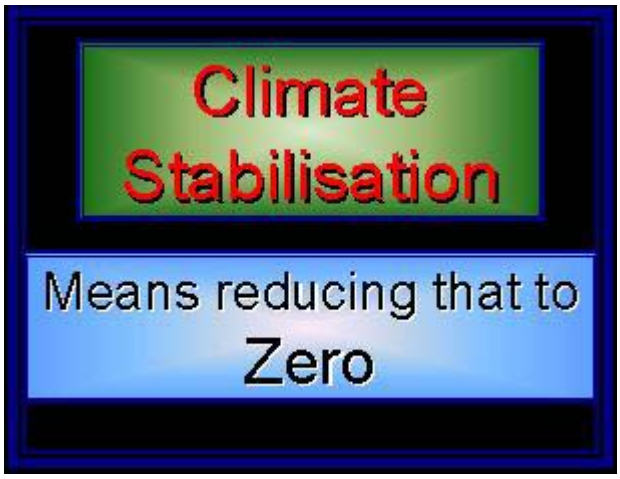


Global heating has already been pushed far out of equilibrium. It is currently running at about 1% of received solar energy.

Or about 2 watts per square meter.

That works out at a million giga-watts over the whole earth, equivalent to the heating from a million million 1KW fires.

It is increasing at about 25% per decade and the rate is accelerating.



Immediate stabilisation of the greenhouse gas concentrations at the current CO_2 equivalent of 450 ppm leaves radiative forcing at 2 wm^{-2}, and a current temperature increase of 0.8ºC above pre-industrial average. It is a politically convenient myth that resultant temperature would eventually stabilise at a "safe" 2ºC above the pre-industrial value. It never was regarded as a "safe" target by the scientific community, even based on mid 1990s understanding of climate behaviour. Current calculations grounded in the present analysis of the complex feedback system indicate that radiative forcing would have doubled by the time that temperature was reached, not reduced to zero. The threshold of unstoppable runaway climate change would already have been crossed.

Next Tuesday sees a massive meeting in the European Parliament Building in Brussels to define "A Global Contract Based on Climate Justice". The official background document has been prepared by staff of PIK Potsdam to underpin the European target of 440 ppm of CO_{2e} and a maximum temperature rise of 2ºC. It is perpetrating a most dangerous illusion. It is sculpted in collusion with the dynamics of denial, formulated to safeguard the profit margins of the economics of exploitation, and designed to placate the politics of appeasement. It does not lead to the stabilisation of the climate. Adherence to those targets leaves us with the comforting delusion that we are within grounds of safety. We are not.

Climate stabilisation will undoubtedly require the substantial reduction of greenhouse gas concentrations from their current level up to and beyond the point at which radiative forcing from all sources not only falls to zero, but moves into negative territory, initiating a managed period of global cooling. Current temperature will have to be reduced if the powerful positive feedback system is to be controlled.

Climate stabilisation is **the** strategic imperative for tomorrow's world. All other objectives pale into insignificance in the light of that overarching agenda. **Can** we do it? The President Elect of the USA answers "Yes we can!" **Will** we do it? The answer to that hangs precariously in the balance.

Perhaps the final word should be left to Gene Kranz, mission controller of Apollo 13 as he led the team struggling to bring the crippled space-capsule safely back to earth: "Failure is not an option".

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The Meridian Programme and Apollo-Gaia Project
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