
# Feedback Dynamics and the Acceleration of Climate change

## An Update of the Scientific Analysis

**Prepared by**

**David Wasdell**

**Director**
**The Meridian Programme**

# Feedback Dynamics and the Acceleration of Climate change

**Warming is accelerating GREATLY, especially "Recently"**

Dennis Bushnell, Chief Scientist, NASA Langley Research Center. 12th January 2007

**What frightens me is the speed at which things are happening, the obvious acceleration of events, and the fast narrowing windows of opportunity left to do something critical about saving our future. The greatest worry is that although things are happening faster, they are not going to follow a smooth curve, however steep. It is absolutely inevitable that we are going to get an abrupt "Climate Discontinuity" within our lifetimes**

Graham Ennis, Director, The Omega Institute. 11th January 2007

**The Earth's climate is remarkably sensitive to global forcings. Positive feedbacks predominate. This allows the entire planet to be whipsawed between climate states…. Recent greenhouse gas emissions place the Earth perilously close to dramatic climate change that could run out of our control, with great dangers for humans and other creatures.**

James Hansen, Director, NASA Goddard Institute for Space Studies. 18th February 2007

**United Nations**
**Framework Convention on Climate Change**

***Aim is to stabilize greenhouse gas emissions…***

***"…at a level that would prevent dangerous anthropogenic interference with the climate system."***

**Earth Summit 1992**

**We have already passed the stage of dangerous climate change. The task now is to avoid catastrophic climate change**

**Prof John Holdren,**
**President AAAS**
**August 2006**

**As expected, intensification of droughts, heat-waves, floods, wildfires, and severe storms is occurring, with a mounting toll on vulnerable ecosystems and societies.**

**These events are early warning signs of even more devastating damage to come, some of which will be irreversible.**

**The American Association for the Advancement of Science (AAAS), Annual Meeting in San Francisco, February 2007.**

**"The possibility of a tipping point in the earth system as a whole which prevents the recovery of stable equilibrium and leads to a process of runaway climate change, is now the critical research agenda, requiring the concentration of global resources in a "Manhattan Project" style engagement. All other work on impact assessment, mitigation and adaptation depends on the outcome of this overarching issue."**

**John Schellnhuber: Director, PIK Potsdam.**
**Quoted from EU Commission Report**
**On Complexity Science Workshop. 15th June 2006**

# Introduction

Over the last two years, there has been a profound shift in the scientific understanding of the behaviour of the earth's climate system treated as a whole. Initially the climate was seen to be in a state of stable equilibrium. Man-made increase in concentration of greenhouse gases would lead to a modest rise in global temperature, a process that could be contained at any point by reducing emissions, stabilising concentration and stopping further temperature increase. Everything was under control. The timing and strategy of intervention should be economically determined and depended on "cost-benefit" analysis.

Today the climate system is recognised as being in a state of unstable equilibrium. The surface heating, caused by man-made increase in concentration of greenhouse gasses, is seen as acting as a trigger to an accelerating process of global warming driven by amplifying ("positive") feedbacks. Most of these are activated by change in temperature and are only just beginning to kick-in. There is only a limited window of opportunity in which it is possible to stop the process of runaway climate change before it passes beyond our control and precipitates "catastrophic climate change", i.e. a major extinction event.

**The following few pages offer an overview of the feedback processes and their consequences, concluding with a review of the intervention strategy required as an effective response to the "State of Planetary Emergency".**

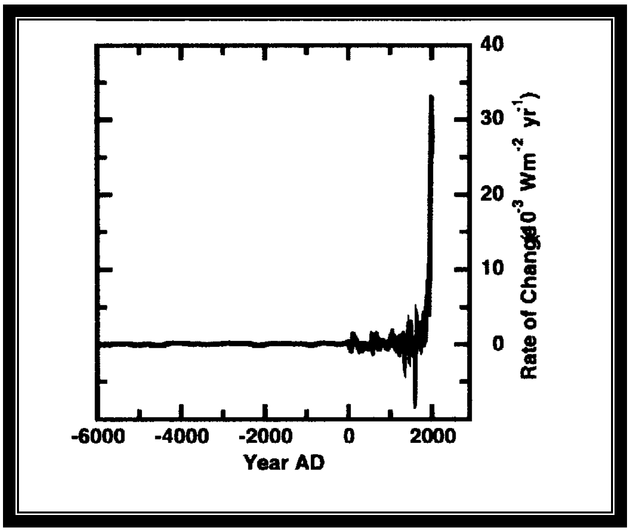
## 1. Time-Delays and Systems Thinking

It takes a long time to raise the temperature of something as massive as the whole earth. Air and land warm fastest. The oceans absorb an immense amount of energy for only a small rise in temperature, a process that is damped even further by evaporation and ice-melt. The result is "thermal inertia". In other words while "global heating" keeps pace with the greenhouse effect and all the associated feedbacks, global warming does not! (Global heating is the energy input usually referred to as "radiative forcing", the difference in watts per square metre between energy received from the sun and energy radiated out again into space.) There is a time-delay between cause and effect of more than half a century. The more intense the radiative forcing, the longer the time-delay before its full effects are seen.

So far we have had a rise of just over 0.7ºC in average global temperature. All the climate impacts portrayed in Al Gore's "An Inconvenient Truth" and in the "One Year on Update" section of the DVD, are a response to this small change. They represent the effects of greenhouse gas concentrations that were reached in about 1960. Meanwhile the rate of global heating (radiative forcing) has soared, (see graph of rate of change of radiative forcing below). Even if we stabilised greenhouse gas concentrations today, we would still face at least a quadrupling of the amount and effects of global warming currently experienced. Feedbacks could make it worse still. "You ain't seen nothing yet!" If storm energy doubled between 1970 and the year 2000 on an increase in temperature of only 0.7°C, then what will the storm energy become when we quadruple that temperature rise? The cause of such a rise in temperature is already in the system. Dangerous climate change is now unavoidable.

**That is why basing strategic policy on observed effects of global warming is totally inadequate. It ignores the time-delays. In climate systems, by the time dangerous**

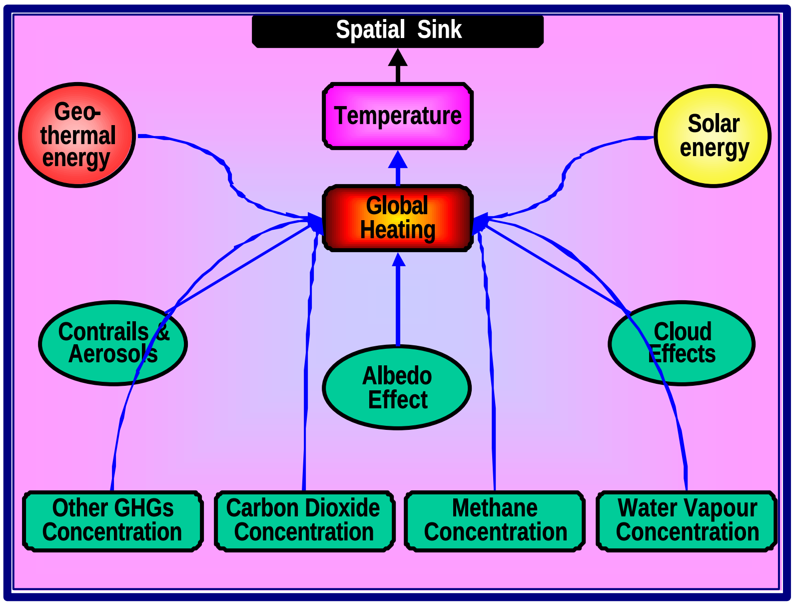
**change is observable, the point of intervention to prevent it is already well passed. Political systems that only respond after the event ("catastrophe first" decision-making) condemn the world to catastrophic climate change.**




Rate of change in radiative forcing
(from draft of IPCC Fourth Assessment Report, Summary for Policy Makers)

## 2. Basic Drivers of Climate Change

Before we begin to look at feedback dynamics, we need to explore the basic factors which drive climate change. These are the processes on which the feedbacks then operate to amplify (or dampen) their effect.



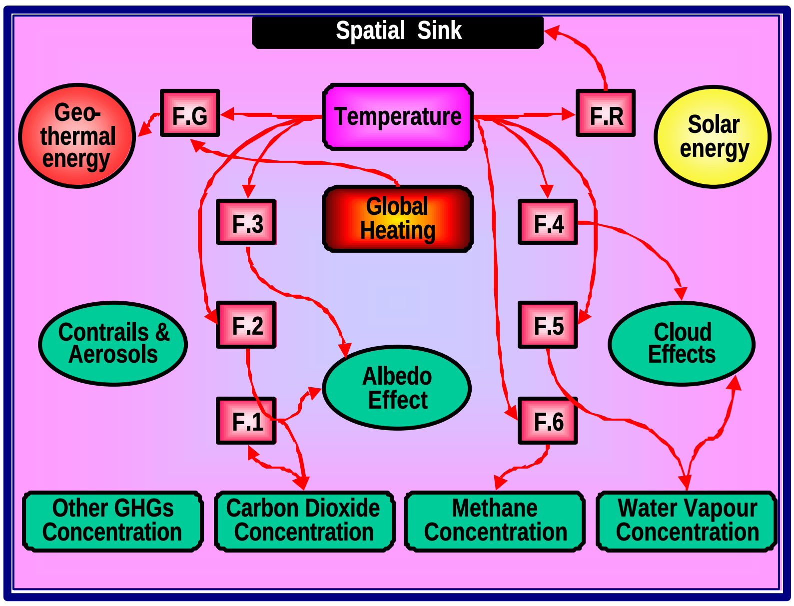

In the given context of the two heat sources and cold spatial energy-sink, we begin by assembling the basic elements that drive climate change. The greenhouse effect of increase in the concentration of **$CO_2$** and **Methane**, initiates **global heating** as a result of which

**temperature** starts to rise. **Geo-thermal heating** is included for completeness, though its order is small compared to solar energy and so in practice we can ignore it at this level. Then we add in **other anthropogenic greenhouse gasses** together with increase in **concentration of water vapour**. Effects of aircraft **vapour trails**, particulate **aerosols** released in forest fires and industrial process, the **Albedo effects** (reflection of solar energy back into space) and finally the complex contribution of **cloud systems** complete the set of drivers of global climate change.

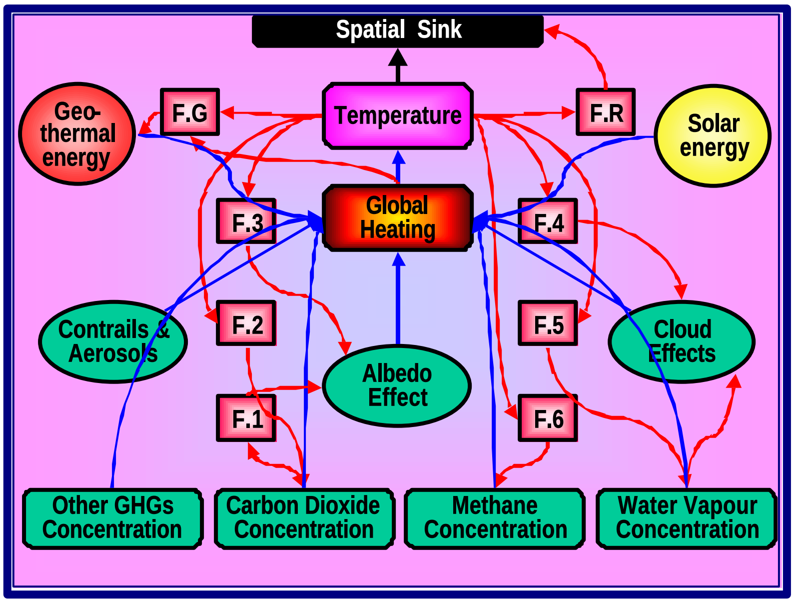
Taken together these elements drive radiative forcing away from equilibrium, so generating global heating which in turn leads to increase in average global temperature, albeit subject to long time-delays. Eventually, surface temperature rises to the point at which radiative loss to the spatial sink establishes a new thermal equilibrium. That is the standard model of climate change. Interacting with that model are the accelerating effects of feedback dynamics to which we now turn.

## 3. Feedbacks operating in the Climate System

A total of eight different categories of feedback mechanism have been identified. Those associated with the minute change in geothermal output [**F.G**] are so small they can be ignored for our purposes. The radiative feedback [**F.R**] that increases energy output to the spatial sink, is the ultimate damping ("negative feedback") mechanism. As global temperatures rise, radiation eventually increases to an equilibrium level at which energy received from the sun is once again in balance with energy radiated to space. At this point, climate stabilises with zero radiative forcing, albeit with a hotter surface temperature.



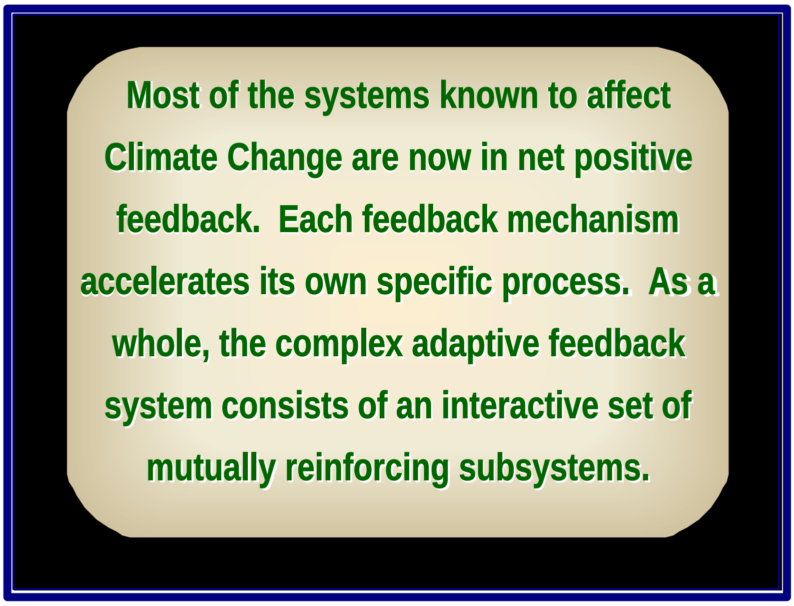

Of the remaining categories only [**F.1**] responds to increase in $CO_2$ concentration. All the others are activated by rising temperature and therefore only come into action once GHG driven global heating begins to take effect. We can then complete the model by overlaying the complex adaptive feedback system on the standard climate change diagram.




The complete feedback links can now be traced. For instance the category [**F.6**] is activated by rising temperature, operates on methane concentration which increases global heating. That leads to rise in temperature which feeds back into the cycle to increase methane concentration, and so on… Feedbacks not only affect the specific functions on which they operate. Their output also changes the driver conditions for other feedbacks, which in turn reinforce the driver of the initial mechanism.

Detailed study of the four main sub-systems (carbon, albedo, methane and water-vapour cycles) together with the specific feedback mechanisms associated with each cycle, can be found at :

www.meridian.org.uk/Resources/Global%20Dynamics/EEA_Presentation/frameset.htm?p=22



**This second order feedback system therefore accelerates the rate of Climate Change**

The inclusion of the complex feedback system in our study of the cumulative effects of greenhouse gas emissions leads to a fundamental shift in our understanding of the dynamics of climate change. The development calls in question the inadequate assumptions underlying all current strategic approaches to the control of global warming. Our world climate responds as a complex adaptive system in which small interventions (GHG emissions) can precipitate large, non-linear effects with long time-delays. **The most sombre outcome of the new research is that we face not just the need to adapt to a shift of a few degrees and its consequences, but that we may well be in the early stages of setting in motion a major extinction event like those in geological history which wiped out between 80 and 95% of all life on earth.**

## 4. Strong Feedbacks and the Acceleration of Climate Change

Feedback mechanisms vary immensely both in power and in the time frame over which they operate. Quantifying the different elements and the non-linear relationships between them requires further detailed research, and many uncertainties still remain. However, we can now identify the major elements and describe their effects on the behaviour of the climate system:

- **Degrade of the carbon sink.** With rising $CO_2$ concentration and increasing temperature, the capacity of the global commons to absorb atmospheric $CO_2$ starts to degrade. As a result, for any given rate of emissions, the concentration increases over time. This is a feedback that accelerates sink degrade, reinforces the increase of concentration of atmospheric $CO_2$ and makes it progressively harder to stabilise the concentration level of atmospheric $CO_2$.

- **Emission of non-anthropogenic carbon-dioxide.** Rising temperatures increase enzyme and bacterial activity, so releasing carbon-dioxide from soil, peat-based and tundra stores. Fires and the clearance and die-back of forests also contribute to this feedback which increases greenhouse activity, drives rising temperature, and accelerates its own process.

- **Increasing atmospheric water-vapour.** Uncondensed atmospheric water-vapour is far and away the most influential greenhouse gas. However, while average global temperature remains close to equilibrium, change in the overall contribution of water-vapour can be ignored. It is only as global temperature begins to rise that we see the start of change in the water vapour concentration. Rising temperature at the water-air interface increases evaporation and raises water-vapour concentration. The resultant increase in greenhouse effect further elevates temperature at the water-air interface. The process therefore constitutes a positive feedback loop in global heating.

  New observational and modelling evidence confirms the importance of the expected feedbacks linked to water vapour, estimated to be approximately 1 W $m^{-2}$ per ºC of global average temperature increase. Water vapour feedback already contributes an amplification of 40-50% of current global heating. If average global temperature increased by just 3ºC, the contribution to radiative forcing from the effects of increased concentration of water vapour would reach 3 W per $m^{-2}$ (double current forcing from $CO_2$ alone). This would overwhelm all other components of the radiative forcing and precipitate runaway climate change. It would also render impotent any anthropogenic reduction in $CO_2$ concentrations designed to prevent further global warming.

- **Ice-albedo effect.** As temperatures start to rise, the area of ice-fields decreases, as do also the area and duration of snow cover. These surfaces reflect about 90% of received solar energy back into space (the albedo effect). The hotter it gets, the less light-energy is reflected back into space, so the hotter it gets… and so on.

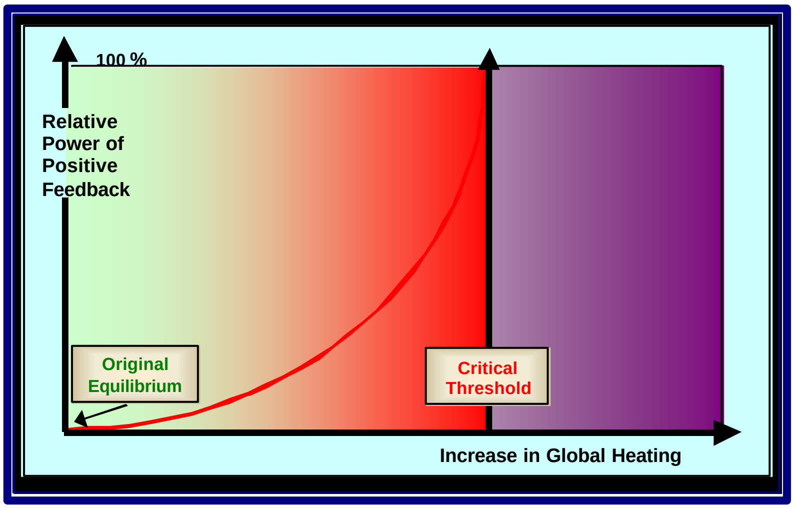
- **Release of stored methane.** There are vast quantities of methane stored in the permafrost of the Tundra regions and also in the sea-bed deposits of the continental-shelf regions of the ocean. As temperatures rise, the permafrost starts to melt and is already releasing methane into the atmosphere. Warming of the shallow seas triggers release of the sea-bed clathrate deposits (methane stores). First evidence of this was recorded by NASA last autumn. Methane is a very powerful greenhouse gas, so these releases increase global warming, accelerate temperature rise and so lead to a slow but strong cascade feedback dynamic.

**Each separate feedback accelerates global warming, but also reinforces the effects of all other temperature-driven feedbacks.**

## 5. The concept of "critical threshold"

At the start of the industrial revolution, amplifying feedbacks were non-operative. Small man-made changes in climate could easily be reversed by man-made intervention. The power of positive feedback relative to the power of human control was negligible.

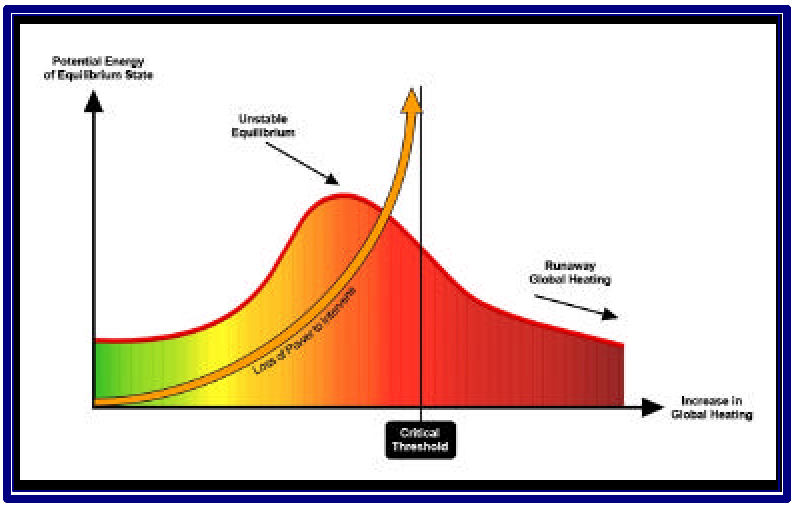
As global heating increased and global warming became detectable, positive feedbacks were mobilised, gaining power relative to the human capacity for intervention. Eventually the positive feedback process takes control and all further effect of emissions reduction is nullified.




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

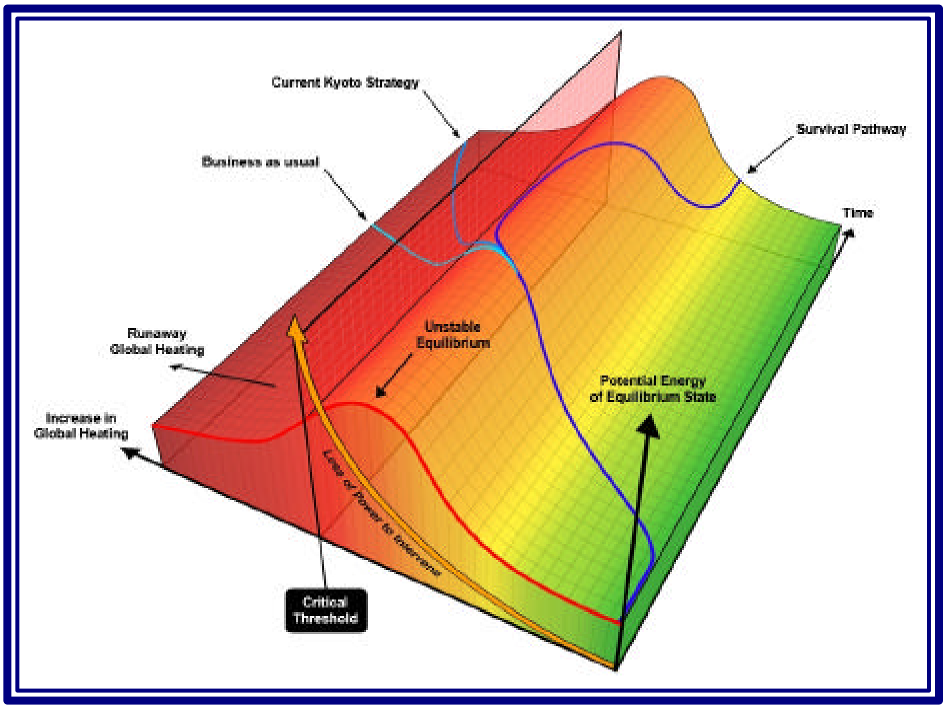
The more powerful the positive feedback loops become, the more massive and costly is the intervention needed to return the system to equilibrium. As the energy exchange approaches the critical threshold, the power ratio between positive feedback and controlling intervention (and the total cost of making an effective intervention) reaches a vertical asymptote. In other words it approaches infinity.

**Beyond that critical threshold in global heating there is no further intervention capable of damping the system. The runaway chain-reaction of uncontrollable climate change will have been initiated, leading inevitably to the sixth or "Anthropocene" extinction event.**



Pre-industrial accumulation of human-generated GHGs just cancelled out the natural damping negative feedback system, leaving the earth in balance in a condition of unstable equilibrium. Exponential increase in GHG concentration driven by the industrial revolution then tipped the system over the top of the hill and into the present state of accelerating climate change. The effects of human-generated emissions are being amplified by an increasingly powerful set of positive feedback mechanisms. The further we move away from the position of unstable equilibrium, the more powerful the positive-feedback system becomes, and the faster is the resultant rate of climate change.

## 6. A "Landscape Presentation" of climate dynamics




See: www.meridian.org.uk/Resources/Global%20Dynamics/TippingPoint/frameset.htm?p=23

The tipping point, or watershed, is represented by the ridge stretching from left to right. Near to the front face is the green valley area of historically stable equilibrium during the glacial/interglacial period. 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, where we now are, the positive feedback loops are dominant and accelerate runaway global heating and the resultant climate change.

The wall marking the critical threshold rises through the down-slope, beyond the peak of the unstable equilibrium. The window of opportunity within which human intervention (by reduction in GHG emissions, increased cloud albedo, etc.) is able to contain the process of global heating and return the system to equilibrium, lies uphill from the critical threshold. It is not yet clear how close to that threshold we are in reality, or whether in fact it has already been passed.

Inactivity is not neutral. Every passing year reduces even further the window of opportunity within which it is still possible to avoid the chain-reaction of uncontrollable runaway climate change. Loss of power to intervene in the system becomes absolute as the wall is approached.

**The closer we come to the critical threshold, the more massive and costly the required intervention becomes.**

Current strategies assume no limit to the time-scale within which it is still possible to intervene effectively. They also deny 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 positive feedback.

**These are false assumptions that are placing the future of our civilisation in extreme danger.**

**We are now in the early stages of runaway Climate Change.**

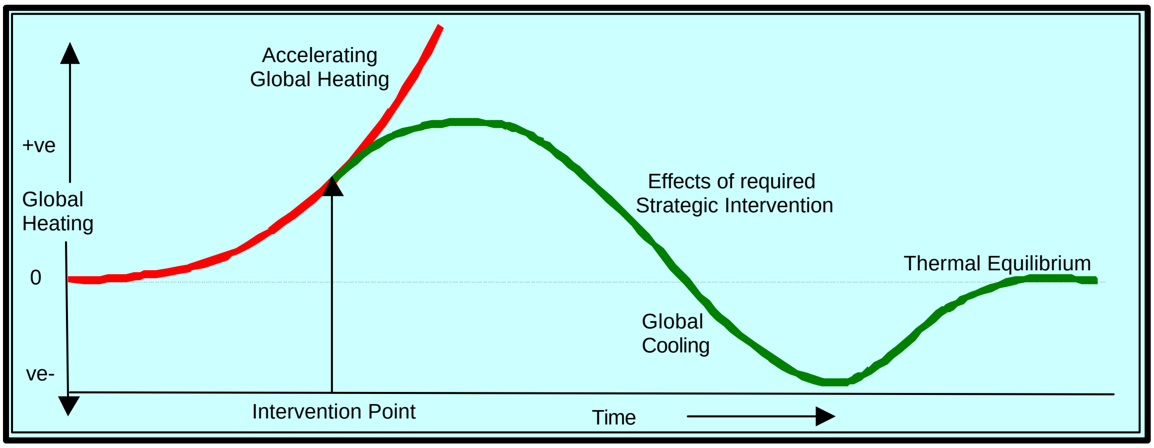
**There does not appear to be any naturally occurring negative feedback process in place to contain its effects.**

**Strategically we have to generate a negative feedback intervention of sufficient power to overcome the now active positive feedback process.**

**Then maintain its effectiveness during the period while temperature-driven feedback continues to be active.**

## 7. Climate Stabilisation: Required Intervention Strategy

**With this new understanding of the dynamics of climate change, we can clarify the intervention strategy required if catastrophic global warming is to be prevented, and climate stabilisation is to be achieved.**




**We start by exposing the inadequacies of some of the current approaches, each of which represents a necessary but not sufficient step on the way to climate stabilisation:**

- Some large energy companies define their "green" strategy as "**slowing the rate of increase in greenhouse gas emissions**", a totally inadequate intervention in terms of climate change, though it may protect the profit-margins of the companies concerned!

- Current national and international political negotiations are aimed at the **stabilisation of greenhouse gas emissions**, (Kyoto targets). If achieved in full such a process would still lead to an accelerating increase in greenhouse gas concentrations.

- If **anthropogenic greenhouse gas concentrations were to be stabilised**, (UNFCCC objective) there would still be an accelerating increase in radiative forcing, driven by temperature-activated feedbacks.

- If **radiative forcing (from all agents) were to be stabilised** (suggested goal in draft text of IPCC Fourth Assessment Report), there would still be constant increase in global heating. Climate change itself would not be stabilised.

- **Climate stabilisation requires that radiative forcing (from all agents) be reduced to zero and then sustained in near-zero equilibrium.**

- **Stabilisation of climate within acceptable levels of dangerous climate change now requires a period of negative radiative forcing before the final equilibrium is achieved. It would be vital to avoid triggering runaway global cooling during this phase!**

* * * * * * * * *

# In Conclusion

**Many of the accelerating and amplifying feedbacks are temperature-driven and independent of the $CO_2$ levels in the atmosphere. These continue to increase and accelerate the rate of climate change while global temperature continues to rise, even if and when we stabilise greenhouse gas concentrations. This major systems instability is the fundamental problem that we now face. This is where the great risk factors are.**

**Regaining the capacity to control runaway climate change (to damp the chain-reaction) is absolutely crucial for the survival of life as we know it. It will require a much more drastic intervention than reducing greenhouse gas emissions, stabilising greenhouse gas concentrations, or even beginning to bring concentrations down in line with the degrade of sinks. Our intervention strategy will have to out-perform the amplifying, positive feedback system already operative and make certain that it continues to out-perform that positive feedback system however powerful it becomes. That is a massive challenge which constitutes a state of global emergency.**

**We cannot offer guarantees of economic sustainability, continuation of a consumer lifestyle, or comfortable protection of our current way of life. We have a crisis on our hands of enormous impact, requiring the mobilisation at a global level of the kind of problem-solving demonstrated in the recovery of the astronauts after the Apollo 13 catastrophe – only this time on a planetary scale.**

David Wasdell
Director,
Meridian Programme.
March 2007.

The Meridian Programme is hosted by:
The Unit for Research into Changing Institutions
Charity Registration No. 284542
Meridian House
115 Poplar High Street
London E14 0AE
Tel: +44 (0)207 987 3600
Fax: +44 (0)207 515 8627
e-mail: wasdell@meridian.org.uk
web-site: www.meridian.org.uk