Feedback Dynamics and the Acceleration of Climate Change

The Westminster Briefing

Summary for Policy-Makers

Background: The Provision of Information

Effective policy-making in the rapidly developing field of climate change depends on the continuous provision of the best available scientific analysis. By their very nature, the Assessment Reports of the Inter-Governmental Panel on Climate Change are not only scientifically conservative and constrained by what is politically and economically acceptable, they are also some two years out of date when published.

Information handling in the national and international decision-making process inevitably adds another layer of inertia. As a result, negotiating processes, strategic policies, target-setting, eventual legislation and binding treaties, are based on information and problem-definition that can be as much as ten years adrift from current reality. "Solutions" offered are to problems that no longer reflect our best understanding of the contemporary situation.

At best the response is harmlessly anachronistic. In today's context of accelerating change and deepening crisis, the outcome is dangerously dysfunctional. It locks us in to a course of action that makes the underlying problem worse, delays the emergence of effective solutions, and lulls us all into a false sense of security. It reinforces the illusion that "everything is now under control and no further initiatives are required". Nothing could be further from the truth.

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The Need for a Scientific Update

In addition to the delays built in to the information-handling process, two further factors underscored the urgent need for a scientific update.

The first imperative stems from observation:

Monitoring of the effects of global warming in virtually every parameter now shows a rate of acceleration that is outside the range of the ensemble of climate models underlying the IPCC 4th Assessment Report. The acceleration can be seen in:

- The rate of thinning of Arctic ice, and consequent predictions of the date of an ice-free North Pole.
- Decrease in reflection of solar energy from the shrinking snow and ice cover, with resultant increase in the rate of global warming.
- Intensification of drought conditions in Sub-Saharan Africa, North Mediterranean areas of Europe, Eastern Australia, etc.
- Increase in the melt-rate of the Greenland ice-cap, evidence of surface-melt in areas of the Antarctic ice cap, rapidation in retreat of glaciers around the world, with implications for the acceleration of sea-level rise.
- Increased intensity of rainfall events with consequent flooding.
- Slow-down in the Gulf Stream (the thermo-haline circulation) with far-reaching consequential changes in the climate.
- Increased energy, wind-speed and damage in tropical storms whether in the typhoons and cyclones of the Pacific or the hurricanes of the Atlantic.
- Increase in speed of up-ward and pole-ward migration of insect species.
- Increased rate of extinction of species of fauna and flora in vulnerable habitats around the world.
- Acceleration in the rate of drying, die-back, burning, and carbon-release from tropical forests.
- Degrade (some of it caused by accelerating de-forestation) in the effective capacity of the carbon-sinks whether in the oceans or in the land-based vegetation, so increasing the pace of accumulation of greenhouse gases in the atmosphere.
- Increased rate of thawing of Tundra permafrost and acceleration in release of methane.

- Start of release of methane from the vast stores of ocean-floor “clathrates” far earlier than predicted.

- Changes in monsoon activity and in the timing and availability of melt-water from mountain glaciers affecting provision for irrigation, drinking water and food production for major sectors of the human population.

It is important to note that these observed impacts of climate change are the current effects of a rise of only 0.73°C in average global temperature. It is pretty certain that we are already “locked in” to at least three times that increase as the effects of greenhouse gases already emitted slowly work their way through the system.

It is these observations that underlie the recent warning from the chief scientist of one of NASA’s research centres that:

“Warming is accelerating GREATLY, especially ‘Recently’”.

The second imperative stems from major advance in our understanding of Climate Dynamics.

Over the last two years there has been a profound shift in the scientific understanding of the behaviour of the earth’s climate system. Although some specific feedback mechanisms were included in some of the more advanced climate models, the analysis of climate dynamics as a whole has proceeded far beyond that portrayed in the latest IPCC Assessment Report. It was not taken into consideration in the Stern Report, in the formulation of the Climate Bill currently before the UK Parliament, or in the process of target-setting of the present round of International negotiations.

The outdated position of classical climate science is epitomised in a recent statement by Professor John Marburger, Chief Scientific Advisor to the White House:

> **“The climate is sensitive to these CO_2 emissions and as they increase, the anthropogenic contribution to global warming and climate change will simply progress. The CO_2.accumulates in the atmosphere and there is no end point. It just gets hotter and hotter, so at some point the planet becomes unliveable.”**

The implication is that we can, at any point, reduce the rate of emissions, stabilise the concentration, and prevent the temperature from rising any further. From this perspective, climate change is seen in terms of simple cause and effect. The choice and timing of intervention point and eventual temperature increase are ours. They will be determined by technology, economics and the level of climate impact we are prepared to tolerate and to which we feel able to adapt.

In contrast, the best modern understanding draws on insights from the discipline of systems dynamics. It is well represented by the following quote from a recent paper co-authored by a team led by Professor James Hansen, Director of NASA's Goddard Institute for Space Studies:

> **"The Earth's climate is remarkably sensitive to global forcings. Positive (amplifying) 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."**

Here it is recognised that anthropogenic emissions act as a trigger to a complex set of mutually reinforcing feedbacks, many of them activated by rising temperature. The resultant climate change is out of all proportion to the precipitating event.

The implication is that climate change is non-linear. Once set in motion it is acceleratingly self-perpetuating. There is then only a small time-window within which human intervention has any (rapidly diminishing) chance of halting the process and returning the system to a stable state. Failure to act effectively within that window of opportunity would inevitably precipitate cataclysmic change on a par with the five mass extinction events known to have obliterated almost all life on earth.

The Briefing in Brief

In this section you will find a summary of the main points of the Briefing, presentation by presentation. The aim is to provide an appetiser before you explore the main course itself.

Presentation 1: An Introduction to Climate Dynamics

There is normally a dynamic balance between the solar energy received by planet earth and energy radiated back out into space. Since the start of the industrial revolution human emissions of "greenhouse gasses" have increasingly disturbed that balance. Less energy now escapes back to space. The difference (known technically as "radiative forcing") drives global warming.

The gap between energy received and the energy radiated is widening faster and faster, accelerated in part by continued increase in the rate of emissions, and now also by powerful feedback mechanisms inherent in the earth system itself.

In the second part of the presentation, focus shifts from the global level of energy dynamics to the specific drivers of global warming and the detail of the feedback mechanisms involved.

Seven factors govern the change in radiative forcing:

- **Atmospheric concentration of carbon-dioxide**

- **Atmospheric concentration of methane**
- **Atmospheric concentration of other greenhouse gasses**
- **Atmospheric concentration of water vapour**
- **Dust and contrails in the atmosphere**
- **Reflectivity of the earth surface (the "albedo effect")**
- **Behaviour of clouds**

Associated with these drivers, six categories of feedback mechanism have been identified, most of them triggered into action as temperature starts to rise. The presentation outlines them in detail. The most powerful amplifiers of global warming are:

- **Degrade of the carbon sinks**
- **Release of non-anthropogenic CO_2**
- **Discharge of methane from tundra and sea-bed deposits**
- **Decreased albedo as areas and duration of snow and ice reduce**
- **Temperature driven increase in the atmospheric concentration of water vapour**

The greater the radiative forcing, (the bigger the gap between solar energy received and energy re-radiated from the earth), the faster the temperature rises. The rate of global warming is also governed by the "**thermal inertia**" of the earth. The excess energy has to heat the air and land as well as ocean and ice. It is also absorbed by melting of ice and evaporation of water. There is therefore a major time lag in the system between the rate of radiative forcing and the resulting rise in temperature. That is why basing policies on observed effects of the current small increase in temperature is so fundamentally inappropriate.

There is one final feedback category associated with thermal inertia. The hotter it gets, the lower the inertia of the system, and the faster temperature rises.

That introductory overview of climate dynamics sets the scene for the next three presentations which provide an in-depth account of a selection of some of the more powerful feedback mechanisms now accelerating climate change.

Presentation 2: Feedback Dynamics of the Carbon Cycle

The feedback between physical climate change and the uptake of CO_2 by ocean and land (the degrade of carbon sinks), is especially important for two reasons:

Firstly, climate change with a given amount of emissions could be faster than previously thought.

Secondly, it has an impact on how much we have to reduce emissions in order to stabilise CO_2 concentration at any particular level.

About half of our CO_2 emissions are currently absorbed by soil and vegetation on land and by plankton and water in the oceans. Climate change could well suppress this sink. Most climate models on which the IPCC Reports depend still take no account of this carbon-cycle feedback.

We know that rising temperature decreases the amount of CO_2 that is absorbed in water. Hot surface water is lighter, so there is also less mixing of the CO_2-rich solution into the ocean depths. These feedbacks reduce the extent to which the natural sinks take up our emissions. The degrade of land-based sinks is even more pronounced. As temperatures rise and CO_2 concentrations increase, land-based sinks reverse and become a source of (non-anthropogenic) emission, so accelerating climate change. When you add in the effects of accelerating deforestation and climate-driven die-back of the Amazonian and other forest areas, the feedback intensifies.

If we take these feedbacks into account, then the "business as usual" scenario would lead to a concentration of about 1,000 parts per million of atmospheric CO_2 by the end of the century, instead of the 750ppm previously predicted. The models now attempting to take account of the carbon-cycle feedbacks have a range of results, so there is some uncertainty about the exact figures involved. But however you look at it, this is a very serious amplification of climate change.

The carbon cycle feedbacks make it harder to stabilise concentration of atmospheric CO_2. We have to start reducing emissions more quickly, cuts have to be deeper, and, because the sinks continue to degrade over time, emissions have to be lowered on a continuous basis well into the future. Total global emissions must not exceed the capacity of the global commons to absorb them, and that is likely to be less than half a gigaton per year.

The higher the chosen stabilisation level, the more difficult these feedbacks make it to maintain that level.

One fifth of global CO_2 emissions currently come from deforestation, a process which also destroys the capacity of the carbon sink. Ending deforestation is therefore a "double win", preventing emissions and preserving sinks.

Because of time-lags in the system, the path of climate change to 2030 is already set. Emissions cuts have to be made long before the need for them becomes apparent from observation.

Presentation 3: Anthropogenic Degrade of the Carbon Sinks

The destruction of rainforest ecosystems is continuing apace with virtually no restraining influence from the Kyoto Protocol. This presentation concentrates on Amazonia where deforestation now releases as much CO_2 into the atmosphere as the rest of the forest absorbs. Human activity has cancelled out the carbon sink of the Amazon rainforest.

The Amazon like all ecosystems is at risk of 'ecosystem failure', the end to the services like carbon sequestration and rain cloud production as a result of degradation by rising atmospheric radiative forcing. Global Climate Models suggest that for many of the earth's ecosystems this may be just a few decades away. Anthropogenic <u>destruction</u> of carbon sinks however, is a different and much more imminent threat. This is the active clearance of forest with the risk that a point may be reached where the remainder is no longer viable as a self-sustaining ecosystem and collapse would result. Critical early indicators of this include drought and frequent fire outbreak.

The drivers of deforestation stem from the financial rewards from industrial logging and monoculture expansion. These in turn are a response to the demand for timber, wood products, animal feed and vegetable oils. More recently there has been an acceleration in deforestation driven by the huge rise in demand from the bio-fuels industry. There is a direct relationship between the rate of Amazonian deforestation and the market price of soya.

Burn-back as part of the deforestation process releases carbon into the atmosphere from the ancient forest store. The pall of smoke also interrupts the evapo-transpiration cycle. The whole process increases the vulnerability of the Amazon forest to climate change, adding an anthropogenic feedback to the carbon cycle. Decrease in the ability of the system to recover from drought (lowered resilience) accelerates the natural climate-driven die back of the Amazon forest, so accelerating and intensifying the carbon feedbacks described in Presentation 2.

Major interruption in the extent of the canopy also destroys the sequential westward progression of rainfall and transpiration, setting off a cascade collapse of the ecosystem across the continent. This would lead to severe changes in global rainfall patterns, with substantial reductions over much of South America and as far North as the US mid-west.

The key factor is dehydration. Under drought conditions fires burn out of control. If much of the forest is dry or damaged, fires could grow into mega-fires. Under these conditions vast tracts may vanish permanently, raising the possibility that ecosystem destruction could lead to collapse on a very narrow time scale.

Some 500 gigatons of carbon are stored in the tropical rainforests of the world. 60% of that resides in the Amazon basin. Eco-system collapse here could therefore discharge many times the annual anthropogenic emission of CO_2. The process could take several decades to unfold, but once started it would be virtually unstoppable. It would put any future prospects of climate stabilisation completely beyond our control.

If we were able to make dramatic reductions in emissions from the burning of fossil fuels but failed to prevent further deforestation, we would still cross the point where climate feedbacks would make all our efforts irrelevant. We are now more likely to trigger runaway climate feedbacks as a result of ecosystem failure than we are as a result of profligate emissions from the use of fossil fuels.

Effective systemic solutions are now both urgent and imperative.

Presentation 4: Feedbacks in Ice and Ocean Dynamics

Antarctic ice cores show that we have gone through a number of glacial cycles in the past half million years. Each cycle also involves change in the level of atmospheric carbon dioxide from about 200 ppm during the glacial phase, to 300 ppm in the warm inter-glacials. In recent years, human activity has precipitated unprecedented and accelerating levels of CO_2 concentration. Average global temperature has followed suit.

If you add in the effects of other anthropogenic greenhouse gasses, coded in terms of CO_2-equivalence, then we already have a concentration of 440 ppm CO_{2e}, and the level is accelerating upwards. There is a general consensus that to avoid disastrously rapid warming we should stop at 450 ppm CO_{2e}. It is hard to see how that can be achieved when emissions are now double the rate of natural absorption.

In this context we are seeing the accelerated reduction of Arctic sea ice. It is shrinking in area and thinning dramatically. Average thickness has reduced by half in the last 25 years. The thickest areas of ridged ice have lost more than ¾ of their depth in the same period. Complete loss of Arctic sea ice in late summer is now expected during the 2030's, way in advance of any model predictions.

The process is driven by climate feedback, and also drives climate feedbacks. The change from ice cover to open water increases the rate of evaporation of water-vapour into the atmosphere. It also reduces the albedo effect, since much less energy is reflected back into space from open water than from ice. Both of these effects accelerate global warming.

As the climate warms, land-based snow cover decreases in extent and duration, so reducing albedo even further and adding to the feedback process.

The absence of sea ice from around the coasts of previously ice-bound land accelerates the rate of melt of land-based ice. This has a particularly marked effect on the Greenland ice-sheet, with implications for acceleration in the rise of sea-level. Increase in global warming also leads to higher temperatures in the ocean surface layer, increased expansion of ocean water volume and further acceleration in the rise of sea level.

Warming of the Arctic Ocean, increased precipitation and decrease in the formation of winter sea-ice are reducing the drivers of the "thermohaline circulation" and slowing the Gulf Stream. This will result in slower rise in temperature for north-western Europe, but hotter ocean temperatures further south. Southern Europe can expect a temperature rise of up to 4°C and more than 30% decrease in rainfall by the end of this century, as North African desert conditions extend across the Mediterranean.

Another ocean feedback is driven by increased acidification of the surface water. Acid water absorbs less CO_2. It also interferes with the ability of some plankton to form chalky shells, one of the long term processes by which CO_2 is removed from the atmosphere and sequestered on the ocean floor. Both of these feedbacks reduce the effectiveness of carbon sinks on which we depend for the absorption of anthropogenic emissions.

In conclusion, anthropogenic emissions of greenhouse gasses produce feedbacks that all tend to be positive (amplifying the rate of climate change). There is therefore a strong argument to achieve much more stringent reductions in carbon emissions than hitherto contemplated.

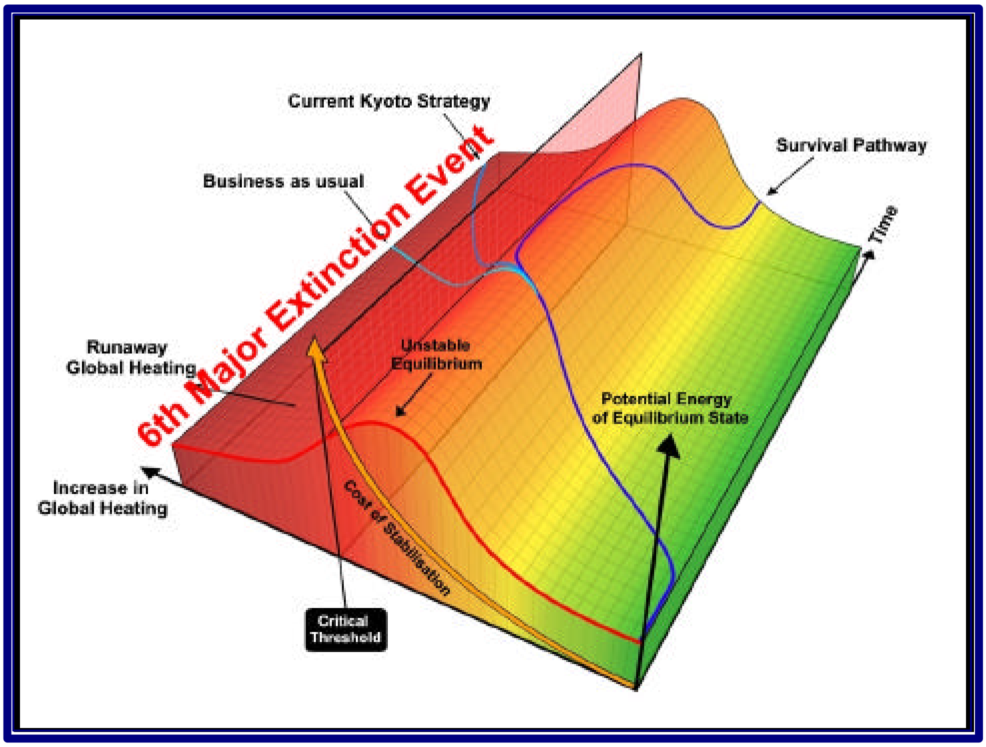
Presentation 5: Accelerated Climate Change and the Task of Stabilisation

Almost all of the systems known to affect climate change are now in a state of net positive (amplifying) feedback. Each feedback mechanism accelerates its own specific process. The output of each feedback is an input to all other feedbacks, so the system as a whole constitutes an interactive set of mutually reinforcing sub-systems.

This "second order" feedback system accelerates the rate of climate change and faces us with the possibility of a "tipping point" in the whole earth system. If we go beyond the point where human intervention can no longer stabilise the system, then we precipitate unstoppable runaway climate change. That would set in motion a major extinction event comparable to the five other extinction crises that the earth has previously experienced.

A state of unstable equilibrium occurs in the natural system when amplifying positive feedback just balances the effects of naturally occurring negative(damping) feedback. Beyond that point positive feedback dominates and runaway change commences. The system can still be stabilised, but only while the power of human intervention is greater than the steadily increasing power of positive feedback.

There is a "critical threshold" in the system beyond which the power of positive feedback overwhelms the capacity for human intervention. The cost of intervention escalates towards infinity as that threshold is approached. The Stern Report noted that the sooner we intervene, the lower would be the cost of climate stabilisation. It did not take into account the existence of a critical threshold beyond which effective intervention becomes impossible. This new analysis turns the accepted economics of mitigation on its head. (See the diagram below)



That is a huge strategic shift in our understanding of climate change. It has not been taken into account in the Kyoto negotiations. It has not been taken into account in current European legislation. It has not been taken into account in the framing of the Climate Bill at present before the UK Parliament.

We are now in the early stages of runaway climate change. There does not appear to be any naturally occurring negative feedback process available to contain its effects. Strategically we have to generate a negative feedback intervention of sufficient power to overcome the now active positive feedback process. We then have to maintain its effectiveness during the remaining period of rising temperature, while temperature-driven positive feedbacks continue to operate. That is an extraordinarily difficult task, out of all comparison with strategies currently in place.

The presentation concludes with a study of the dynamics of radiative forcing in order to illustrate the strategic intervention now required.

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