A CLOSING WINDOW OF OPPORTUNITY - GLOBAL GREENHOUSE REALITY 2008

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Summary

Scientific evidence accumulating since the IPCC's Fourth Assessment Report reveals that global warming is accelerating, at times far beyond projections outlined in earlier studies, including the latest IPCC Report. New modelling studies are providing updated and more detailed indications of the impacts of continued warming.

The emerging evidence is that important aspects of climate change seem to have been underestimated and the impacts are being felt sooner. For example, early signs of change suggest that the less than 1°C of global warming that the world has experienced to date may have already triggered the first tipping point of the Earth's climate system – a seasonally ice-free Arctic Ocean. This process could open the gates to rapid and abrupt climate change, rather than the gradual changes that have been projected so far.

At the same time, updated 21st century anthropogenic emission figures reflect the lack of sufficient concerted global actions on reducing atmospheric greenhouse gas concentrations. Atmospheric CO_2 concentrations are tracking those predicted for IPCC's non-mitigation "intensive dependency on fossil fuels" scenario (SRES A1FI). Scenario calculation that include the recent atmospheric greenhouse gas levels highlight the pressing urgency for actions achieving those stabilisation levels - identified by the IPCC- that are needed to avoid "dangerous anthropogenic interference" with the climate system in the 21st century.

In combination these two lines of evidence –presented in context in this paper- clearly demonstrate the inexorably closing window of opportunity to confront the challenge and implement stringent emissions cuts sufficient to maintain a functioning planet that we recognise. The reality of 2008 tells us that climate change is causing dangerous anthropogenic interference at lower thresholds and earlier than expected, both for reasons we control (emissions) and have already caused (earlier and stronger than expected impacts). The cogent implication of this closing pair of scissors is that our mitigation response to climate change now needs to be even more rapid and ambitious.

The integrated basis: IPCC's Fourth Assessment Report

In 2007 the UN Intergovernmental Panel on Climate Change (IPCC) set out an overwhelming body of scientific evidence which put the reality of human-induced climate change beyond any reasonable doubt. During 2007 the IPCC was also awarded the Nobel Peace prize in clear recognition that climate change poses a major challenge to the security of mankind in the 21st century.

Involving over 3800 scientists from over 150 countries and six years of work, the IPCC Fourth Assessment Report (IPCC 4AR), published in instalments between January and November 2007, reviewed and analysed scientific studies published up to the end of 2006, and in a few cases, to early 2007.

The IPCC report provided an integrated scientific assessment of the causes, impacts and consequences of climate change, and linked this evidence with realistic response strategies considering costs, policies, and technologies. The stated objective of the United Nations Framework Conventions on Climate Change (UNFCCC), and through it, IPCC, is the stabilisation of atmospheric greenhouse gas concentrations at a level that will prevent "dangerous anthropogenic interference" with the climate system. Staying below this level would allow ecosystems to adapt naturally to climate change, ensure that food production is not threatened and would enable economic development to proceed in a sustainable manner.

Dangerous interference: a sharpening picture

In the late 1980s, an advisory group formed by the World Meteorological Organization, the International Council of Scientific Union, and the United Nations Environment Program recommended 2°C global mean surface warming from preindustrial levels as the threshold for dangerous anthropogenic interference (DAI) (Rijsberman & Stewart, 1990). This recommendation has now been accepted by the European Council and the German Advisory Council on Global Change, among other national and international bodies.

The approach of DAI is centred on the normative definition of key vulnerabilities to global warming that are deemed unacceptable (Schneider & Mastrandrea, 2005). Therefore, DAI is not only subject to the societal interpretation of what changes would be acceptable, it is also continuously updated by the growing scientific insight into the global climate system. The association of impacts with average global temperature increase presented by the IPCC 4AR provides an alarming image of the impacts of global warming and has affirmed the notion of that more than 2°C global warming represents dangerous interference (Fig. 1).

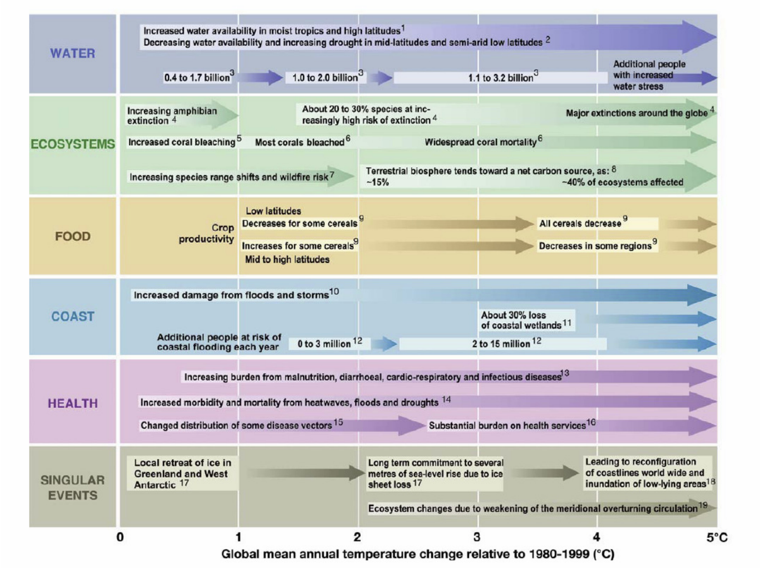

Figure 1. Examples of impacts associated with global average temperature change in the 21st century (note that x axis is relative to temperature increase in 1980-1999, which is 0.5°C *above pre-industrial). From IPCC 4AR (WGII Table TS 4).*

Recent insight has now led to an important shift in emphasis of the arguments defining DAI. Current science is providing evidence that in order to avoid DAI in the long term the global mean temperature threshold would have to be no higher than 1.7°C above preindustrial levels (Hansen et al.,2007). The improved understanding is based on the recognition that DAI must involve a range of regional threshold values of global surface temperature change, a concept consistent with IPCC 4AR (see e.g. “Singular Events” in Fig. 1). This perception has linked to DAI the concept of tipping elements of the climate system that can -triggered by climate warming- cross a threshold and enter a new state without necessary further forcing by the original warming (Lenton et al., 2008).

Some of the tipping elements are to the best of current scientific knowledge anticipated to be triggered by global warming in the range of 1-2°C, and many others when global warming is in the range of 3-5°C (Table 1). Most notably, the majority of tipping elements will – once triggered- result in step changes in the Earth’s climate system that are hard or impossible to reverse by human actions, and many will accelerate the warming, or have other severe continental-scale or global impacts.

As northern polar temperatures are increasing at approximately twice the rate of the global mean, the loss of the perennial arctic sea ice system and the disintegration of the Greenland Ice Sheet are to the best of current knowledge triggered inside the global 2°C limit (Table 1). The current status of both systems will be discussed in detail below.

Table 1: Policy-relevant potential future tipping elements in the climate system. From Lenton et al., 2008, modified

Tipping element and feature	Critical value	Global warming	Transition timescale	Key impact
Arctic summer sea ice: decreased areal extent	Unidentified air and ocean surface temperature	+0.5-2°C	~10yr (rapid)	Amplified warming, ecosystem change
Greenland Ice Sheet: decreased ice volume	+~3°C local air temperature, unidentified ocean surface temperature	+1-2°C	>300 yr (slow)	Sea level +2-7 m
West Antarctic Ice Sheet: decreased ice volume	+~5-8°C local air temperature, or less for ocean surface temperature	+3-5°C	>300 yr (slow)	Sea level +5 m
Atlantic thermohaline circulation: decreased overturning	+9-45 km^3/day freshwater input into North Atlantic	+3-5°C	~100 yr (gradual)	Regional cooling, sea level, shift of Inter-tropical Convergence Zone
El Nino-Southern Oscillation: increased amplitude	Unidentified thermocline depth	+3-6°C	~100 yr (gradual)	Droughts in SE Asia and elsewhere
Sahara/Sahel/West African Monsoon: decreased rainfall	100 mm/yr precipitation	+3-5°C	~10 yr (rapid)	Increased carrying capacity
Amazon rainforest: decreased tree fraction	1100 mm/yr precipitation	+3-4°C	~50 yr (gradual)	Biodiversity loss, decreased rainfall
Boreal forest: decreased tree fraction	+~3-5°C local air temperature	+3-5°C	~50 yr (gradual)	Biome shift

These updated insights now highlight the uncontrollable risks involved for accepting even 2°C global warming, for severe impacts and feedbacks accelerating climate change are likely to be triggered within this range.

Staying well below 2°C global warming compared to pre-industrial levels substantially reduces the risk of triggering step-changes amplifying global warming. Going beyond the 2°C threshold has to be avoided by all means, as impacts are likely to become self-accelerating and in some cases irreversible (Hansen et al., 2007; IPCC 4AR, 2007; Baer & Mastrandea, 2006; Meinshausen, 2006; Knutti et al., 2008).

The earlier and stronger impacts of climate change on key components of the climate system discussed below highlight sharply how real this risk already has become. These extremely high stakes clearly limit the stabilisation options for atmospheric CO_2 that should reasonably be pursued.

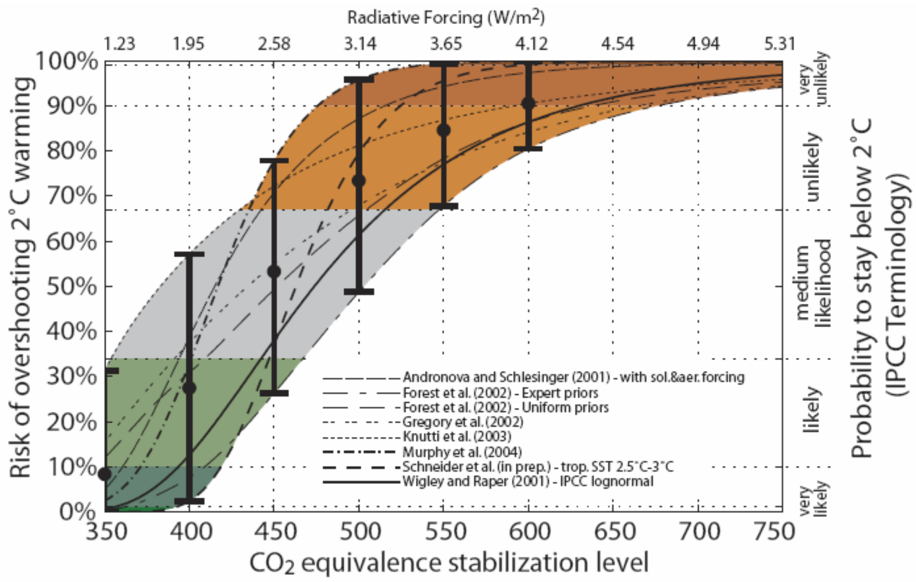

Figure 2. The risk of overshooting 2°C global equilibrium warming for different CO_2 equivalent stabilisation levels (from Meinshausen 2006, modified).

Recent modelling studies link the likelihood of staying within eventual – or equilibrium- temperature bounds to different atmospheric CO_2 stabilisation levels. They paint an alarming picture of the risks involved for even moderate further increases in atmospheric CO_2 to cause 2°C and more global warming.

One study (Meinshausen, 2006) concluded that only at a stabilisation of 400 ppm CO_2 equivalents was the risks of overshooting low enough that the achievement of a 2°C target could be termed "likely". It showed that a stabilisation level of 450 ppm CO_2 equivalents carries a risk of 26 to 78 per cent (mean 47 per cent) to exceed 2°C (Fig. 2). Another assessment (Baer & Mastrandea, 2006) concluded that stabilising at 450 ppm CO_2 (454-480 ppm CO_2 equivalents) risk exceeding 2°C by 46 to 85 per cent, and therefore was more likely than not to exceed the desired temperature threshold. Overshooting a stabilisation target for limited time only significantly increases the likelihood of exceeding the desired temperature threshold, even when the long term stabilisation level would be avoiding this (Schneider & Mastrandea, 2005, Hansen et al., 2008).

A pincer movement: the reality of 2008

Climate impacts: earlier and stronger than predicted

Recent observations have highlighted that climate change is impacting key natural systems earlier and stronger than predicted by the IPCC 4AR.

This evidence suggests that the approximately three quarter of a degree C global warming to date has already triggered feedbacks that are accelerating warming earlier than predicted, and through it, possibly climate change itself.

Arctic sea ice at its tipping point and what lurks behind

Arctic sea ice is recognised as an indicator of global climate change (ACIA 2005). It has been in decline for three decades, foremost in summer but also in winter. But while IPCC 4AR reported the area covered by summer sea ice to decline linearly at 7.4 per cent per decade (1979-2005), the last four years have seen three record minima that led to the long-term average of decline now being 11.7 per cent per decade. The recent minima fell 39 per cent (2007) and 34 per cent (2008), respectively, below the long-term (1979-2000) average (SEARCH, 2008). This dramatic loss of sea ice means a complete departure of observations from the range IPCC model projections (Fig. 3), demonstrating that actual impacts of climate change were underestimated and that a key component of the climate system was affected much earlier and stronger than predicted.

Anthropogenic induced warming played a substantial initial role in causing the loss of ice (Stroeve et al., 2007). Warmer arctic air and sea surface temperatures affected the sea ice so that an internal feedback mechanism – the ice-albedo effect- caused substantial and widespread thinning (Rigor & Wallace, 2004). With more ocean water exposed to sunlight, more heat was absorbed that caused more ice to melt and more water to be exposed. This self-perpetuating process dominates the loss of arctic ice. It decreased average ice thickness by one third between 1975 and 2000 (Rothrock et al., 2008) and reduced the area covered by ice older than 4 years by more than half between 1985-2007 (Maslanik et al., 2007).

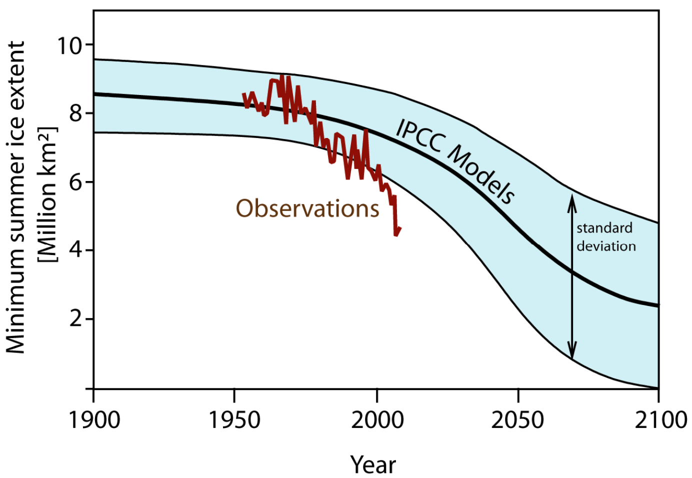

Figure 3. Observations (1953-2008) and predictions (mean and range of IPCC models driven with the A1B scenario) of arctic minimum summer sea ice extent (courtesy of D. Notz, Max Planck Institute for Meteorology).

The future trend of the extent of summer sea ice is primarily determined by its thickness. With the ice-albedo feedback dominating its overall becoming thinner and younger the area of the sea ice is consequently forecast to deteriorate further (Holland et al., 2006). As the majority of first-year ice melts in an average arctic summer, the Arctic Ocean is now seen to be at or maybe past its tipping point to become ice-free during summers (Lindsey and Zhang, 2005). Already before the minima of 2007 and 2008 observations were approximately 30 years ahead of the mean IPCC model forecast driven by the A1B scenario that predicts an ice-free Arctic Ocean during summer between 2050 and beyond 2100 (Stroeve et al., 2007). Given the unbroken trend of declining summer sea ice, the underestimated magnitude of the ice-albedo effect, and the predictions of continued warming (IPCC 4AR) it is now very likely that an ice-free Arctic Ocean during summer will become reality before mid century (Serreze et al., 2007). Such a state has not occurred in the last one million years (Overpeck et al., 2005).

The implications of the sea ice decline are enormous, both within and beyond the Arctic. The reduction in ice cover has caused the Arctic to warm at a higher rate than the rest of the globe. This additional heat absorbed by the surface waters is warming the Arctic Ocean and the arctic atmosphere (Steele et al., 2008; Serreze & Francis, 2006), feeding it into the global climate system, where it contributes to more global warming.

There is concern that the additional heat will unleash carbon cycle effects that accelerate global warming at an earlier date than previously assumed. The Arctic holds vast stores of carbon that are vulnerable to regional warming and could be partially released to the atmosphere as methane or carbon dioxide, or both. Latest modelling evidence suggests that rapid sea ice loss increases arctic land warming more than three times compared to warming previously predicted for the 21^{st} century. This warming is apparent year round and is felt up to 1500 km inland (Lawrence et al., 2008). The additional warming of the land is shown to lead to rapid thawing of certain permafrost soils, which would cause higher emissions of methane and carbon dioxide (Schuur et al., 2008; Khvorostyanov et al., 2008), adding to global warming. Additionally, warming of the shallow arctic shelf seas could potentially destabilize frozen sub-sea sediments and release methane from frozen methane hydrate stores the size of which are estimated to be immense. It is not yet known how much carbon could be released to the atmosphere by such carbon cycle feedbacks triggered by rapid sea ice decline, but any release would accelerate global warming. The earlier than expected loss of sea ice might well trigger an earlier than expected rise of arctic carbon cycle feedbacks accelerating global warming. IPCC projections do not yet incorporate the contribution of greenhouse gases from the Arctic to 21^{st} century climate.

Greenland and sea level rise

The rate at which the Greenland Ice Sheet has been losing ice has accelerated two- to three-fold between assessment periods in the 1990s and the first five years of the 21^{st} century (Chen et al., 2006; Velicogna & Wahr, 2006; Krabill et al., 2004, Rignot & Kanagaratnam, 2006). The reason for the accelerated losses is accelerated glacier flow, partly attributed to observed regional sea surface temperature increases. The extent and duration of surface melt caused by warmer air temperatures recently also reached record highs in both southern (2007) and northern (2008) parts of Greenland. Both air and sea temperatures are projected to increase further with global warming, substantially accelerated in periods of rapid sea ice loss, as discussed above. Greenland Ice Sheet melt rates are thus forecast to accelerate further.

The primary reason for global concern about the increased melting of the Greenland Ice Sheet is contribution to global sea level rise. IPCC 4AR had excluded ice dynamics from estimates of sea level increase because the limited understanding of these processes did not allow adequate representation in models. Therefore projections of sea level rise of 0.18-0.59 m until 2100 as stated in IPCC 4AR have to be viewed as lower bound (Rahmstorf et al., 2007). The annual contribution of the Greenland Ice Sheet to sea level rise has doubled recently, compared to IPCC 4AR, to now more than 5 cm per decade (Rignot and Kanagaratnam 2006, Chen et al 2006). It is thus believed that the Greenland Ice Sheet will contribute much more than previously estimated to global sea-level rise during the 21st century.

Recent projections of sea level rise of this century including the contribution of the Greenland and West Antarctic (Pritchard & Vaughan, 2007) Ice Sheets show far greater increases than those reported in the IPCC 4th Assessment Report. They conclude that a 2100 sea level rise of 50-140 cm over 1990 is most likely (Rahmstorf, 2007), 80 cm most plausible, and 200 cm theoretically possible (Pfeffer et al., 2008), if global warming is left to continue. To the 80 to 200 cm range the Greenland Ice Sheet is contributing 17 and 54 cm, respectively. However, these 2100 values don't tell the full story.

Paleo-evidence shows that with a warmer climate the Greenland Ice Sheet will substantially decrease in volume and area over the course of many centuries. A threshold beyond which the ice sheet will show self-sustained melt (Ridley et al., 2005) is expected to be crossed if global annual mean temperature exceeds 1.9-4.6°C, or the annual mean temperature for Greenland exceeds 2.7-6.2°C (Gregory and Huybrechts, 2006; Lowe et al., 2006), or 3°C (ACIA, 2005). Temperatures of this order are well within the range of IPCC projections now realistic within this century (see below), making the status of the Greenland Ice Sheet a concern for contemporary policy. Once the threshold is crossed, it is believed that the melting of the Greenland Ice Sheet will be irreversible and may take place within a few centuries –as has occurred in the past (Hansen et al., 2007; Rohling et al., 2008). The resulting sea level rise of several metres over the coming centuries would flood vast coastal areas, directly putting millions of people at risk. The Stern Report (2007) concluded that already a sea level rise of one meter may threaten up to 200 million people.

Waning sinks – and mounting sources

Natural sinks on land and in the oceans remove about half of the anthropogenic CO_2 emitted into the atmosphere. As a result the annual increment in atmospheric CO_2 is substantially smaller than the increment in anthropogenic emissions. Between 2000 and 2007 natural CO_2 sinks absorbed 55% of all anthropogenic carbon emissions (29% Land, 26% Ocean), slowing down climate change significantly (Global Carbon Project, 2008). The efficiency of these sinks is sensitive to climate change (Friedlingstein et al., 2006). Consequently, while in 1960 60% of emissions were taken up by the Earth's natural sinks and the rest remained in the atmosphere, this figure has decreased to 55% in 2006 (Fig. 4). The Earth's natural sink strength has decreased by 5% over the last 50 years (Global Carbon Project, 2008).

This reduction matters for two reasons. First, it implies a weakening in the ability of the Earth system to mitigate the effects of emissions, and secondly it highlights a potential positive feedback to global warming that is strongly indicated to strengthen in the future.

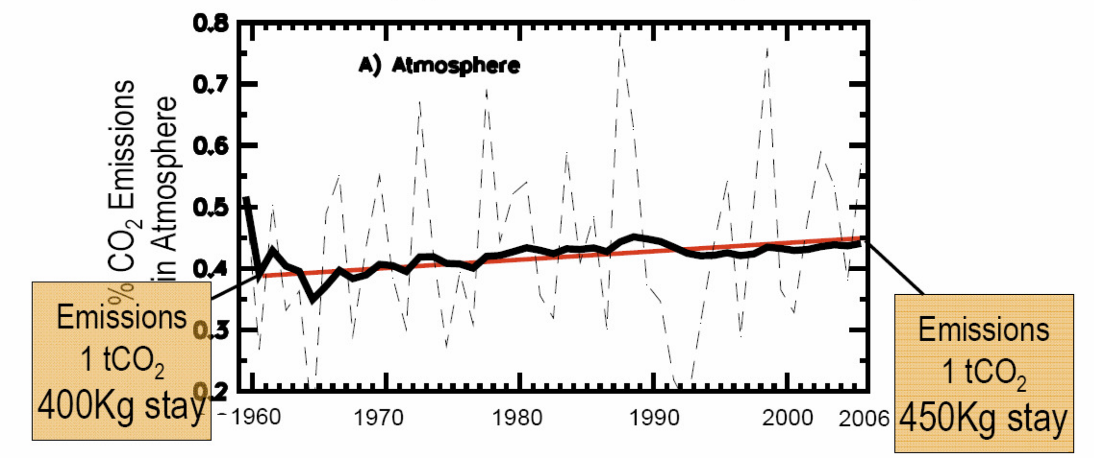

Figure 4. Fraction of anthropogenic emissions that stay in the atmosphere (from Canadell et al., 2007,updated by Global Carbon Project, 2008).

Almost half of the reduced global ocean sink strength is attributed to an up to 30% decrease in the efficiency of the Southern Ocean sink over the last 20 years (Canadell et al., 2007). This sink removes annually 0.7 Pg (or Gigatons (Gt)) of anthropogenic carbon, and the decline is attributed to the strengthening of the winds around Antarctica enhancing ventilation of natural carbon-rich deep waters (Le Quéré et al., 2007). As the increased intensity of the winds is attributed to global warming and the ozone hole, and the strengthening of Southern Ocean winds is projected to intensify with global warming throughout the 21st century, the sink strength of the Southern Ocean is forecast to be declining further.

Northern hemisphere land ecosystems have recently seen reduced sink strength due to experiencing meteorological conditions forecast to be more frequent in a warmer world (Canadell et al., 2007). Major droughts reduced the summer uptake of CO_2 by vegetation in mid-latitudes, and two decades of warmer autumns over northern ecosystems have increased their overall carbon losses (Ciais et al., 2005; Angert et al., 2005; Breshears et al., 2005). In combination, these recent assessments highlight that the ability of these land ecosystems to act as sinks may well diminish earlier than previously expected (Piao et al., 2008).

Ocean sink strength will be further reduced in the future as carbon dioxide from emissions affect ocean chemistry, and through it the biological carbonate pump responsible for a substantial part of the ocean's uptake of CO_2. As carbon dioxide dissolves into the ocean, the water becomes less alkaline (increased acidity). Global average surface seawater pH has been reduced by 0.1 since the industrial revolution (currently 8.18). With emissions continuing to rise as they currently do, pH is estimated to decrease by a further 0.4 by 2100 (Caldeira & Wickett, 2003), a rate of change unprecedented for probably the last 20 million years (Raven et al., 2005). There is concern that ocean organisms, amongst them corals and certain plankton, will not be able to adapt to the rate and scale of this pH change, as their access to carbonate –a chemical form of CO_2 in water- becomes restricted. Through access to and processing of this carbonate into solid shells these organisms are controlling the ocean's current uptake and storage of carbon dioxide from the atmosphere. Corals alone account for between a third and half of the global production of solid carbonate (Borges, 2005). The efficiency of corals to built carbonate shell structures will be reduced with further increases in atmospheric CO_2 concentrations (Kleypas et al., 1999). Such a decline in the effectiveness of the biological pump would further reduce the ocean sink strength and leave more of CO_2 emissions remaining in the atmosphere to amplify warming.

The implication of a continuing decline in natural sink strength is of great concern for contemporary policy. The longer it takes to begin reducing emissions significantly, the larger the cuts that will be needed to stabilise atmospheric CO_2, as at that time we can no longer rely on past proportions of emissions to be removed from the atmosphere by natural sinks. IPCC 4AR suggests that including carbon cycle effects into emission scenarios stabilising at 450 ppm CO_2 would require cumulative emissions over the 21st century to be reduced by more than a quarter over scenarios excluding these effects. Intact natural sinks can thus be regarded as a huge subsidy to the global economy if an equivalent sink had to be created using other climate mitigation options.

The potential of the decreasing efficiency of natural sinks to aggravate global warming has been underestimated in the past. When modelling past and projected behaviour of the carbon cycle with a number of IPCC models driven by emission scenario A2, carbon cycle feedbacks were shown to contribute an additional 20-200 ppm CO_2 to the atmosphere up to the year 2100. It is equally important that all models underestimated considerably the observed trend at which the natural sinks strength decreased over the last century (Friedlingstein et al., 2006). This sobering insight makes clear that carbon cycle acceleration of global warming is likely to emerge sooner and stronger than predicted. Given the large fraction of emissions that are taken up by natural sinks, any such predicted changes are of serious concern for today's policy.

A further component of the carbon cycle with substantial potential for accelerating global warming has recently started to mount again. Methane levels in the atmosphere have more than doubled since pre-industrial times, accounting for around one-fifth of the human contribution to global warming. Following almost a decade with little change in global atmospheric methane concentration, the last two year have shown renewed sustained growth again (NOAA, 2008). A substantial part of this added methane may well have originated from increased bacterial emissions from Siberian wetland soils, most presumably due to the very warm conditions that were observed in the region. Similar conditions are forecast to be more regular in the region with climate change.

Global carbon status

Anthropogenic greenhouse gas emissions: above the IPCC's worst case scenario

The rise in atmospheric CO_2 concentration is not only proceeding unhalted – it is increasingly accelerating. The rate of increase has accelerated from 1.5 ppm per year in the 1990s to 2.0 ppm per year since the year 2000, and has reached 2.2 ppm per year in 2007 (Global Carbon Project, 2008; Raupach et al., 2007). We now stand at 383 ppm atmospheric CO_2, which amounts to 37 per cent above the pre-industrial level (NOAA, 2008).

After atmospheric methane concentrations – the second largest contributor to warming- were virtually stable for about a decade, the last two years have seen an increase again. Together, CO_2 and other relevant anthropogenic trace gases currently warm the planet at a rate of about 435 ppm CO_2 equivalents (NOAA, 2008). While the warming contributed by anthropogenic greenhouse gases increased about 22 per cent from 1990 to 2006, CO_2 has accounted for about 80 per cent of this increase.

Anthropogenic CO_2 emissions from fossil fuel are growing four times faster since 2000 than during the previous decade (1990-99: 0.9 per cent/yr; 2000-2007: 3.5 per cent/yr), and above IPCC's worst case emission scenario (A1FI – intensive dependency on fossil fuels) that predicts 4°C global warming (2.4-6.4°C) for 2100 (Fig. 5). Total 2007 anthropogenic emissions amount to 10 Pg C (or Gigatons (Gt) C), with 8.5 Pg C contributed from fossil fuels and 1.5 Pg C from tropical deforestation of 13 million hectares per year (2000-2007) (Global Carbon Project, 2008).

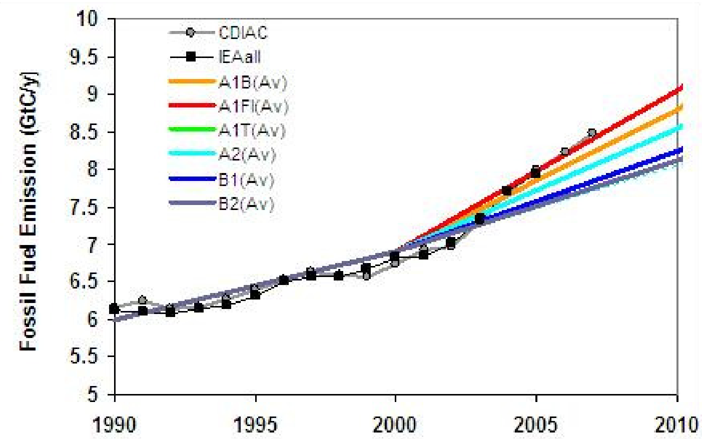

Figure 5. Actual (two sources: International Energy Agency: IEA; Carbon Dioxide Information Analysis Center: CDIAC) and projected (mean of IPCC scenarios) emissions from fossil fuel (from Raupach et al., 2007,updated by Global Carbon Project, 2008).

Atmospheric CO_2 trend: the heat is on

For the 2000-2006 period the drivers of accelerating atmospheric CO_2 concentrations have been assigned to the increased activity of the global economy (65 per cent), the deterioration of the carbon intensity (17 per cent), and the decreased efficiency of natural sinks (18 per cent) (Canadell et al., 2007). Emissions of less developed but rapidly industrialising countries have increased so that they are now emitting more carbon than developed countries. Over the last decade the carbon intensity of the world's economy (the amount of carbon used to produce an amount of the gross world product) is improving slower than in previous decades, mainly as a result of the combustion of relatively more coal (IEA, 2008). As a result of climate change the efficiency of natural sinks- land

and oceans-has decreased by 5 per cent over the last 50 years, so that today already 45 per cent of emissions remain in the atmosphere. This implies that the longer it takes to begin reducing emissions significantly, the larger the cuts needed to stabilize atmospheric CO_2.

In combination, these drivers have led to an acceleration of atmospheric CO_2 growth one third faster since 2000 than in the previous two decades. This implies that climate forcing will take place stronger and sooner than expected. It has to be stressed here that this stronger climate forcing has not triggered the earlier than expected impacts of climate change discussed above, but will rather soon add to these.

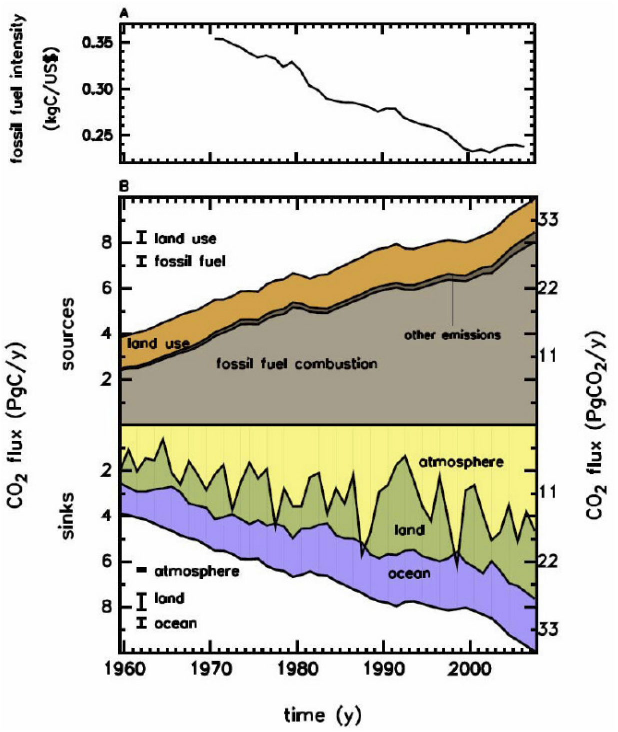

Figure 6. Fossil-fuel intensity of the gross world product (GWP) from 1970 to 2007 (A) and the CO_2 budget from 1959 to 2007 (B). Fossil-fuel intensity uses GWP data based on market exchange rates, expressed in U.S. dollars (referenced to 1990, with inflation removed). (B Upper) CO_2 emissions to the atmosphere (sources) as the sum of fossil fuel combustion, land-use change, and other emissions, which are primarily from cement production. (Lower) The fate of the emitted CO_2, including the increase in atmospheric CO_2 plus the sinks of CO_2 on land and in the ocean. Flux is in Pg/y carbon (left axis) and Pg/y CO_2 (right axis) (From Canadell et al., 2007, updated by Global Carbon Project, 2008).

By today, anthropogenic greenhouse gas emissions have increased the global temperature by 0.74°C compared to pre-industrial. But in reality these emissions have already committed the planet to more warming.

First, system inertia, mainly of the oceans, is masking the true warming caused by emissions that have already occurred. Due to the mass and thermal capacity of the oceans and ice, and the slowness of heat transport processes, it takes a long time before the atmosphere reflects in full the consequences of the increased greenhouse gas signal. In consequence, another 0.6°C has to be added to the current warming to account for the eventual warming caused by past emissions (Meehl et al., 2005).

Furthermore, while so far a majority of studies –including IPCC 4AR- are connecting emissions to current century temperature increase by considering only "fast feedbacks" of the global climate system to increased atmospheric greenhouse gas concentration, the committed long-term -or equilibrium- impact of today's emissions increasingly links the timescale of centuries to contemporary policy (Lenton et al., 2008; Hansen et al., 2007). This link is reasoned by strong evidence from paleoclimate, the residence time of CO_2 in the atmosphere (Fig. 7), the inertia of the climate system, and the possibility of crossing thresholds of irreversible climate feedback processes accelerating the warming along the path of the projected temperature increase (Table 1).

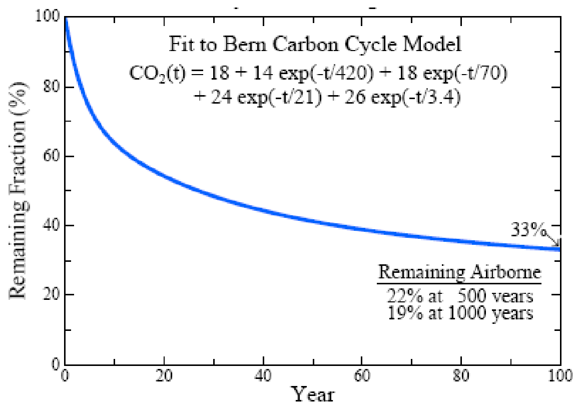

Figure 7. The fraction of CO_2 remaining in the atmosphere of a pulse CO_2 emission, through time. One third remains in the atmosphere after a century, one fifth is still present after one millennium (From Hansen et al., 2007).

With climate change affecting important feedback components of the global climate system earlier than expected, the previously mostly excluded "slow feedbacks" increasingly become a responsibility of today's emission policies. Carbon cycle feedbacks are of particular importance as they matter both in the context of natural sink activities and the prospect of providing additional sources for both atmospheric methane and carbon dioxide. However, such processes are currently not (methane), or not adequately (soils) considered for climate projections. Nevertheless, a recent analysis (Friedlingstein et al., 2006) using a number of IPCC models driven by scenario A2 showed how already within this century carbon cycle feedbacks are unanimously materialising by reducing the efficiency of natural sinks, and providing an additional 20-200 ppm CO_2 (4-44 per cent) to the atmosphere which leads to an additional warming of 0.1 to 1.5°C. IPCC 4AR suggests that including carbon cycle effects into its emission scenarios stabilising at 450 ppm CO_2 would require cumulative emissions over the 21st century to be reduced by 27 per cent over scenarios excluding these effects.

Inaction is the tightest spot

What is the situation of today that we have manoeuvred the climate system into by our inaction on tackling atmospheric greenhouse gas concentrations?

A shifting emphasis towards the potential triggering of tipping elements of the global climate system highlights that dangerous anthropogenic interference with the global climate system may well start below a 2°C global mean temperature increase over pre-industrial levels. Setting off these tipping elements would trigger step changes towards accelerated warming, accelerated sea level rise, and fundamentally changing water regimes.

At the same time climate change is affecting key components of the global climate system earlier and stronger than previously projected. The most critical systems to show such effects – the Greenland Ice Sheet and the arctic sea ice- have the potential to substantially aggravate sea level rise and trigger releases of more greenhouse gases from frozen arctic stores, respectively. This evidence provides urgency as it signals higher – not lower- sensitivity of key climate system components to climate change.

Emission rates are accelerating, rapidly increasing the baseline from which reductions of atmospheric greenhouse gases will have to start. Due to the long residence time of CO_2 in the atmosphere they constitute a long term commitment to further warming. At the same time climate change is already reducing the efficiency of natural sinks that are the primary reducers of atmospheric CO_2.

Considering the actual emission numbers from 2000-2008 and the best available scientific understanding of the relationship between emissions and the time course of resulting atmospheric concentrations, recent research (Andersen &Bows, 2008) has demonstrated the increasingly demanding nature of reconciling the 2°C global temperature increase threshold with emission pathways of all anthropogenic greenhouse gases. An upper threshold of atmospheric concentration of 450 ppm CO_2 equivalents is necessary to stay below 2°C, applying the IPCC 4AR's climate sensitivity with carbon cycle feedbacks included. The study brings into sharp focus that today only the most stringent actions on all aspects of mitigation – earliest possible emission peak, highest practical emission reduction thereafter, and highest action tackling deforestation – would result in keeping the planet within the bounds of 2°C temperature increase compared to preindustrial levels. For greenhouse gas concentrations to stabilise at 450 ppm CO_2 equivalents – bearing only a 53 per cent chance to stay below 2°C (Meinshausen, 2006)- emissions need to peak by 2015 and then decrease by 6-8 per cent each year, with full decarbonisation to occur soon after 2050 (Anderson & Bows, 2008).

Also other recent studies, including IPCC 4AR, have demonstrated that atmospheric CO_2 concentration exceeding those we experience today and peak emission years past 2015 carry a serious risk of exceeding a global mean 2°C temperature increase compared to pre-industrial levels. The modelling clearly demonstrates that any delay, even by a few years, in cutting emissions, significantly reduces the probability of staying below 2°C (Knutti et al., 2008; Van Vuuren et al., 2008; Hansen et al., 2008; IPCC 4AR, 2007; Hansen et al., 2007; Baer & Mastrandea, 2006; Meinshausen, 2006).

The stringent conclusion from this updated evidence is that a global agreement on mitigation comprising ambitious and rapid actions needs to be agreed upon now and enforced as soon as at all possible.

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Full references, and electronic version of the article:

http://www.panda.org/about_wwf/what_we_do/climate_change/publications/index.cfm?uNewsID=151042