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Closing Windows and Opening Flood Gates:

Recent Climate Change Science and Implications for Climate Policy

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Introduction

The Fourth Assessment Report (AR4) by the Intergovernmental Panel on Climate Change (IPCC), released in four volumes during 2007, provides a commanding summary of global knowledge about climate change[1]. It covers the scientific basis of climate change, its potential impacts, and response options through adaptation, mitigation and their links with sustainable development (IPCC, 2007a, b, c, d).

The AR4 added significant momentum to international negotiations, and the United Nations climate change conference in Copenhagen in December 2009 is tasked with hammering out a new global agreement based on AR4 conclusions (UNFCCC, 2007). The IPCC was also awarded the Nobel Peace Prize in 2007, jointly with Al Gore, for its efforts in building up and disseminating knowledge related to climate change and possible responses. In bestowing this award the Nobel Committee recognised that climate change is rapidly moving from an environmental issue to one of economic and international security.

While the AR4 is widely regarded as the most authoritative and comprehensive assessment of climate change science and relevant response options, it is nonetheless a snapshot in time, since it is based on peer-reviewed literature published up to about the end of 2006. This article aims to provide an update on two particular areas of research where significant developments have occurred, and on their policy implications. These two areas are, on one hand, recent information on the risk of an accelerated rise in sea level from the loss of polar ice, and on the other hand, increasing evidence that the window of opportunity to stabilise greenhouse gas concentrations at low levels is closing rapidly. Both areas have important implications for global and national policies to address climate change, including the interaction of climate policies with government responses to the global economic crisis.

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The growing commitment to future climate change and its impacts

A fundamental message from the recent IPCC assessment is that current emissions of long-lived greenhouse gases, particularly CO_2, are creating a legacy that will last for millennia. About 20% of all CO_2 emitted into the atmosphere today will remain there for more than 1,000 years (IPCC, 2007d). The warming effect of those emissions on the climate is essentially irreversible over many human generations, unless we actively remove CO_2 from the atmosphere. Techniques for doing so exist in principle, but their environmental and economic feasibility and sustainability at sufficiently large scales are at best speculative at present (IPCC, 2007c; also, for example, Broecker, 2007; Boyd, 2008; Marland and Obersteiner, 2008; Read, 2008).

In addition, some components of the climate system, in particular the world's oceans and polar ice sheets, take a long time to respond to the heating effect of greenhouse gases. This inertia means that even if greenhouse gas concentrations could be held constant at today's levels, the atmosphere would continue to warm for more than a century by about another 0.6°C, and sea level would continue to rise for a thousand years or more (IPCC, 2007d).

Unfortunately, holding greenhouse gas concentrations constant at today's levels is an entirely hypothetical scenario, as it would require an immediate, large and sustained drop in global emissions of CO_2 and other long-lived greenhouse gases. More gradual emissions reductions inevitably lead to further increases in greenhouse gas concentrations and associated climate change. Even the most ambitious scenario for emissions reductions assessed by the IPCC, where global CO_2 emissions peak by about 2015 and decline to almost zero by 2100, would still lead to temperature increases of about 2°C above pre-industrial levels, or about another 1.5°C above average 1980–1999 temperatures. For such an amount of warming, sea level would rise inexorably for many centuries by 0.4-1.2m from thermal expansion alone, with additional contributions from melting of glaciers and ice caps and possibly several metres due to loss of parts of the polar ice sheets. Greater delays in emissions reductions imply even higher greenhouse gas concentrations and consequently greater temperature increases and long-term sea level rise (IPCC, 2007a).

Apart from climate change itself, recent studies show that some of its impacts are also likely to be irreversible. For example, 20–30% of all species assessed so far are projected to be at an increased risk of extinction once global average temperatures rise by 2–3°C above pre-industrial levels. For temperature increases above 4°C, ecosystem models project extinctions around the globe of 40–70% of species assessed. Some key ecosystems are at high risk even within the next few decades, for example coral reefs and the sea ice biome (IPCC, 2007c, a; Eisenman and Wettlaufer, 2009; Silverman et al., 2009).

Some other key impacts would be effectively irreversible at least over many human generations. For example, warming of only another 1°C is expected to increase water stress for hundreds of millions of people, mainly in subtropical regions due to a combination of reduced rainfall, rising temperatures and the shrinkage of glaciers in the Andes, Himalayas and European alps. For temperatures above 3°C, the number of additional people affected by water stress is projected to be above one billion. Many of those impacts are projected to emerge at very low levels of warming; indeed, regional warming observed over the past three decades has already affected many natural systems on all continents and most oceans (IPCC, 2007c).

Solomon et al. (2009) confirmed that sea level rise and rainfall reductions in many already dry parts of the world would be essentially irreversible over at least the next 1,000 years even if CO_2 emissions are stopped entirely after the year 2100. The magnitude of those persistent changes crucially depends on CO_2 emissions (and/or efforts to reduce those emissions) during the 21st century.

In light of this information, it is by now a distinct understatement to say that climate change requires a 'precautionary response', since this phrase implies much greater uncertainty about the negative consequences of climate change than there is. The nature of science lies in efforts to understand and reduce uncertainties. The image that therefore often emerges in the public arena is one where scientists discuss, and sometimes argue about, recent research and its implications. Since the remainder of this article aims to contribute to this debate, it seems necessary to state up front that even just those climate change projections that we already have very high confidence in (e.g. impacts on water security and some key ecosystems, and long-term sea level rise from thermal expansion alone) require urgent, global and sustained emissions reductions to keep those impacts within (barely) manageable limits. The more recent scientific findings discussed below only add to the urgency of such measures.

Opening floodgates: recent studies relating to sea level rise

Rising sea levels present a significant risk to infrastructure around the world. The thermal inertia of oceans and the polar ice sheets implies that sea level would rise inexorably for many centuries in a warmer world as the ocean water warms up and expands, and land-based ice continues to melt. For this reason, projections of sea level rise in the long term (i.e. many centuries into the future) are generally much higher than increases projected by the year 2100. Indeed, the last time the Earth was a few degrees warmer than at present for an extended period (about 125,000 years ago), sea levels were 4 to 6m higher, mainly from the loss of polar ice (IPCC, 2007d).

Given the unavoidability of rising sea levels in a warming world, the critical question is only partly *how much* sea level will rise; it is also *how quickly* any given rise might be realised: how much may occur within the next 100 years (the lifetime of an individual house) or over the next millennium (the lifetime of large coastal cities). The rate of change is critical since it will influence the ability to respond without major social and economic upheavals in highly developed coastal regions.

Based on current models and for the highest emissions scenario, the AR4 found that sea levels would rise by up to about 59cm by the end of the 21st century.[2] However, the AR4 warned that sea level rise could exceed this rate because these projections do not include uncertainties due to feedbacks between the climate system and the global carbon cycle, nor the possible further acceleration of the flow of glaciers that drain the polar ice sheets. Such acceleration has been observed during the past decade where glaciers lost their buttressing ice shelves, but is not incorporated into current models because the understanding of the relevant processes is too limited. The AR4 noted that if the enhanced ice flow from Greenland and Antarctic glaciers were to increase linearly with temperature, this would add another 10 to 20cm to sea level by the end of the 21st century, but greater increases could not be ruled out if the enhanced loss of polar ice accelerates non-linearly with rising temperatures (IPCC, 2007d).

Numerous studies published since the AR4 have attempted to understand and quantify this potential additional contribution of polar ice sheets to sea level rise. These recent studies point to a potentially significant additional contribution from dynamic ice sheet discharge, which could increase total sea level rise by 2100 to between about 70 and 160cm, although even 2m cannot be ruled out entirely.

These studies used a range of techniques, including the empirical correlation between temperature and sea level observed during the 20th century (Rahmstorf, 2007; Horton et al., 2008); efforts to quantify potential rates of ice loss from polar glaciers based on observed mechanisms (see, for example, Das et al., 2008; Holland et al., 2008; Joughin et al., 2008; Pfeffer et al., 2008; Rignot et al., 2008; Stearns et al., 2008; Nick et al., 2009); and observed rates of sea level rise the last time the Earth entered a warm interglacial period (Rohling et al., 2008; Blanchon et al., 2009).

There is as yet insufficient convergence or technical consistency amongst those studies to assign probabilities to any of the recent higher projections, let alone provide a 'best estimate' – a wide range of possible answers remains. It is worth noting, though, that none of the recent studies suggests sea level rise at the lower end of the range given in the AR4. The most robust information that can be drawn from the recent studies is that at present, the quantitative range presented in the AR4 should probably be regarded as a lower bound, and no specific figure represents a reliable upper bound for sea level rise by the year 2100 (Alley et al., 2008).

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Implications of sea level rise uncertainties for policy responses

The relevance of these recent studies for coastal planning depends to some extent on the nature and lifetime of relevant coastal infrastructure. The lack of a robust upper bound of sea level rise forces us to evaluate infrastructure developments for their ability to adapt to sea level rise *if and when* any particular level may be realised. In other words, adaptation to sea level rise may need to be adjusted as necessary over time rather than designed to cope with a specific maximum sea level rise by a specific date. This 'adaptive management' approach has been employed in planning for the Thames (UK) estuary and is beginning to be incorporated in government guidance on climate change in the UK (DEFRA, 2006; Ramsbottom and Reeder, 2008).

In New Zealand, technical guidance on sea level rise for local authorities recognises the uncertainties in sea level rise and suggests the need to evaluate a range of scenarios and to consider the potential for adaptation to sea level rise in excess of any default assumption (Ministry for the Environment, 2008, Table 2.2 and Figure 2.8). However, local-scale decision-making processes might struggle to follow such an adaptive management approach unless they are provided with additional central government guidance regarding the fundamental principles and priorities that need to be applied (see, for example, Environment Waikato, 2008a; LGNZ, 2008).

Adaptation requirements will also depend on the level of risk that communities are prepared to accept. For example, building infrastructure that can be adapted to a sea level rise of 0.5m but not to 1m or more is not necessarily 'wrong' (since sea level *may* rise no more than 0.5m over the next century), but it clearly is a risky proposition in light of the recent scientific evidence. Whether such risks are worth taking, and who should bear the related costs and benefits, cannot be answered by science but requires a societal debate and political decisions that are informed by science.

In the context of urban settlements, specific time horizons for planning and consent processes carry their own problems. While individual buildings and infrastructure have a limited (albeit long) lifetime, settlements *per se* usually exist for many centuries. They will have to deal with an inexorable further rise in sea levels beyond 2100 in a warmer world. At some stage, retreating rather than protecting them from the rising sea will almost certainly become the only option. However, a regulatory framework with adequate technical and financial support that would allow the widespread and consistent practical implementation of 'managed retreat' remains to be developed. In the absence of such a national framework, the combination of 'existing use rights' and inevitable local conflicts between public and private benefits and costs of protecting either infrastructure or the natural character of the coast create significant challenges (see, for example, Environment Waikato, 2008a, b). These challenges can only intensify over time as sea level continues to rise.

Sea level rise presents a challenge not only for adaptation policies but also for global climate agreements concerned with emissions reductions. Even though it may be technically feasible to adapt to sea level rise of several metres for some countries over the next few centuries, this is very unlikely to be implemented effectively given the scale of the challenge, and it would come at enormous social and environmental costs. Developing countries in particular would have neither the financial, economic or technical resources nor governance systems to deal with changes of this magnitude (IPCC, 2007c, chapters 17 and 19). This means that the risks associated with sea level rise on the scale of several metres can in practical terms only be reduced significantly by limiting the emissions of greenhouse gases and resulting long-term climate change itself.

The AR4 already noted that one of the reasons for increased concern about climate change is exactly the fact that we *do not* have a good understanding of how much sea level rise could accelerate over the 21st century. The most recent research on sea level rise confirms this perspective and places climate policy decisions squarely in a risk-management framework: the need to reduce emissions is driven not only by those impacts that we can foresee already with a reasonable degree of certainty; it is made even more urgent by the need to avoid potential impacts that may have a lower probability (or where we have lower levels of confidence in projections) but that would have catastrophic effects on human well-being and ecosystems on a global scale if realised (Stern, 2006, IPCC, 2007a; Weitzman, 2009).

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Closing windows: pathways to climate stabilisation

Even though recent scientific developments suggest that stabilisation targets even lower than those evaluated by the IPCC may be desirable, recent greenhouse gas emissions trends suggest that the window of opportunity to stabilise greenhouse gas concentrations at low levels and costs is closing fast.

The AR4 evaluated a large number of integrated assessments of the global macroeconomic cost of reducing greenhouse gas emissions and stabilising CO_2-equivalent concentrations. The lowest stabilisation level evaluated in the AR4 was for concentrations of 440 to 490ppm CO_2-equivalent. Limiting the increase in concentrations to such a level would require global emissions of CO_2 to peak by about 2015, decline to about 50–85% below 1990 levels by the year 2050, and fall further to almost zero emissions in 2100 (IPCC, 2007b). As discussed above, this level would still result in long-term warming of about 2°C relative to pre-industrial temperatures and some significant associated impacts, especially in the most vulnerable regions.

The AR4 also provided information on the near-term emissions targets that developed and developing countries would have to achieve by 2020 if they want to remain consistent with this stringent mitigation pathway. A large variety of metrics was used to compare mitigation targets for various country groups, taking their different financial and technological capacities, historical responsibilities for climate change, and general state of development into account. Based on these metrics, the AR4 found that developed countries listed in Annex I of the UNFCCC (United Nations Framework Convention on Climate Change) would need to reduce their collective emissions by 25–40% below 1990 levels by 2020, while developing countries would need to reduce their collective emissions to substantially below business-as-usual (i.e. below emissions in the absence of any mitigation measures) by the same date (IPCC, 2007b, Table 13.7).

Recent analyses have confirmed the robustness of this analysis in principle, and also clarified that the 'substantial' reduction from business-as-usual for developing countries would need to amount to about 10–30% by 2020 (den Elzen and Höhne, 2008). Given the vastly different development stages amongst developing countries, this implies even stronger emissions limitations for the most advanced developing countries and more relaxed (or no) limitations on least developed countries.

A suite of recent studies pointed out that the ability to follow such a global mitigation path is rapidly disappearing, because emissions from developing countries have accelerated over recent years while concurrently many developed countries failed to halt the growth in their emissions. The reasons for these trends include the increased global investment in coal-fired power generation, the aspiration of middle classes in many developing countries to reach living standards of the developed world, and failure in many countries to implement a clear price on carbon emissions and/or policies that could overcome market failures and social or information barriers (IPCC, 2007b; Anderson and Bows, 2008; den Elzen and Höhne, 2008; Lankao et al., 2008; Meinshausen and Hare, 2008; Sheehan, 2008; van Vuuren and Riahi, 2008).

The potential rate of future emissions reductions is constrained fundamentally by the lifetime of capital infrastructure, which has a turnover rate of about 1-3% per annum. The global diffusion of low-carbon technology is therefore expected to take many decades even if investment in such technologies is made financially attractive or the cost of such technologies falls below that of current carbon-intensive options (IPCC, 2007b, chapter 11). This applies particularly to developed economies that are unlikely to undergo major growth in new power generation but rather gradually transform their existing generation. Decarbonising the economies of developed countries at rates in excess of 1–3% per year over extended periods will therefore only be possible if existing infrastructure is retired prematurely in favour of new low-carbon technologies, or by retro-fitting existing installations (e.g. with carbon capture and storage technology). Either of those options usually results in significantly higher costs. Nonetheless, delays of only a few more years in achieving real emissions reductions will make sustained decarbonisation rates in excess of 3% per year necessary if low concentration targets are to be attained. Such delays will therefore saddle future generations with escalating mitigation costs and/or increasing impacts from climate change and increasing risk of catastrophic events.

Implications of recent emissions and economic trends for climate policy

Even though the required scale of emissions reductions relative to business-as-usual may appear significant, macroeconomic modelling indicates that if a price on carbon were implemented globally now, stringent emissions reductions would reduce growth in global GDP by less than 0.12 percentage points per year on average until 2050 (IPCC, 2007b). However, costs for specific countries, sectors and over more limited time periods could deviate significantly from this long-term global average. Concerns about the uneven or unfair distribution of costs amongst different parts of society therefore continue to make it difficult to implement effective policies that would achieve a globally optimal outcome at lowest cost.

The current global economic crisis is likely to put a short-term dent in the otherwise relentless growth of global emissions.[3] However, if policy packages to stimulate ailing economies focus on traditional and hence carbon-intensive infrastructure projects, the longer-term effect of economic recovery is likely to see rapid further growth in global emissions once national economies recover, and the additional carbon-intensive infrastructure would be locked into place for many more decades.

Earlier analysis suggested that the window of opportunity to stabilise greenhouse gas concentrations at low levels is closing fast; if economic recovery over the next few years is fuelled by investments in carbon-intensive infrastructure, such investments would slam this window firmly shut for the rest of this century.

Fortunately, a recent analysis (Edenhofer and Stern, 2009) gives some hope. The stimulus packages of the G20 nations have devoted significant fractions of their new and redirected funds to green investments. Of the roughly US$2,160 billion in economic stimulus packages unveiled so far, the tentative analysis by Edenhofer and Stern suggests that about US$400 billion are directed at areas that reduce greenhouse gas emissions, for example through investments in energy efficiency in buildings, renewables and associated upgrades to networks, transport systems, and water and waste management. These investments are expected to capitalise on reduced labour costs and provide training and employment opportunities, while at the same time reducing direct immediate and longer-term costs due to reduced greenhouse gas emissions and energy demand combined with increased energy security.

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Edenhofer and Stern (2009, pp.6 and 12) argue that:

> providing a stimulus to the economy and protecting the climate do not stand in opposition to each other. … Ensuring that national recovery programmes are 'green' makes sense not only because climate change poses a far more serious threat to the global economy in the long term than do temporary economic downturns. It makes sense because otherwise, once the world economy

recovers, sharply increasing energy prices are likely at some stage to trigger subsequent slowdowns. Without the transition towards a low-carbon global energy system, the next economic crisis is pre-programmed. 'Green' recovery programmes are not only an option for sound and effective crisis relief; they are a precondition.

The investment derivatives that supported the housing bubble were driven by hypothetical 'business-as-usual' returns, but this expectation was itself based on a decade of unusual growth in the housing sector that has now been brought to an abrupt halt. Non-transparent investment vehicles hid the escalating risk from investors. The key challenge for public policy now is to establish a more sustainable platform for economic recovery, and to ensure that the hunt for short-term economic returns does not saddle the next generation with escalating risks arising from climate change and 'toxic assets' in the form of carbon-intensive industries. Making the structural adjustments in national economies required for significant and sustained greenhouse gas emissions reductions was never going to be easy. Nonetheless, the current economic crisis could prove to be a blessing in disguise if governments use the opportunity to guide the transition into a carbon-constrained world, and avoid the creation of yet another bubble that will again be pierced when yesterday's 'business-as-usual' expectations begin to clash with fundamental external constraints.

New Zealand in the international context

This article would appear incomplete without at least a brief look at how New Zealand's domestic approaches compare with these broad international trends and recent insights. It is noteworthy that most of the fiscal stimulus in New Zealand consists of tax cuts. Almost all other OECD countries seem to inject a much higher fraction of their stimulus in response to the economic crisis through direct government investments. This includes significant 'green' packages that aim to deliver both employment and transformation of energy demand and supply systems (Ban, 2009; Edenhofer and Stern, 2009; Kissel, 2009). Where additional direct investments are planned in New Zealand, there is as yet little evidence that the government is concerned with the potential lock-in effect of investment in traditional infrastructure projects such as roading or thermal power generation, which commit New Zealand to further increases in greenhouse gas emissions as the economy recovers. At the same time, New Zealand is beginning to mount a case internationally that its projected growth in greenhouse gas emissions should be seen as a reason to also give it lighter future targets (see NZ, 2009). If this gamble fails, the hoped-for economic payback from tax-cut driven spending priorities and carbon-intensive infrastructure investments could quickly turn into a liability.

Opportunities for direct government investment abound that could deliver benefits in employment and in developing expertise, and that could at the same time contribute to the transformation of our energy and transport supply and demand patterns. Relevant energy policies include training, employment and regulatory and financial support for small-scale renewables such solar hot water heating and enhanced housing insulation; feed-in tariffs for renewables such as solar photo-voltaics; and regulatory support for net metering. Investments in public and private transport infrastructure both can deliver short-term employment opportunities, but they create vastly different social, environmental and economic legacies through their associated carbon footprints, energy demands, social access to mobility and health co-benefits or trade-offs.

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These potential benefits of 'green' stimulus measures suggest a clear need for government agencies to analyse options for aligning economic recovery measures (tax cuts and direct government investments) with New Zealand's strategic energy and transport goals. At the same time, it is clear that any private sector capital investments that may be stimulated by tax cuts can only contribute to long-term climate goals if there is sufficient certainty about a price on carbon in the New Zealand economy. Urgent clarification and implementation of the New Zealand Emissions Trading System can thus be regarded as a precondition, rather than a barrier, for sustainable future economic growth.

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2 Whereas over many centuries, the AR4 found that sea level rise can be expected to exceed one metre even for the lowest emissions scenario that involves stringent greenhouse gas emissions reductions.

3 Between 1970 and 2004, overall CO_2-equivalent emissions increased by about 70% and CO2 by about 80%. Under various business-as-usual scenarios, global CO_2-equivalent emissions are projected to grow by another 25 to 90% until 2030 relative to the year 2000 (IPCC 2007b).

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