A Race Against Time: The Urgency of Mitigating Climate Change and Managing Extreme Events

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"*The inhabitants of Earth are quietly conducting a gigantic experiment. So vast and sweeping will be the consequences that, were it brought before any responsible council for approval, it would be firmly rejected. Yet it goes on with little interference from any jurisdiction or nation… We play Russian roulette with climate, hoping that the future will hold no unpleasant surprises. No one knows what lies in the active chamber of the gun, but I am less optimistic about its contents than many.*" Wallace S. Broecker (1987)[1]

Climate change in context

The world's climate depends on dynamic interactions between the atmosphere, hydrosphere, cryosphere (ice sheets) and biosphere. Past aeons have borne witness to a planet choked by intense volcanic activity, heated by major emanations of greenhouse gases from the oceans and from dried and burnt vegetation to the point where polar oceans were free of ice, pole-ward migration of climate zones resulting in expansion of vast circumglobal deserts, or frozen in successive ice ages that entombed northern Eurasia and America under miles of ice[2]. These changes imposed great stresses upon ecosystems, often leading to mass extinction of species[3]. Early people, as hunters and gatherers, had to cope with these changing conditions, mostly through migration between different climate zones. The world was a different place. Whereas some species survived under the most adverse conditions, other species disappeared while vacated habitat niches allowed new life forms to appear.

Modern people, a single species, are now the agent of global change[4]. We are undertaking an unplanned and unprecedented experiment in planetary engineering. The forces of global change are already unravelling through physical and biological systems on a scale never before witnessed by civilization, overshooting greenhouse peaks reached during the recent history of Earth. Human actions are causing a massive loss and fragmentation of habitats (e.g., deforestation of the tropical rain forests), over-exploitation of species (e.g., collapse of major fisheries), and severe environmental degradation (e.g., pollution and excessive draw-down of rivers, lakes and groundwater)[5]. As a culmination of all of this we are confronted by the rising spectre of global climate change.

When climate change is discussed in public forums, it is usually with reference to global warming, caused by anthropogenic pollution from the burning of fossil fuels. Since the furnaces of the industrial revolution were first ignited a few centuries ago, we have treated the atmosphere as an open sewer, dumping into it more 300 billion tonnes of heat-trapping carbon in the form of long-lived greenhouse gases such as carbon dioxide (CO_2), methane and ozone-destroying CFCs, as well as non-carbon gases such as nitrous oxide and sulphur hexaflouride[4]. The atmospheric concentration of CO_2 is now 37% higher than at any time over the past million years, and is now fast tracking toward greenhouse gas levels not seen for 3 million years, when sea levels were around 30 metres higher than the present day[6]. At current rates of emissions, this trend will lead to atmospheric conditions that have not existed for 55 million years, when the world suffered a major greenhouse event and was largely ice free.

Average global temperature[4] has risen by 0.74°C in the hundred years since 1905. Temperature rise from 1975 to 2005 is ~0.6°C. That is, 80% of global warming since the dawn of the industrial age has occurred since the mid-1980s, underpinning sharp acceleration of the process. Arctic Sea ice cover has plummeted since 2005 (see below). Both likely represent breached climate change thresholds, or “gates”.

Future shock?

Although the current heating trend is clear, and predictions for future climate are well supported by robust models, the timing of potential amplifying climatic and biological ‘feedback’ effects remain unknown. Worryingly, the pace of observed recent changes has exceeded even the most pessimistic forecasts by climate scientists, a point illustrated by Prof Stephan Rahmstorf[7] and in a recent contribution by former CSIRO Climate Impacts leader, Dr Barrie Pittock[8]. More than half of the ambiguity captured in the scenarios of the Intergovernmental Panel on Climate Change (www.ipcc.ch), is related to our inability to forecast the probable economic and technological development pathway global societies will take during the 21st century[4]. We need to be able to anticipate the manifold impacts of anthropogenic climate change and make key economic and technological choices accordingly. But will we act in time, and will it be with sufficient gusto? The question at the forefront of future planning for global change is whether natural inertia and climate thresholds will prevail over humanity’s ability to forecast, mitigate and adapt to the worst consequences of runaway climate change.

The choice of on-going deferment of action is stark (Fig. 1). If we do not commit to deep emission cuts in the near future (see below on *Mitigation*), both the current generation of humans, and our descendents for generations to come, will likely suffer from a globally averaged temperature rise of 3–6°C, a consequent collapse of the Greenland and the West Antarctic ice sheets with an attendant 12–14 metres of sea level rise[9], more frequent and severe droughts, more intense flooding, a major loss of biodiversity, and the possibility of a permanent El Niño. This includes frequent failures of the tropical monsoon and complete loss of mountain glaciers, which together provide the water required to feed the billions of people in Asia, Africa and South America. Sea level rise, estimated on the scale of meters through the 21st century[7, 9, 10], will result in displacement of many millions of climate refugees in coastal and low-lying regions and port cities, and in major disruption of harbours and of sea trade.

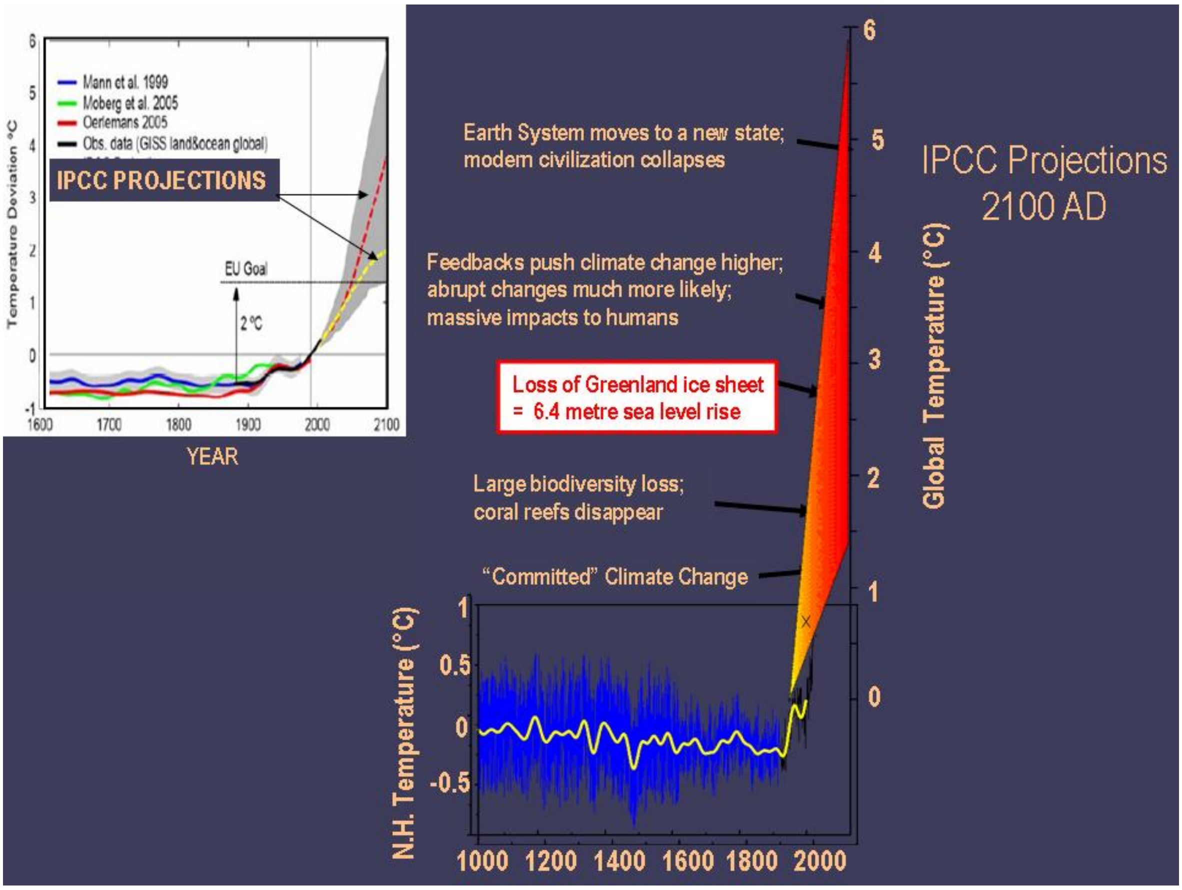

Figure 1. Record of past temperature change and future projections. The light yellow line (with blue shading for uncertainty bounds) is the reconstructed temperature since 1000AD. The black line is the instrumental (thermometer) temperature record since 1850 (with dark yellow line representing the smoothed mean). The red shaded area and inset diagram represent the uncertainty range of the IPCC scenarios[4], and illustrates how close the Earth already is to the EU goal of 2°C and subsequent major climate change impacts.

The European Union has judged that a warming of just 2°C above pre-industrial levels constitutes 'dangerous anthropogenic interference with the climate system' (Fig. 1), as codified in the 1992 United Nations Framework Convention on Climate Change[4]. Yet even if we can manage to stabilise CO_2 concentrations at 400 parts per million (it is currently 383, and rising at 2 – 3 parts per million per year), we would still only have a 66% chance of averting dangerous climate change[4, 11]. At 550 parts per million CO_2, the 'baseline' scenario envisaged in the Stern Report[11], the chance of holding global warming to < 2°C is less than 1% and the risk of exceeding 4°C is 24%. Yet with any amount of atmospheric heating beyond about 2°C of warming, the likelihood of crossing catastrophic and irreversible physical, biological and, ultimately, economic thresholds, such as rapid sea level rise associated with the disintegration of the polar ice sheets, a shutdown of major oceanic currents which control temperature variations, a mass extinctions of species, and a collapse of the natural hazards insurance industry, becomes unacceptably high[10, 12].

The warning signs are that we are rapidly approaching irreversible tipping points[10]. For instance, observations made this year (too recent to be included in the IPCC 2007 report) include the summer melting of the Arctic Sea ice growing[13] by 23 percent between 2005 – 2007, and an increase in spring melt area of the Greenland ice sheet by 16 percent during 1979 – 2002 and later years, showing the melt continuing to accelerate[14]. This is compounded by extensive land clearing, which despite new growth and re-fertilization of soil and vegetation by carbon, sulphur and nitrogen, results in net reduction in the capacity of vegetation to sequester carbon dioxide and minimise its impact on climate. The oceans are also losing their capacity to sink carbon at a faster rate than expected[15]. Another major danger arises from the warming and drying of Tundra and tropical methane-rich wetlands, with the peat bogs of Europe, Siberia and North America alone estimated to hold the equivalent carbon of >50 years of global industrial emissions. Methane is a powerful greenhouse gas with 23 times the infrared absorption/emission capacity of carbon dioxide[16].

The need to mitigate

As yet there is no evidence that global society is taking meaningful action to decarbonise the global economy (Fig. 2). Indeed, it is just the reverse, with a recent study showing that energy efficiency (expressed as GDP per tonne of carbon) in developed nations such as the US and Australia has decreased over the last decade[17]. Over the last decade, the world's rate of emissions growth has tripled, and total CO_2-equivalent emissions now exceed 40 billion tonnes a year[17] (8 billion tonnes of carbon). China overtook the US in 2006 as the single biggest greenhouse polluter, and within a decade, it will be producing twice as much CO_2. This remarkable rate of growth, if continued, will mean that over just the next 25 years, humans will spew into the atmosphere an additional volume of CO_2 that exceeds the total amount emitted during the 150 year industrial period of 1750 to 2000. Of particular concern is that long-lived greenhouse gases, like CO_2, will continue act to amplify global warming for centuries to come. For every four tonnes added during a year in which we prevaricate about reducing emissions, one tonne will still be trapping heat in 500 years[18]. It is a bleak endowment to future generations.

Modelling of alternative 'stabilisation scenarios' by the IPCC, shows that, to avoid dangerous planetary heating, global emissions must be reduced by 50 to 85 per cent relative to 2000 levels by 2050[4]. Moreover, under a globally equitable allocation of future carbon, even more drastic reductions will be required of developed nations, due to their disproportionately high per capita emissions and historical debt. Emissions, which are presently growing at around 3 per cent each year[7, 17], must peak between 2000 and 2015[4].

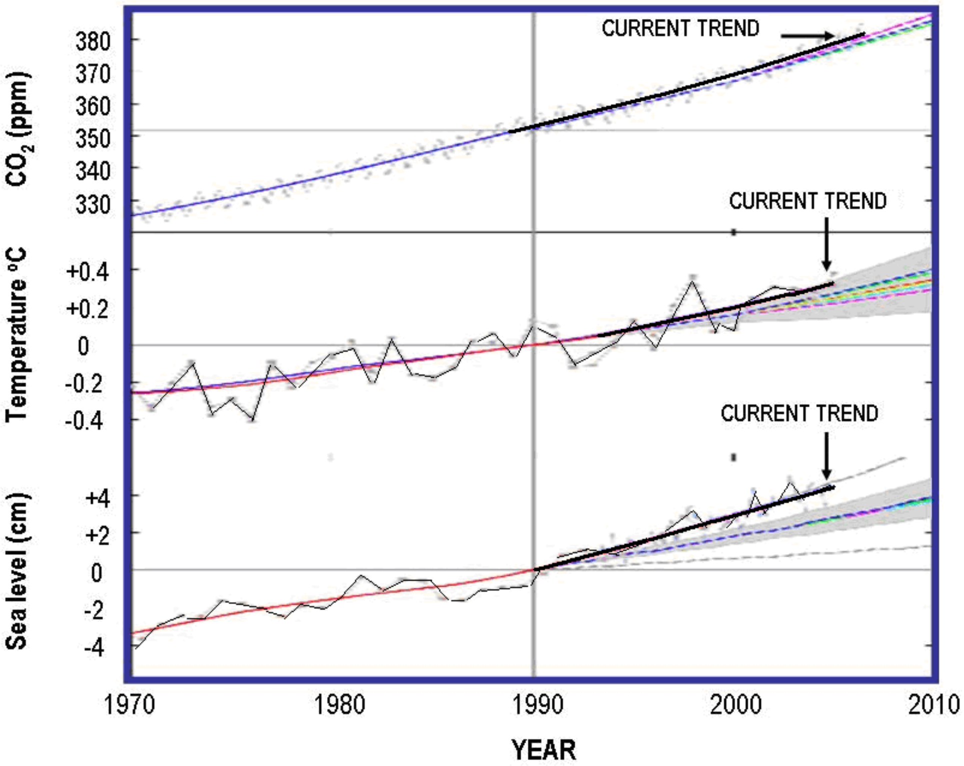

Figure 2. Changes in key global climate parameters since 1973, compared to the scenarios of the IPCC [shown as dashed lines and gray ranges in all panels]. (a) Monthly carbon dioxide concentration and its trend line at Mauna Loa, Hawaii up to January 2007, from Scripps in collaboration with NOAA. (b) Annual global mean land and ocean combined surface temperature from GISS and the Hadley Centre up to 2006, with their trends. (c) Sea level data based primarily on tide gauges (annual) and from satellite altimeter (three month data spacing up to mid- 2006) and their trends. Note that the solid line, representing currently observed trends, exceeds the IPCC projections (after Rahmstorf, 2007).[7]

The economic cost of transformation from fossil fuel-based technologies to alternative energy sources (solar thermal, photovoltaic, geothermal, wind, hydrogen) has been estimated at around 0.1% of GDP per annum (IPCC Working Group III, the Stern Report, Australian Business Roundtable, AGL-WWF study)[4, 11]. This contrasts with the trillions of dollars currently used for destructive purposes. We risk being "penny-wise but pound foolish".

Irrespective of what we do now, we are committed to adaptation. If all pollution was shut off immediately, the planet would still continue to warm by at least a further 0.5°C. Under the current business-as-usual scenario of carbon emissions, the planet is predicted to experience five to nine times the rate of twentieth-century warming over the next hundred years. An obvious question is, will human and natural systems be able to keep pace and adapt to these changes?[19]

Risks to natural and human systems

Past global natural climate cycles unfolded over many millennia, mostly triggered by changes in the Earth's orbit (Milankovic cycles)[2]. Current climate change is demonstrably triggered by (a) emission of over 300 billion tonnes of Carbon since the down of the industrial revolution, and (b) extensive de-vegetation of the planet. Yet, if emissions are not soon checked, planetary heating on a scale comparable to the difference between the last ice age and the current interglacial period, namely 4 to 5°C, would ensue over a period of less than one century. It has been estimated that 20 to 60 per cent of species might become extinct in the next few centuries if global warming of more than a few degrees occurs[4, 5, 20]. Such level of mass extinction is commensurate with major geological catastrophes, including large asteroid strike from space or major volcanic eruptions, which triggered mass extinctions on similar scale[2, 3]. A clear lesson from the past is that the faster and more severe the rate of global change, the more devastating the biological consequences. The recent history of Earth allows calibration of average global temperature rises to sea level rise, leading to projections on the scale of tens of metres, should greenhouse gas emissions proceed unchecked[9] (Fig. 3).

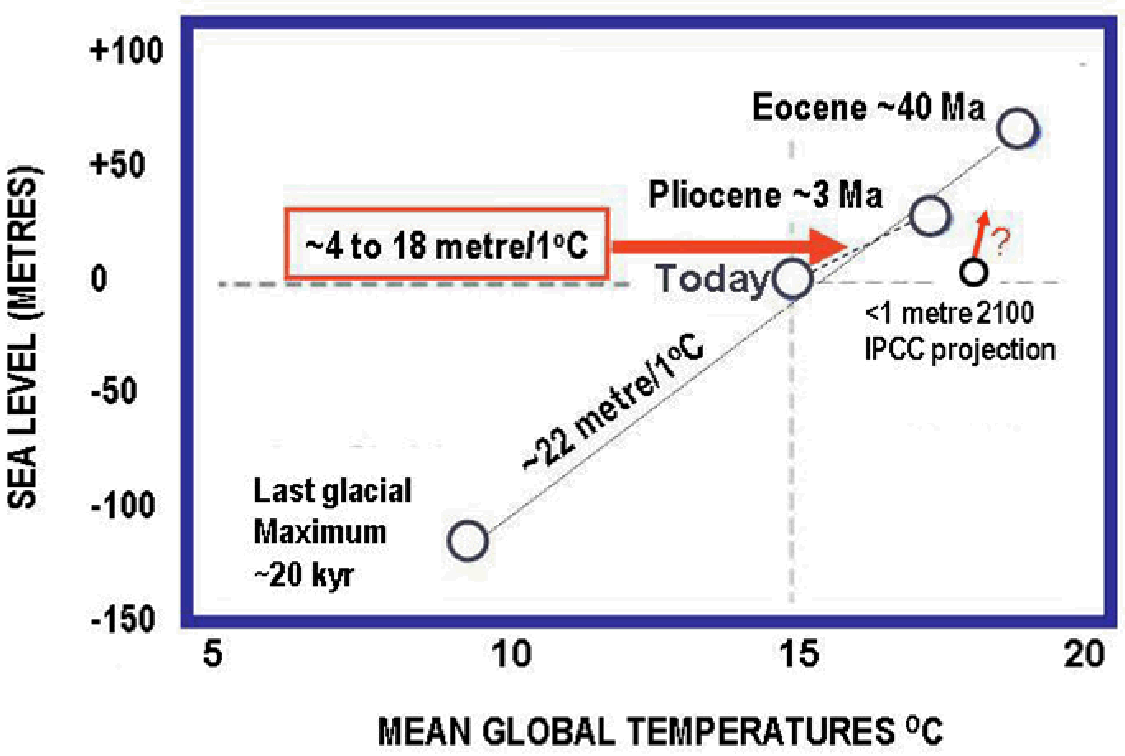

Figure 3. Time averaged sea level–temperature relationships in the Eocene (~40 million years ago), mid-Pliocene (3 million years ago), last glacial maximum (~20 thousand years ago) and at present, including projections to the year 2100. The slope between the mid-Pliocene and the present ranges from a minimum of 4 m/1°C to a maximum of 18 m/1°C, defining the medium to long term sea level rises as a function of temperature rise during the 21st century (from

Rahmstorf, 2007).

The short-term risk of more frequent and intense extreme events is also pronounced for humanity. Among the many effects of anthropogenic global warming are rising sea levels and more intense cyclones in the tropics. About 17 centimetres of sea level rise occurred during the twentieth century[7]. At least triple that amount – and perhaps up to 30 times more, if polar ice sheets continue to rapidly disintegrate[10], is predicted for the twenty-first century[4, 9, 10]. Thus, over the last decade, the rate of sea level rise has more than doubled; coincident with staggering net annual loss of 150 cubic kilometres from the land-based polar ice caps.

Both sea level rise, and larger storm surges associated with more powerful tropical cyclones, will increase the regularity and severity with which saline water encroaches upon low-lying coastal water tables and damages infrastructure. One sentinel of this threat of diluvium lies at the mouth of the Mary River in the Northern Territory of Australia, where levees have already been built in an attempt to hold the burgeoning sea at bay.

In summary, multiple consequences may flow if global warming is allowed to proceed unchecked:

1. Pole-ward shift of climate zones, with increased temperature and fire conditions in tropical and subtropical latitudes, desertification in low-mid latitudes, and extensive mountain and polar ice melting. In Australia contraction of the Antarctic wind vortex results in reduction of rainfall in mid-latitudinal wheat belts;
2. Melting of Greenland ice, causing a slowdown and perhaps eventual collapse of the Gulf Stream. This results in sharp reduction of temperatures to freezing levels in Western Europe and northeast America, and elevated surface water temperatures in tropical oceans, with consequent increase in the frequency and intensity of hurricanes;
3. Melting of mountain glaciers and consequent reduction of water supply for major river valley agricultural systems;
4. Rising sea levels. Total Greenland and west Antarctic melt lead to about 14 metres sea level rise, with resulting flooding over coastal zones and lower river valleys world-wide.
5. Acidification of sea water, with consequent reduction of marine biological activity and CO_2 sequestration.

First order focus of adaptation: extreme events

Mitigation is clearly the single highest priority for the global community. Without effective curbing of anthropogenic emissions of long-lived greenhouse gases, and concomitant revegetation campaigns, any adaptation measures will fail to cope with the scale and magnitude of the coming changes. One of the authors (Brook) has recently commented in *Nature*[21] on progress towards 'Kyoto Phase 2', to be cemented in international agreement in Copenhagen in 2009, and in *Cosmos* on the recent United Nations Bali Summit (see: http://www.cosmosmagazine.com/node/1759).

What of regional and local adaptation to inevitable shorter-term climate change? Two major forms of adaptation are required: (1) incremental adjustment of social, economic and environmental systems to cope with gradual change, and (2) risk averse measures designed to anticipate, and cope with, elevated frequency and intensity of 'extreme events'.

Point (1) involves an extensive review of current cross-sectoral activity, identification of knowledge gaps, and an evaluation of cost-effective strategies for 'evolutionary' management. Such a review will be a primary role of the newly established Australian Centre for Climate Change Adaptation and its ancillary body, the Climate Change Adaptation Research Facility, hosted by the Australian Greenhouse Office (http://www.greenhouse.gov.au/impacts/).

Point (2) is critically important, since it involves managing for:
(a) High consequence events that are relatively rare but will become more frequent, and
(b) Future cascading scenarios that, if eventuated, would create an intolerable burden on society.

The probability of occurrence of some severe events, such as the sudden collapse of the Amazon or the release of stored methane from the ocean floor, is largely unknown[22] (see **Risks to natural and human systems** section above for some other anticipated 'tipping points').

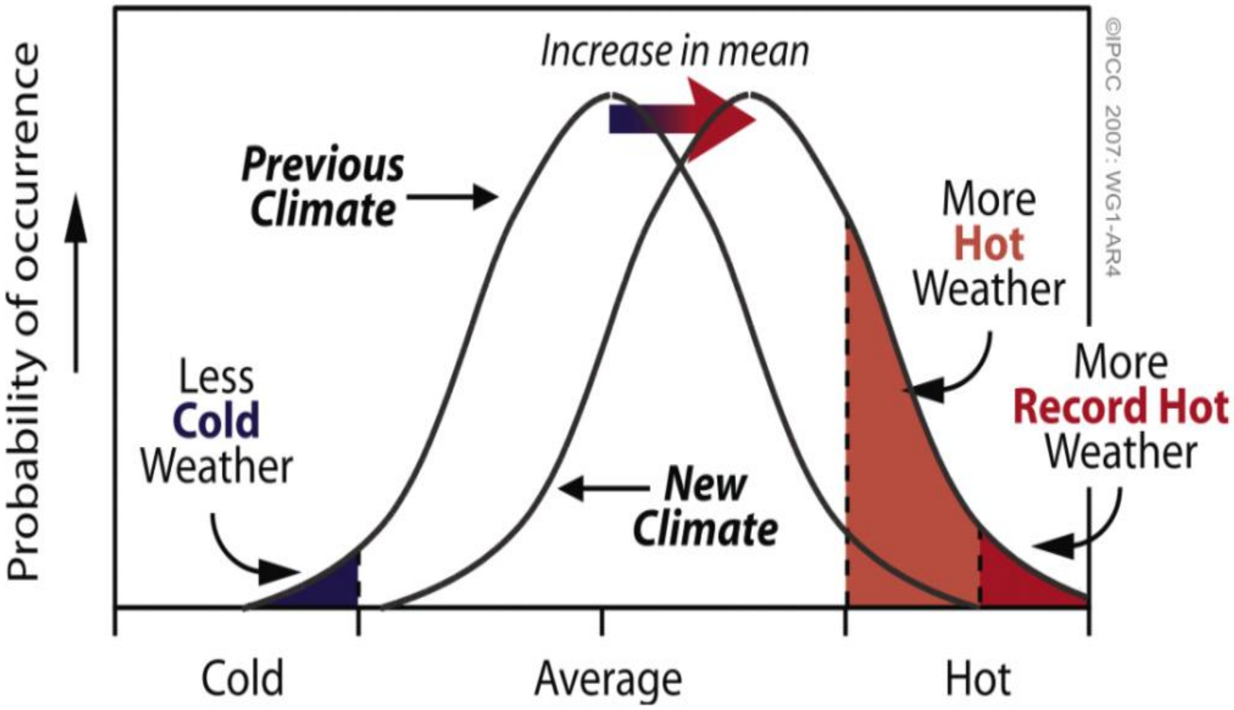

Figure 4. Schematic illustrating the disproportionate effect on extreme and record temperatures when the mean temperature increases, for a normal temperature distribution[4].

The problem of a rising frequency of extreme and record events is illustrated well by the schematic presented below, which appeared in the 2007 IPCC AR4 report (Fig. 4)[4]. This shows that an apparently small increase in the average (mean) climate will result in a substantial rise in the frequency ('More Hot Weather' in the figure) and intensity (More Record Hot Weather) of extreme events – those at the tail of the distribution of day-to-day or year-to-year variation. Two examples for Australia are the projected increase in the frequency and duration of summer 'tinderbox conditions', which promote extreme wildfire, and increasingly regular and severe storm surges, causing coastal flooding, linked to even modest levels of sea level rise.

These types of risks were a particular focus of a recent meeting of climate change scientists in Sydney (Greenhouse 2007, October 2007: abstracts at http://www.greenhouse2007.com). One report, by J Hunter [pg 37 of abstract book], used extensive coastal tidal gauge data to show that for every 10 cm of sea level rise, the risk of a given extreme event tripled. To put this in context, a rise in average sea level of just 30 cm (at the low end of projections, see above) would cause a 'once-in-a-century storm' to occur once every 3 years. Similarly, the frequency of very high and extreme fire danger days is likely to increase by 4 – 25 percent by 2020 and 15 – 70 per cent by 2050 across south-east Australia[23].

Given all of the above, we propose the following point of discussion for the Climate Change Roundtable meeting on 21 February 2008.

- How might regional Governments develop policy in areas such as species loss, land use planning and fire reduction, coastal protection, and water security, which is able to cope adequately with extreme events? *Who should be consulted or commissioned*?
- What disaster management systems must be put in place or how should existing systems be modified to cope with higher future risks? *How should long-standing operational structures be modified in light of these shifting baselines*?
- How might further research be targeted to best address local and regional needs? *What type of funding structure, and at what level, is required to support this research*?

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