December 2009

Friends of the Earth

Briefing

Our Unstable Planet

A brief look at some recent climate change science

Introduction

In December 2009, the UN meeting in Copenhagen will discuss once again the possibilities for a global agreement to curb greenhouse gas emissions and limit global warming and climate change. If the world's leaders manage to reach an effective agreement we may just have chance to stop the worst impacts of climate change, but we are on the very edge of transforming our world into one never before experienced by humans.

This briefing takes a look at some current observations of climate change, some of the recent science and how the future may unfold. This is not a comprehensive review, although it certainly dips into the epic work of thousands of scientists that contribute to the Intergovernmental Panel on Climate Change (the IPCC)[i]. It does try to bring together some important facts and forecasts to build a view of a warming world and some of the severe consequences for humanity.

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Small changes, large consequences

When climate change and global warming are discussed, the reader could be forgiven for thinking that the temperature changes sound small. But over the long-term (and climate is judged over the average of 30 years or so) these subtle differences in average temperature start to affect major components of the Earth's physical geography – such as the large scale features of the polar caps and ocean circulation patterns - with significant consequences for our weather.

On average, the world has warmed by close to one degree (0.7^{o}C) since pre-industrial times and more warming is inevitable[ii]. It is generally considered that two degrees of warming is the ceiling to avoid the worst effects of climate change[iii]. Yet two degrees of warming isn't necessarily "safe" and the world would be warmer (by long-term average) than it has been for maybe a few million years[iv]. Such warming would already cause harm to countless people, many of them in the poorest countries of the world which have done little or nothing to cause the problem. And warming far beyond two degrees is entirely possible unless swift action is taken.

Profound changes in the world's climate system are already taking place, some faster than scientists had predicted, and some are irreversible, at least over a timescale of less than a thousand years. Yet the chances of exceeding two degrees by 2100 are alarmingly high if greenhouse gas emissions are not curbed almost immediately. Four to seven degrees of warming this century are possible[v]. This may even be an underestimate since additional feedback effects – such as melting permafrost releasing large quantities of methane – will be triggered by the higher temperatures[vi]. The consequences for humanity will be grave – we will risk mass extinction of species, the collapse of agricultural systems, the inundation of coastal cities and communities by rising sea-levels, and chaos for economies and governance. This should be unthinkable – but this is where humanity's current business-as-usual approach would take us.

Three key facts

Three key facts highlight how we are already changing the course of history.

1. **Carbon dioxide levels in the atmosphere are higher now than at any time over the last 800,000 years. They may be at their highest level for the last 20 million years.**
   During the last glacial age temperatures were at their minimum 5 or 6 degrees cooler than currently. Large parts of what are now Britain and Germany were covered in ice sheets. Over the last 10,000 years, however, relatively stable climatic conditions allowed agricultural systems to develop and civilisation to be established. CO_2 levels remained fairly steady at around 280 parts per million (ppm). The burning of fossil fuels and forest destruction since the Industrial Revolution has now raised CO_2 to its highest level (385 ppm) for at least 800,000 years, and possibly for 20 million years[vii]. Levels are still rising because, while the Earth is currently capable of absorbing around half our emissions each year, in oceans, soils and plants[viii], the remainder accumulates in the atmosphere.

2. **Emissions are accelerating.**
   In the 1990s global carbon emissions grew by 0.9% per annum[ix]. Despite almost

universal recognition of the dangers of climate change, in the first years of the 21st century (to 2007) carbon dioxide emissions accelerated, rising by 3.5% per annum – a rate of change faster than the "worst-case" scenario set out by international scientists in 2007[x]. World-wide economic recession is likely to cause this to slow, but recovery would soon stimulate emissions again in the absence of reduction policies. Put another way, we have emitted half a trillion tonnes of carbon in 250 years since 1750: the next half trillion tonnes could be released in just 40 years under current trends, taking us to the very brink of the two degree target[xi].

3. **Irreversible climate changes due to carbon dioxide emissions have already taken place[xii].**
   Higher CO_2 levels will be with us for a very long time. Because CO_2 persists for so long in the atmosphere and not all of it can be dissolved in the oceans, even completely halting carbon emissions today would not return CO_2 back to pre-industrial levels by the year 3000, a thousand years from now, and beyond[xiii]. This also means that the average global temperature will not return to pre-industrial levels, and that sea levels will continue to rise due to warming of the oceans alone (aside from melting of ice sheets and glaciers) for over a thousand years. Today's emissions will have a very long-term impact.

Anthropogenic climate change and science

There is a vast amount of research behind our understanding that global warming and climate change are very much linked to human activities. These include direct observations (for example measurements of the concentration of carbon dioxide in the atmosphere – including in ice cores going back thousands of years – and temperature data), the physics of greenhouse gases and computer models. Alternative theories have been looked at but systematically rejected.

In the past, the climate has changed without human influence – for example the planet has cycled between glacial and inter-glacial periods and has even been ice-free in the geological past. The sun's energy varies and affects climate[xiv]. These natural cycles are still operating; nevertheless there is overwhelming evidence that additional changes are being caused by the increased levels of greenhouse gases in the atmosphere.

Computer models are used to test our understanding of the forces that influence climate. We can measure how good these models are by running them from a point in the past, and seeing how well they match up to actual records, including from ice-cores and paleontological evidence. Models can now simulate past climate quite well – for example clearly showing the cooling effect of volcanic eruptions that block sunlight. If human-caused greenhouse gases are omitted from the models, the calculations of past climate differ noticeably from our direct knowledge of climate. Once the human-caused greenhouse gas emissions are factored in, the models generate predictions that fit much more closely with the observations. This can be seen with global models and also with regional data[xv].

Since 1988, thousands of scientists and experts have contributed to the reviews of climate change carried out by the Intergovernmental Panel on Climate Change (IPCC)[xvi]. The IPCC was set up by the World Meteorological Organization and United Nations Environment Programme and is funded by governments which choose to do so. Authors are not paid for their time and effort, and the final reports are approved by governments as well as experts. The most recent review in 2007 was supported by 500 lead authors and 2000 expert reviewers, and scrutinised by over a hundred governments[xvii]. The 2007 report remains a key document, but further research and observations are constantly being published in peer-reviewed scientific journals[xviii].

Climate change: affecting us now

We can still limit the damage. If we do not act, greenhouse gas levels could rise to over 1500 parts per million (ppm) this century[xix], around a four-fold increase over pre-industrial levels and risking a temperature increase of up to 7 degrees[xx]. Yet with global warming of less than one degree the Earth is already showing alarming signs of change. Data accumulated in many ways in many different places clearly demonstrate this.

The global temperature is rising
Although 2007 and 2008 saw gloomy summers in the UK, on a global scale these years still ranked in the top ten hottest years on record, which have all occurred since 1997[xxi]. The world's average temperature has risen by 0.7°C since pre-industrial times. The UK has warmed by 1°C; the Arctic region even more, with winter warming of 3°C-4°C observed in Alaska and Western Canada[xxii]. As temperature rise lags behind rising greenhouse gas levels, even if atmospheric levels could be held constant at today's level (which is clearly not going to happen), the Earth will inevitably warm further – to more than one degree – by the end of the century. As noted above, much greater temperature rises – even up to 7°C – are possible if greenhouse gas emissions continue unabated.

Arctic summer sea-ice is disappearing rapidly
An area of the Arctic sea-ice around the North Pole melts in summer and re-freezes in winter. The extent of summer melting has increased dramatically in recent years. The extent of ice reached a record low in summer 2007, with only a slight recovery in 2008. Scientists had previously predicted that the summer sea-ice would more or less disappear entirely (for the first time since the ice cap was formed about 50 million years ago) towards the end of the century[xxiii]. Now there are concerns that it could disappear much earlier, around 2030-2040, perhaps even before that[xxiv].

Melt of the Greenland ice sheet has increased recently
Melting of Arctic summer sea-ice does not contribute to sea level rise because it is floating and reduces in volume as it melts. But the Greenland ice sheet (one-tenth of the world's freshwater) is on land and summer melting has been increasing, adding to sea level rise. Exceptionally high rates of melting were seen in 2007[xxv]. A key question surrounded by much uncertainty is the rate of melting this century and predictions of sea level rise. It had been assumed that full melting would take around 1,000 years – eventually adding seven metres to sea levels[xxvi] – but this time scale is now being questioned[xxvii]. Loss of the ice sheet might take far less time.

Mountain glaciers may almost entirely vanish this century
Mountain glaciers are also receding faster than predicted and many may vanish this century. The United Nations Environment Programme (UNEP) has concluded that continued warming "*may lead to the deglaciation of large parts of many mountain ranges by the end of the 21st century*" [xxviii]. In the last three decades the rate of water loss from glaciers has quadrupled.

Antarctica is warming
Whilst warming had been clearly measured in all other continents, only recently has it been

shown that, overall, the Antarctic region is also warming and contributing to sea level rise[xxix]. Antarctica has vast ice reserves and the warming effects are not uniform across the continent. The West Antarctic ice sheet is more vulnerable to melting and disintegration than the Eastern Antarctic where temperatures are extremely cold.

Collapsing ice shelves speed up the flow of inland ice into the oceans
The West Antarctic peninsula (which juts out towards South America) is home to a number of research stations, including the British Antarctic Survey. This area has seen warming above the global average and a number of ice shelves (thousands of square kilometres in size and thousands of years old) alongside the peninsula have collapsed since 1950 due to surface and base melting in warmer ocean waters[xxx]. When ice shelves disappear, the flow of adjacent inland ice into the oceans speeds up and this will add to sea level rise. Doubling of rates is common, and even eight-fold accelerations have been measured[xxxi]. This effect has also been noted in Greenland.

Sea level rise could be metres this century
Sea level rose 17 cm in the 20th century and levels will inevitably rise further (for many centuries as noted earlier) simply due to the increasing volume of warming water[xxxii]. But disintegrating glaciers and ice sheets will add further to sea level rise. At what rate is not exactly known, but taking into account the loss of glaciers and the fracturing and melting processes in Greenland and West Antarctica, it is conceivable that levels will rise by 0.8 - 2 metres by 2100 if these processes accelerate[xxxiii]. Another recent estimate puts sea level rise at 1 metre plus or minus a half meter[xxxiv]. Satellite measurements indicate that melting ice now contributes 80% of sea level rise currently, up from 40% in the 1990s[xxxv]. James Hansen, a NASA climatologist, has stated that "*it is almost inconceivable that "business as usual" climate change will not result in a rise in sea level measured in metres within a century*" [xxxvi].

The oceans are becoming more acidic
The higher levels of carbon dioxide dissolving in ocean water have already made sea-water more acidic, by about 30% (0.1 pH unit), and this could increase by up to 200% (0.35 pH units) by the end of the century without action to curb emissions[xxxvii]. Although acidification is not the only threat to coral reefs, this increased acidity is an extremely serious problem in itself because it will harm plankton, shellfish and coral reefs by interfering with their ability to absorb calcium, with knock-on impacts for food chains and fisheries. The biodiversity of coral reefs is awesome - around a million animal and plant species are associated with reefs[xxxviii]. Half a billion people depend on coral reefs for their livelihoods[xxxix].

Points of no return may be reached this century
Large-scale components of the Earth's systems, such as the Arctic ice cap or the Amazon rainforest, may exhibit "tipping points" – a critical temperature which leads to rapid change of the feature. There is debate about whether the tipping point has been reached already in the Arctic, and there are a number of other tipping points that could be reached this century if emissions are not curbed. Some of the consequences of this (such as total loss of the Greenland ice sheet and seven metres of sea level rise) would not be fully felt until far beyond this century; nevertheless, past the tipping point there would be no return, at least in any meaningful time scale for humanity.

<table>
<tr><th>Met Office Scenario</th><th>Change in annual emissions by 2050, compared to 1990</th><th>Global temperature rise by 2100:
10% chance
50% chance</th><th>Some major impacts and tipping points that could be reached this century</th></tr>
<tr><td>Business as usual; no action</td><td>132% increase</td><td>7.1 °C (10% chance)

5.5 °C (50% chance)</td><td rowspan="4">• Major changes in Atlantic circulation, including the Gulf Stream (3 - 5 °C)
• Eventual loss of W Antarctic ice sheet and a further 5m of sea level rise (3 - 5 °C)
• 40-70 % species extinction (3.5 °C)
• Amazon die-back (3 - 4 °C)

• 20 - 30% of species at risk of extinction (1.5 - 2.5 °C)
• Melting of Greenland ice sheet and eventual 7m of sea level rise (1 - 2 °C)
• Loss of Arctic summer sea ice (0.5 - 2 °C)</td></tr>
<tr><td>Late (2030) and slow decline</td><td>76% increase</td><td>5.2 °C

4 °C</td></tr>
<tr><td>Early (2010) but slow decline</td><td>Emissions return to 1990 levels</td><td>3.8 °C

2.9 °C</td></tr>
<tr><td>Early and rapid decline (3% p.a.) starting 2010</td><td>47% decrease</td><td>2.8 °C

2.1 °C</td></tr>
<tr><td>Current situation</td><td>Globally, emissions of GHGs have increased by about 30% between 1990 and 2007[xl]</td><td>0.7 °C warming already observed</td><td>Current observations include:
Arctic summer sea ice declining;
glaciers retreating;
17 cm sea level rise in the 20th Century, with more inevitable;
higher likelihood of heat waves, droughts and water stress;</td></tr>
</table>

			ocean acidification; changes in weather patterns; changes in ecosystems – for example, many coral reefs are at threat of "imminent" decline[xli].

Table 1. Emission scenarios and associated temperature rises from the Met Office (2009)[xlii], along with expert opinion on possible tipping points for major features of the Earth[xliii]. Estimates of species extinctions are from the IPCC[xliv].

Feedback mechanisms

There are a number of recognised positive feedback loops that are enhancing, or will enhance, greenhouse gas releases and global warming. Uncertainties about when or how fast these mechanisms will kick in mean that we may be underestimating the speed with which change will take place. Whilst we can choose to prevent emissions from fossil fuel deposits (by not exploiting them), we have no control over these feedback processes which could release enormous quantities of greenhouse gases or accelerate global warming processes.

Ice-albedo flip
Ice reflects sunlight but meltwater or open sea absorbs incoming radiation and so warms faster. This reflectivity is known as albedo – ice has a far higher albedo than water. So a warming world with less ice starts to warm even more quickly. This is at least partly responsible for the higher levels of warming seen in the Arctic region already, as sea-ice melts each summer.

Thawing permafrost
The Arctic region also has huge areas of continuously and discontinuously frozen ground and peat-bogs known as permafrost. When it thaws – as is being observed in some areas already – the potent greenhouse gas methane is released[xlv].

Methane deposits
Further deposits of methane, known as clathrates, are trapped under pressure and/or at cold temperatures in sediments under parts of the ocean. Some deposits are quite shallow (e.g. under the Arctic ocean) and could be relatively vulnerable to warming. Recent computer modelling warns that a rise of just one degree at the sea floor could release significant quantities of methane[xlvi].

Between them, permafrost and clathrates hold vast quantities of carbon (in the form of methane), maybe more than all the carbon in fossil fuels[xlvii]. There is considerable uncertainty about the rates at which this carbon might be released (up to thousands of years for deep deposits) but methane levels in the atmosphere suddenly surged in 2007, giving rise to speculation that methane feedback mechanisms might have been triggered. Scientists have found lakes bubbling with released methane[xlviii] and also high methane levels in areas off the Siberian coast[xlix].

Warmer and more acidic oceans
The oceans are a major sink for carbon dioxide emissions. But as the oceans warm and become more acid due to dissolving carbon dioxide, they become relatively less able to

dissolve more carbon dioxide. The Southern Ocean is believed to have lost capacity as a sink already due to stronger winds around Antarctica bringing carbon from deep carbon-rich waters to be lost to the atmosphere. The stronger winds are linked to global warming and the ozone hole[l].

Carbon uptake by land-based ecosystems
Carbon dioxide is absorbed by growing plants and trees. It seems likely that this uptake will weaken or even reverse this century and so amplify climate change[li]. Warming could also lead to much greater releases of carbon from soil. Soil acts as a carbon sink currently, but a warming climate could reverse this. This has been described as a potential “climate surprise” by international scientists worried that rapid changes and releases of carbon could occur[lii].

As the future unfolds

> **“Climate change threatens the basic elements of life for people around the world –**
> **access to water, food production, health, and use of land and the environment.”**
> **Sir Nicholas Stern**

The impacts of climate change are and will be many and varied. The effects are already beginning to be felt now. In 2007, the UN Office for the Co-ordination of Humanitarian Affairs issued an “unprecedented” 15 funding appeals after sudden natural disasters – 14 were climate related[liii].

The effects in the future will depend very much on how much our planet warms and indeed how societies prepare to adapt to change. A comprehensive look at this is beyond the scope of this paper, but we touch upon major impacts.

Sea level rise
Pacific island countries such as Vanuatu, Tuvalu, Kiribati and the Marshall Islands, and the Maldives in the Indian Ocean, are already suffering the consequences of a mere 17 cm of sea level rise. Flooding, salt intrusion into freshwater sources and agricultural impacts make the islands less and less habitable. Migration, even evacuation, looms for the 400,000 people of these island nations – where to, no-one can be certain since that will depend on the generosity of other countries.

Sea level rise in the order of one or two metres – a quite possible outcome this century alone – would have far wider impacts. Over 200 million people and $1 trillion of assets are located in coastal plains around the world[liv]. Twenty-two major cities are located on the coast, including London, New York, Tokyo, Shanghai and Mumbai. Flood defences will become increasingly costly and at risk of being overwhelmed.

Migration
There are currently over 11 million refugees globally[lv]; rising sea levels alone would see this figure dwarfed. The mega-delta regions of Asia and Africa will see huge numbers of people affected. In Bangladesh, already densely populated, 17 million people would be displaced from their homes by 1.5m of flooding and one-sixth of the land area would be lost[lvi]. Combined with other factors such as crop failure and loss of freshwater supplies, by 2050 in the region of 200 million environmental migrants, perhaps even more, could be created[lvii]. The UN predicts millions of “environmental” migrants by 2020 alone, almost certainly

increasing the pressure on Europe and more stable areas, and possibly leading to tension and conflict in transit and destination areas[lviii].

Food supplies

Rising temperatures will see increasing disruption to agriculture. There may be some (temporary) rises in yields in northern latitudes, but it has been estimated that every one degree rise directly decreases the yields of major grain crops in the tropics and sub-tropics by between 2.5 and 16%, with additional losses due to both drier soils and land loss due to erosion or flooding[lix]. In France, the heat wave of 2003 (which could become the norm by the end of the century) reduced fodder yields by around 60%, maize yields by nearly 30% and wheat yields by 21%[lx]. Across the EU, it is estimated that agricultural losses amounted to 13 billion euros[lxi]. Prices were relatively unaffected as food from other regions of the world was available. But with temperatures rising more generally around the world, such availability cannot be assumed and prices are almost bound to rise. In 1972, a hot summer in Russia and Ukraine contributed to a tripling in the price of wheat[lix].

The acidity of the oceans will seriously affect biodiversity and food chains, the fishing industry and the primary food source for many of the world's population. Warming seas are also affecting coral reefs, and some are already in serious decline[lxii]*.* Over 150 marine scientists have recently expressed their concern in the Monaco Declaration, addressed to the world's political leaders[lxiii].

Water stress

Drought and water stress will increase due to changing weather patterns and disappearing glaciers. Loss of glaciers alone will affect freshwater supplies for a billion people, including in India, Pakistan, China and South America. Many other regions will suffer drought and water supply shortages and more variable rainfall patterns. Major drought could be created in the Mediterranean region, across Africa, eastern South America , western Australia, southeast Asia and the southwest of North America by seemingly modest reductions (10% and over) in rainfall associated with 2 degrees of warming[lxiv]. Some areas (the moist tropics and higher latitudes generally) will see an increase in rainfall[lxv].

There is already evidence of water stress in the Middle East: roughly two-thirds of the Arab world relies on water from other countries[lxvi]. Future decreases in water availability in the region will reduce crop yields, increase tensions, and even have knock-on impacts on Europe's energy security.

Drought will also increase vulnerability to wildfires. For example, Australia has suffered some catastrophic bushfires in 2009, killing over 200 people and scorching vast areas after a record-breaking drought and a heat wave[lxvii].

Health

Good health is dependent on a number of factors that are themselves intimately linked to the environment. Water stress and droughts, failed crops and malnutrition, the direct effects of increased heat, the geographical range of disease-carrying pests such as mosquitoes, floods spreading water-borne diseases, and extreme weather events will all affect levels of ill health and mortality. The poorest communities will suffer most. Malaria and diarrhoea, both described as "climate-sensitive," kill millions of people every year, many in Africa. The World Health Organisation looked at a limited number of possible health impacts and estimated that 150,000 deaths in 2000 were related to the effects of climate change that had already happened[lxviii]; more recently the Global Humanitarian Forum has estimated that around 300,000 deaths per year may already be due to climate change, mainly because of increased malaria, diarrhoea and malnutrition[lxix]. By 2030, this figure could rise to half a million each year.

Biodiversity
Wildlife will be increasingly vulnerable. Many species are already moving towards the poles or higher up mountains as their habitats warm and change, and climate change is adding to the lists of endangered species. It is estimated that a rise of 2 - 3^{o}C risks 20 - 30% of all species becoming extinct; a rise of 4^{o}C may lead to extinction for 40 - 70% of species[lxx]. One in 8 birds is now listed as in danger of extinction, and although there are a number of reasons for this, including habitat loss, climate change is acknowledged as having serious long term consequences[lxxi].

Storms
Some aspects of the science of hurricane and typhoon prediction are rather uncertain. However the IPCC report (2007) concluded that it is likely (but not certain) that tropical cyclones will become more intense with higher wind speeds and heavier rainfall, due to warming sea temperatures[lxxii]. They may also become less frequent according to some models[lxxiii]. Hurricanes like Katrina (New Orleans 2005) and Mitch (Honduras and Nicaragua 1998) show that hurricane damage can be immense, and "normal" hurricanes combined with rising sea levels will make coastal communities much more vulnerable in future[lxxiv]. More generally, storms and floods are predicted to increase.

Where should we aim?

Much of the discussion and political intent with regard to global warming focuses on limiting the average global temperature rise to two degrees. This is usually equated with greenhouse gas concentrations of 450 ppm[lxxv]. But this gives only a roughly 50/50 chance of staying within a two degree rise – or a 50/50 chance of exceeding two degrees, not very good odds given what is at stake[lxxvi].

Some scientists now think that stabilising no higher than 350 ppm should be the goal[lxxvii]. Some 80 countries, comprising the Association of Small Island States and a number of less developed countries have also called for this target, with the intent of limiting warming to a 1.5 degree rise maximum[lxxviii].

The urgency required

"There is not a moment to lose."
Dr Rajendra Pachauri, Chair, Intergovernmental Panel on Climate Change

Numerous scientific papers have looked at the data and projected the necessary pathways to bring us back from the brink of climate crisis. It is quite clear that any delay in reducing emissions (and remember they have been increasing at accelerated rates to 2007) has significant consequences. The major greenhouse gas, carbon dioxide, is so long-lived that every year's emissions add to the burden in the atmosphere. We have already pushed atmospheric levels of carbon dioxide to concentrations unprecedented in human history, and now there is little room for manoeuvre.

According to the Met Office Hadley Centre, 10 years delay in reducing emissions will incur an extra half a degree of warming; 20 years delay commits the world to a further whole degree of warming[lxxix]. Work for the UK's Climate Change Committee comes to broadly similar conclusions[lxxx].

Scientists at the Tyndall Centre for Climate Research have calculated that emissions need to peak by 2015 at the latest, otherwise the chance of staying within two degrees of warming becomes an almost impossible technical and social challenge[lxxxi].

So it is clear that steep declines in emissions are needed just about immediately, and even then, as has been described above, the planet will still be a changed place. With extremely serious impacts in view already – such as heat waves, droughts and forest fires, the melting of glaciers and decreasing freshwater availability, increasingly intense storms, acid oceans, the loss of ice caps and sea-level rise – it is clear that we face some catastrophic changes to our planet. The urgency of the situation cannot be overstated; it is time to take responsibility and act.

[i] The IPCC papers and reports can be accessed at www.ipcc.ch.

[ii] IPCC (2007). Climate Change 2007: Synthesis Report. At: http://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr_spm.pdf

[iii] The UK and the EU explicitly support a target of limiting warming to two degrees Celsius even though overall policies are inadequate for the EU's "fair share" of this task.

[iv] IPCC (2007). Working Group 1: The Physical Science Basis of Climate Change. Chapter 6, page 440. During the mid-Pliocene, around 3 million years ago, temperatures are estimated to have been 2 – 3^0C higher than pre-industrial temperatures. At: http://www.ipcc.ch/pdf/assessment-report/ar4/wg1/ar4-wg1-chapter6.pdf

[v] Prinn, R. et al (2009). *Journal of Climate*. In press. Also MIT News, 19 May 2009 at: http://web.mit.edu/newsoffice/2009/roulette-0519.html; Also see: Pope, V. (2008). The scientific evidence for early action on climate change. At: http://www.metoffice.gov.uk/climatechange/policymakers/action/evidence.html

[vi] Methane (CH_4) is a greenhouse gas, more potent than carbon dioxide molecule for molecule, although not so long-lived in the atmosphere.

[vii] Jouzel, J. et al (2007). Orbital and Millennial Antarctic Climate Variability over the Past 800,000 Years. *Science*, 10 August 2007, 793-796; 20 million years: Canadell, P. et al (2009): Global carbon sources and sinks: 2007 update. *Earth and Environmental Science*, **6,** 082001.

[viii] Pope, V. (2008). The scientific evidence for early action on climate change. At: http://www.metoffice.gov.uk/climatechange/policymakers/action/evidence.html

[ix] Canadell J.G. et al (2009). Global carbon sources and sinks: 2007 update. *Earth and Environmental Science,* **6,** 082001.

[x] Raupach M.R. et al (2007). Global and regional drivers of accelerating CO_2 emissions. *Proceedings of the National Academy of Science,* 14, 10288-10293

[xi] Allen, M. Et al (2009). The Exit Strategy. *Nature Reports Climate Change*. Published online: 30 April 2009. At: http://www.nature.com/climate/2009/0905/full/climate.2009.38.html

[xii] This is a quote from a recent scientific paper by Susan Solomon (chief author), co-chair of the IPCC Working Group on the physical science of climate change. Solomon, S. et al (2009). Irreversible climate change due to carbon dioxide emissions. *Proceedings of the National Academy of Science*, 106, 1704-1709.

[xiii] CO_2 levels and temperatures would fall from their peak somewhat, but not back to pre-industrial levels within a thousand years and more (assuming no development of carbon removal technologies). Sea-levels will continue to rise during all this time due to thermal expansion because of the lag in warming of the ocean water. Solomon, S. et al (2009). Irreversible climate change due to carbon dioxide emissions. *Proceedings of the National Academy of Science*, 106, 1704-1709.; Eby et al (2009). Lifetime of anthropogenic climate change: time-scales of CO_2 and temperature perturbations. At: http://www.iop.org/EJ/article/1755-1315/6/4/042015/ees9_6_042015.pdf

[xiv] IPCC (2007). Working Group 1: The Physical Science Basis of Climate Change. FAQs. At: http://ipcc-wg1.ucar.edu/wg1/FAQ/wg1_faq-6.1.html

[xv] IPCC (2007). Climate Change 2007: Synthesis Report. Figure 2.5. At: http://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr.pdf

[xvi] IPCC (2004). 16 Years of Scientific Assessment in Support of the Climate Convention. At: http://www.ipcc.ch/pdf/10th-anniversary/anniversary-brochure.pdf

[xvii] IPCC (2007). Climate Change 2007: Synthesis Report. At: http://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr.pdf

[xviii] Readers may find the Synthesis Report from a 2009 conference a relatively quick way of catching up. Synthesis Report from "Climate Change: Global Risks, Challenges & Decisions, Copenhagen 2009, 10-12 March", University of Copenhagen. At: http://climatecongress.ku.dk/pdf/synthesisreport

[xix] The IPCC's worst case scenario (a fossil-fuel based illustration known as A1F1) leads to GHG levels of 1550 ppm by 2100. IPCC (2007). Climate Change 2007: Synthesis Report. At: http://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr.pdf

[xx] See reference 8. The Met Office analysis gives a 10% chance of reaching 7.1^{0}C of warming, and a 50% chance of 5.5^{0}C this century if emissions continue on a business as usual pathway. The possible range of temperature rise reflects some uncertainty about how exactly the world's climate will respond to such emission levels. If a 10% chance sounds unlikely and not worth planning for, ask yourself if you would cross the road if there was a 1 in 10 chance of being hit by a car.

[xxi] NASA/Goddard Institute for Space Studies (2009). GISS Surface Temperature Analysis. Global Temperature Trends: 2008 Annual Summation. At: http://data.giss.nasa.gov/gistemp/2008/

[xxii] Arctic Climate Impact Assessment (2005). Executive Summary. Cambridge University Press. At: http://amap.no/acia/

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