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CLIMATE CHANGE UPDATE 2009

An overview paper, which updates climate change, providing recent findings of research conducted by climate scientists world-wide. Key data presented on carbon dioxide emissions, global surface temperatures and sea level rise, with a brief guide to the United Nations Climate Change Conference in Copenhagen.

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Note

The authors declare that they are solely responsible for the material that appears in this paper.

Introduction

Over the last twelve months climate scientists from around the world have published new research which confirms that climate change is occurring, and at a rate that is consistent with, or goes beyond, the upper reaches of the climate projections contained within the Intergovernmental Panel on Climate Change (IPCC) fourth assessment released in 2007.[1] Concentrations of CO_2 in the atmosphere are increasing, global temperatures are rising, and sea levels continue to rise.

These changes are occurring at such a rate that the impacts of climate change on human communities are already being felt: Sea level rise is impacting on delta populations, such as those on the Bay of Bengal and the Mekong Delta, and on small island communities throughout the Pacific; drought conditions are occurring in many locations, including the western United States, China, southern Europe, and eastern Africa; the pattern of India's monsoon is probably changing; extreme weather events of historic magnitude have occurred in multiple locations; mountain glaciers, such as those in Tibet, which are crucial sources of freshwater, are in rapid retreat; and our oceans are acidifying.[2] These are just a handful of the impacts and changes that are already in motion, and which are affecting human populations around the globe.

This paper is designed to update the research paper released last year by the DPS Library Research Service titled, *Accelerating Climate Change*.[3] In that paper we provided an overview of the key findings of the IPCC fourth assessment, and details of the principal climate science research that had been published in its aftermath. This paper contains new data on three specific indicators in relation to climate change; CO_2 emissions, global average surface temperature, and sea level rise. The paper draws on the latest research available in each of these areas, including observational datasets, research published in scientific journals, and significant scientific reports. The principal findings and key messages are contained within the 'Overview' section which follows this introduction.

At the time of writing, climate scientists, policy makers and world leaders are meeting in Copenhagen under the auspices of the United Nations Framework Convention on Climate Change (UNFCCC). The Copenhagen Conference is designed to negotiate a new global agreement on climate change to replace the Kyoto Protocol, which expires in 2012. We provide a brief overview of the aims and outcome of the conference in the last section of this paper.

While this paper concentrates on just the three areas of CO_2 emissions, global average surface temperature, and sea level rise, it would be remiss not to mention, however briefly, the broad and varied research being undertaken in the arena of climate science: Mitigation and

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[1] Intergovernmental Panel on Climate Change (2007) *Climate Change 2007 – Synthesis Report, A Report of the Intergovernmental Panel on Climate Change*, IPCC.

[2] See C. McMullen and J. Jabbour (2009) *Climate Change Science Compendium 2009*, United Nations Environment Programme (UNEP), Nairobi, EarthPrint; J. Smith et al. (2009) 'Assessing dangerous climate change through an update of the Intergovernmental Panel on Climate Change (IPCC) "reasons for concern"', *PNAS*, pp. 4133 – 4137; G. Meehl et al. (2008) 'Effects of Black Carbon Aerosols on the Indian Monsoon', *Journal of Climate*, vol. 21, pp. 2869-2882; I. Allison et al. (2009) *The Copenhagen Diagnosis: Updating the World on the Latest Climate Science*, UNSW Climate Change Research Centre, Sydney; W. Steffen (2009) *Climate Change 2009: Faster Change and More Serious Risks*, Department of Climate Change, Canberra.

[3] G. Gardiner (2008) 'Accelerating Climate Change', *Research Paper*, No. 2, Melbourne, Parliamentary Library.

adaptation to climate change are growing areas of research, inquiry and discussion; the various planetary boundaries within which human civilisation can persist are being investigated; the nature and operation of regional weather systems are being examined and better understood; and, improving the capacity of climate modelling, including closing the 'gap' on climate prediction and projection, is being undertaken.[4] The work of climate scientists is also increasingly influencing developments in the social sciences, as society faces climate change challenges in energy, housing and infrastructure, health, food security and agriculture. The issue of global equity, human rights and the disproportionate impacts of climate change on poorer communities, nations and continents, is also gaining significant attention.

One of the key notions to emerge in the science this year has been the understanding that, far from being an event that can be transformed in one or two generations, climate change is a process of centuries duration. The implications of this understanding for the development of policy are immense.

[4] See K. Richardson et al. (2009) *Synthesis Report*, from 'Climate Change: Global Risks, Challenges & Decisions – 10-12 March 2009, Copenhagen', University of Copenhagen; J. Rockstrom et al. (2009) 'Planetary Boundaries: Exploring the safe operating space for humanity', *Ecology and Society*, vol. 14, no. 2, pp. 1-36, viewed 19 November 2009, <http://www.ecologyandsociety.org/vol14/iss2/art32/>; Steffen (2009) op. cit.; Allison et al. (2009) 'The Copenhagen Diagnosis', op. cit.; McMullen & Jabbour (2009) op. cit.

Overview

Global fossil fuel emissions

- ***Key message: Global CO_2 emissions continued to rise in 2008, and the concentration of CO_2 in the atmosphere continues to rise***

  - In 2008 global CO_2 emissions from fossil fuels and cement totalled 8,671 million metric tons - the highest release of CO_2 into the atmosphere on record
  - In 2008 the concentration of CO_2 in the atmosphere rose to 384.8 parts per million (ppm) – by September 2009 it had reached 386.71ppm
  - Australia produced 96.2 million metric tons of carbon dioxide from fossil fuels and cement in 2008, and ranked 18th overall for total CO_2 emissions
  - On a per capita basis Australia ranked second for CO_2 emissions in 2006

Global average surface temperature

- ***Key message: Global average surface temperatures continue to rise – on the current trend the first decade of the 21st century is set to become the hottest on record***

  - 2008 was the tenth warmest year on record - thirteen of the warmest years on record have now all occurred in the last fourteen years
  - The first decade of the 21st century is set to become the hottest decade on record on the current trend
  - Australia's annual mean temperature for 2008 was 0.41°C above the standard average
  - In Australia as a whole August 2009 experienced the highest mean temperatures ever recorded for that month
  - The winter in 2009 was the warmest on record for Victoria, NSW and South Australia

Sea level rise

- ***Key message: Sea levels continue to rise, with 1/2 to one metre of rise projected by 2100***

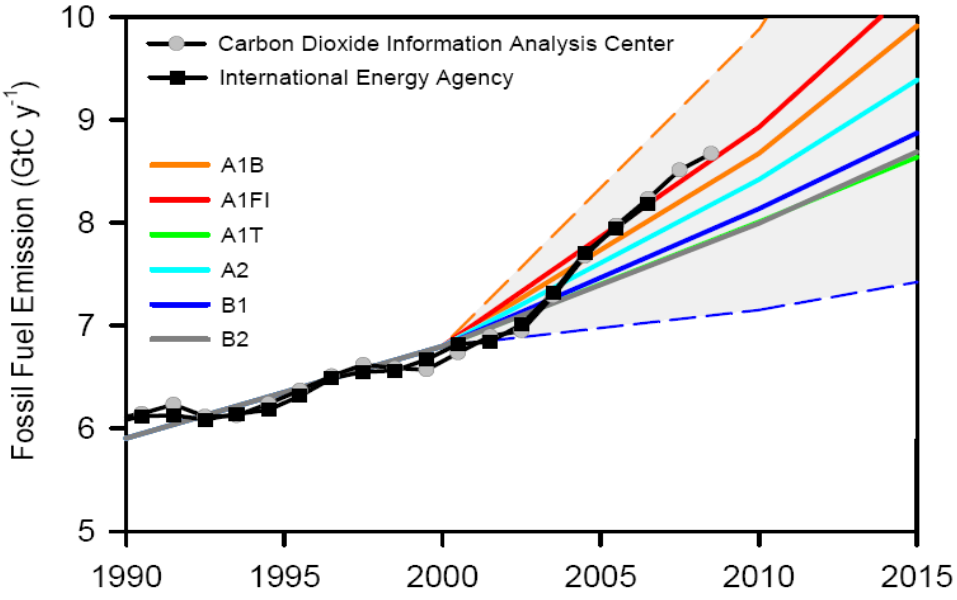
  - Sea level is rising at an average rate of around 3.32mm per year
  - Sea level rise by 2100 is projected in the range of 0.5 and 1.0 metre
  - From 2003 to 2008, melting from Greenland and Antarctica ice sheets contributed around 1mm per year of sea level rise, a significant rise from the mid-1990s
  - Arctic sea ice is now declining at an average rate of 11.2 per cent per decade - some models predict that the Arctic summers may be ice free within 20 years

1. Carbon Dioxide Emissions

Global fossil fuel emissions

According to the latest data released by the Carbon Dioxide Information Analysis Center (CDIAC), in 2008 global CO_2 emissions from fossil fuels and cement totalled 8,671 million metric tons.[5] This is the highest release of CO_2 into the atmosphere on record and represents a 2.0 per cent increase from 2007, a 29 per cent increase from 2000 and a 41 per cent increase from 1990.[6] Figure 1 below shows global carbon dioxide emissions growth from 1990 to 2015, and compares actual emissions with IPCC emissions scenarios.

Figure 1: Global fossil fuel emissions and IPCC scenarios (1990 to 2015)



Source: Global Carbon Project (2009)[7]

As Figure 1 illustrates, actual emissions to 2008 (represented by the grey dots linked by black lines), are currently tracking at the top end of the IPCC emissions scenarios, including the most fossil fuel intensive emissions scenario, A1Fl (represented by the red line).

The rise of 2.0 per cent in CO_2 emissions in 2008 is significant, given that the average yearly rate of growth for CO_2 emissions in the 2000s has been over 3 per cent.[8] This reduction in the growth rate is almost certainly related to the impact on the global economy of the global financial crisis in the second half of 2008.

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[5] Carbon Dioxide Information Analysis Center (CDIAC) (2009) 'Fossil-Fuel CO_2 Emissions: Preliminary 2007-08 Global & National Estimates by Extrapolation', U.S. Department of Energy, Oak Ridge, Tenn., viewed 18 November 2009, <http://cdiac.ornl.gov/trends/emis/meth_reg.html>.

[6] ibid., and C. Le Quere et al. (2009) 'Trends in the sources and sinks of carbon dioxide', *Nature Geoscience*, Advanced Online Publication, DOI: 10.1038/NGEO689, viewed 18 November 2009, <http://www.nature.com/ngeo/journal/vaop/ncurrent/abs/ngeo689.html>, p. 1.

[7] Global Carbon Project (2009) *Carbon Budget 2008 - Presentation*, viewed 18 November 2009, <http://www.globalcarbonproject.org/carbonbudget/08/presentation.htm>.

[8] See J. Canadell et al. (2007) 'Contributions to accelerating atmospheric CO_2 growth from economic activity, carbon intensity, and efficiency of natural sinks', *PNAS*, Early Edition, viewed 16 September 2008, <www.pnas.org/cgi/doi/10.1073/pnas.0702737104>, p. 18866.

The International Energy Agency (IEA) has stated that the GFC will temporarily ease the rate of emissions growth from energy use in 2009, but projects that growth in energy related CO_2 emissions will resume from 2010.[9]

Land use change

Land use change, such as deforestation, is the second largest source of CO_2 emissions after fossil fuels and cement. According to Le Quere et al., from 1990 to 2005 there was an estimated 1,500 million metric tons of CO_2 emitted as result of land use change each year.[10] By 2008, this figure had dropped to approximately 1,200 million metric tons, which has been attributed to wet La Nina conditions resulting in reduced fire use and deforestation in Southeast Asia, and a decline in the deforestation rate in the Amazon.[11]

Land use change contributed 12 per cent of total emissions in 2008, a significant decline from 20 per cent in 1990.[12] In total, fossil fuel and cement emissions combined with land use change emissions are estimated to have totalled 9,900 million metric tons of CO_2 released into the atmosphere in 2008.[13]

Concentration of atmospheric CO_2

According to the U.S. National Oceanic and Atmospheric Administration (NOAA), the concentration of atmospheric CO_2 reached 384.8ppm in 2008.[14] This is almost a 38 per cent increase from levels at the start of the industrial revolution; in 1750 the concentration of CO_2 in the atmosphere was approximately 280ppm.[15] In 2008 the rate of growth in atmospheric CO_2 was 1.8ppm per year, slightly lower than the rate of growth for the period 2000 to 2008,[16] but still higher than the mean rate for the past 20 years.[17]

According to the most recent observations up to September 2009, at the Mauna Loa Observatory, the current global CO_2 concentration is 386.71ppm.[18] As the Global Carbon Project notes, this concentration of atmospheric CO_2 is the highest in at least the last 2 million years.[19]

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[9] International Energy Agency (2009) World Energy Outlook, Executive Summary, viewed 18 November 2009, <http://www.worldenergyoutlook.org/docs/weo2009/WEO2009_es_english.pdf>, p. 4.
[10] Le Quere et al. (2009) op. cit., p. 2.
[11] ibid., p. 2.
[12] Global Carbon Project (2009a) 'Carbon Budget Highlights', *Carbon Budget 2008*, viewed 18 November 2009, <http://www.globalcarbonproject.org/carbonbudget/08/hl-full.htm>.
[13] Le Quere et al. (2009) op. cit., p. 2.
[14] P. Tans (2009) 'Globally averaged marine surface annual mean data', Trends in Atmospheric Carbon Dioxide – Mauna Loa, National Oceanic and Atmospheric Administration, viewed 18 November 2009, <ftp://ftp.cmdl.noaa.gov/ccg/co2/trends/co2_annmean_gl.txt>.
[15] Global Carbon Project (2009a) 'Carbon Budget Highlights', op. cit.
[16] P. Tans (2009a) 'Globally averaged marine surface annual mean growth rate', Trends in Atmospheric Carbon Dioxide – Mauna Loa, National Oceanic and Atmospheric Administration, viewed 18 November 2009, <ftp://ftp.cmdl.noaa.gov/ccg/co2/trends/co2_gr_gl.txt>.
[17] Global Carbon Project (2009a) 'Carbon Budget Highlights', op. cit.
[18] See P. Tans (2009b) 'Globally averaged marine surface monthly mean data', Trends in Atmospheric Carbon Dioxide – Mauna Loa, National Oceanic and Atmospheric Administration, viewed 18 November 2009, <ftp://ftp.cmdl.noaa.gov/ccg/co2/trends/co2_mm_gl.txt> .
[19] Global Carbon Project (2009a) 'Carbon Budget Highlights', op. cit.

Australia

Using the most recent data from the CDIAC, in 2008 Australia was ranked 18th in the world in terms of total CO_2 emissions from fossil fuels and cement.[20] Table 1 below shows the top 20 countries in relation to total CO_2 emissions from fossil fuels and cement production.

Table 1: Total CO_2 emissions (million metric tons) by country for 2008

2008 Ranking	Country	2008 Emissions
1	China	1922.7
2	United States	1547.5
3	India	479.0
4	Russia	435.1
5	Japan	357.5
6	Germany	210.5
7	Canada	153.7
8	UK	148.8
9	South Korea	142.2
10	Iran	134.0
11	Italy	125.0
12	Mexico	124.4
13	South Africa	120.5
14	Saudi Arabia	119.4
15	Brazil	110.8
16	France	103.8
17	Indonesia	99.6
18	**Australia**	**96.2**
19	Spain	94.5
20	Poland	90.1

Source: Carbon Dioxide Information Analysis Center (2009)

As Table 1 shows, Australia produced 96.2 million metric tons of carbon dioxide from fossil fuels and cement in 2008, just behind Indonesia, and ahead of Spain and Poland. This represents a decline in emissions from 2007, when Australia emitted 101.1 million metric tons of CO_2.[21] Australia's CO_2 emissions in 2008 are equivalent to the entire globe's emissions from fossil fuels and cement production in 1861.[22] Table 1 also illustrates China's position as the world's largest emitter of CO_2.

While Australia is ranked 18th overall for total CO_2 emissions, on a per capita basis Australia ranks near the top of the table. Using the latest CDIAC data on per capita emissions, compiled for 2006, Australia ranked second of the 20 countries listed above, with 4.90 metric tons of CO_2 emitted per person.[23] China ranked 16th with a per capita emission level of 1.27 metric tons of CO_2, while the US ranked first with 5.18.[24]

[20] CDIAC (2009) 'Fossil-Fuel CO_2 Emissions', op. cit.
[21] ibid.
[22] ibid., and CDIAC (2009a) 'Global CO2 Emissions from Fossil-Fuel Burning, Cement Manufacture, and Gas Flaring: 1751-2006', U.S. Department of Energy, Oak Ridge, Tenn., viewed 25 November 2009, <http://cdiac.ornl.gov/ftp/ndp030/global.1751_2006.ems>.
[23] CDIAC (2009b) 'Ranking of the world's countries by 2006 per capita fossil-fuel CO2 emission rates', U.S. Department of Energy, Oak Ridge, Tenn., viewed 25 November 2009,

Natural sinks

Last year we reported that there was emerging evidence to suggest that the airborne fraction of CO_2 emissions remaining in the atmosphere was increasing. Recent research finds that the in the past 50 years, the fraction of CO_2 emissions remaining in the atmosphere has likely increased, from about 40 to 45 per cent.[25] The airborne fraction has been increasing by around 0.3±0.2 per cent per year between 1959 and 2008. This positive trend has been attributed to a decline in the ability of natural sinks, such as the ocean and forests, to absorb CO_2.[26] Observations of natural sinks show no long term trend for the land sink, but a significant downward trend for the oceanic sink over the past 40 years.[27] In 1960 the oceans absorbed around 32 per cent of anthropogenic emissions, but this has since declined to around 26 per cent.[28]

Ocean acidification

One of the observable impacts of increased CO_2 absorption by the ocean is acidification. When CO_2 is absorbed by the ocean it reacts with the seawater to create carbonic acid. Since the industrial revolution approximately one quarter to one third of all CO_2 from fossil fuels has been absorbed by the oceans and as a result the level of acidity in the oceans has significantly increased.[29] Increased levels of acidity reduce the availability of carbonate in the ocean, a substance crucial for tens of thousands of marine species to form shells and skeletons, thus threatening the viability of these species.[30] Several recent studies have observed the impact of ocean acidification on marine species.[31]

A recent study observed similar results on Australia's Great Barrier Reef and found that calcification had declined by 14.2 per cent since 1990. As the authors note, 'such a severe and sudden decline in calcification is unprecedented in at least the past 400 years'.[32] According to Steffen, rising acidity and sea surface temperatures will, on current trends, likely overwhelm even the most resilient reefs this century.[33]

<http://cdiac.ornl.gov/trends/emis/top2006.cap>. Note that some smaller, mainly oil producing economies, with low populations, have higher per capita emission rates than either Australia or the US.

[24] ibid. It is interesting to note that China's national per capita emission level is approximately in line with world per capita emissions, see Global Carbon Project (2009a) 'Carbon Budget Highlights', op. cit.; Le Quere et al. (2009) op. cit., p. 1.

[25] Le Quere et al. (2009) op. cit., p. 1.

[26] ibid., pp. 2-3.

[27] Steffen (2009) op. cit., p. 35.

[28] ibid.

[29] ibid., p. 22.

[30] ibid.

[31] See, for e.g., A. Moy et al. (2009) 'Reduced calcification in modern Southern Ocean planktonic foraminifera', *Nature Geoscience*, vol. 2, April 2009, doi:10.1038/NGEO460. This study compared the shell weights of a planktonic species in the Southern Ocean with those preserved in the underlying Holocene-aged sediments and found that the modern weights were 30 to 35 per cent lower than those from the sediments, establishing a link between higher atmospheric CO_2 and low shell weights.

[32] G. De'ath et al. (2009) 'Declining Coral Calcification on the Great Barrier Reef', *Science*, vol. 323, doi: 10.1126/science.1165283, pp. 116 – 119. This study investigated 328 colonies of Porites corals from 69 reefs.

[33] Steffen (2009) op. cit., p. 24.

Irreversible change and CO_2 emissions

Recent research indicates that the climate change that occurs due to increases in carbon dioxide concentrations in the atmosphere is 'largely irreversible for 1,000 years after emissions stop'.[34] Solomon et al. have demonstrated the longevity of an atmospheric CO_2 perturbation, and concluded that it is not generally appreciated that temperature increases caused by rising CO_2 concentrations are not expected to decrease significantly even when emissions cease.[35] While removal of atmospheric CO_2 will, over time, decrease radiative forcing, this is largely compensated for by slower loss of heat to the oceans. As Steffen states, if CO_2 levels continue to rise, climate change will be effectively irreversible on timescales of relevance to human societies, with permanent changes in regional climate, and sea level rise that could exceed several metres.[36]

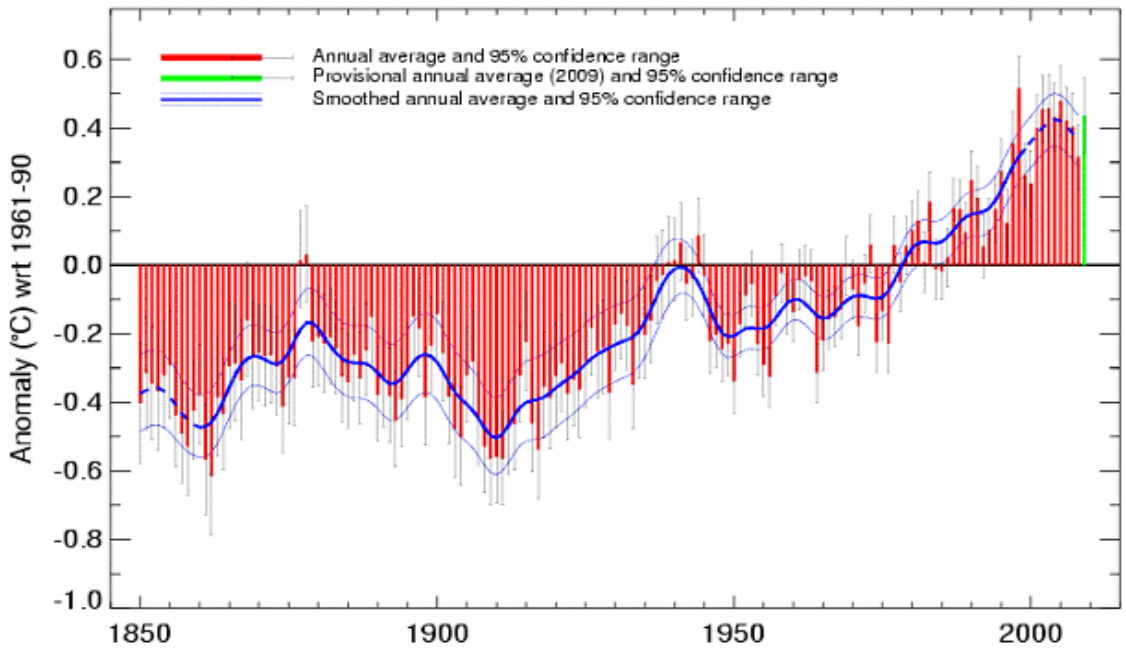
[34] S. Solomon et al. (2009) 'Irreversible climate change due to carbon dioxide emissions', *PNAS*, Vol. 106, no. 6, p. 1704.
[35] ibid.
[36] Steffen (2009) op. cit., p. 34.

2. Global Average Surface Temperature

Global surface temperature

As was pointed out in last year's report, global average surface temperatures provide the most direct evidence that climate change is a contemporary event, not a distant future possibility. In 2007 the IPCC reported that the global average surface temperature had risen by 0.74°C in the last 100 years, with most of this rise occurring in the last half century. Following the IPCC report, Rahmstorf et al. found that global average surface temperature increase was 0.33°C in just 16 years since 1990, in the upper part of the range projected by the IPCC in its fourth assessment.[37] The most recent data indicates that the global warming trend is continuing. According to the latest data from the UK, the year 2008 was the tenth warmest on record, that is, the tenth warmest year in the period since 1850. Thirteen of the warmest years on record have now all occurred in the last fourteen years (1995-2008).[38] Figure 2 below shows the combined global land and marine surface temperature record from 1850 to 2009, compiled jointly by the UK Meteorology Office Hadley Centre and the Climatic Research Unit.[39]

Figure 2: Global surface temperature 1850-2009 by yearly record



Source: UK Met Office Hadley Centre (*HadCRUT3* dataset) © Crown copyright 2009, the Met Office

[37] S. Rahmstorf et al. (2007) 'Recent Climate Observations Compared to Projections', *Science*, vol. 316, p. 709.
[38] See Climatic Research Unit (2009) 'Global Temperature Record', *Information Sheet no. 1*, CRU, University of East Anglia, viewed 18 November 2009, <http://www.cru.uea.ac.uk/cru/info/warming/>; UK Meteorology Office Hadley Centre (2009) *Observations Datasets*, UK Met Office, viewed 18 November 2009, <http://hadobs.metoffice.com/hadcrut3/diagnostics/global/nh+sh/>. The other major dataset on global surface temperature is maintained by the NASA Goddard Institute for Space Studies (GISS). There are some minor variations between the two data sets – for example NASA GISS places 2008 as the ninth warmest on record – but the general trend of a warming climate is consistent throughout, see NASA GISS (2009) *GISS Surface Temperature Analysis*, New York, NASA GISS, viewed 18 November 2009, <http://data.giss.nasa.gov/gistemp/>.
[39] This time series is based on temperatures expressed as anomalies for the period 1961-1990. Red lines indicate temperatures above or below the base period, and the dark blue line represents the smoothed annual average. The thinner blue lines represent the uncertainty range in the smoothed data. It is important to note that the green bar represents provisional data for 2009, which may change when the 2009 data set is complete.

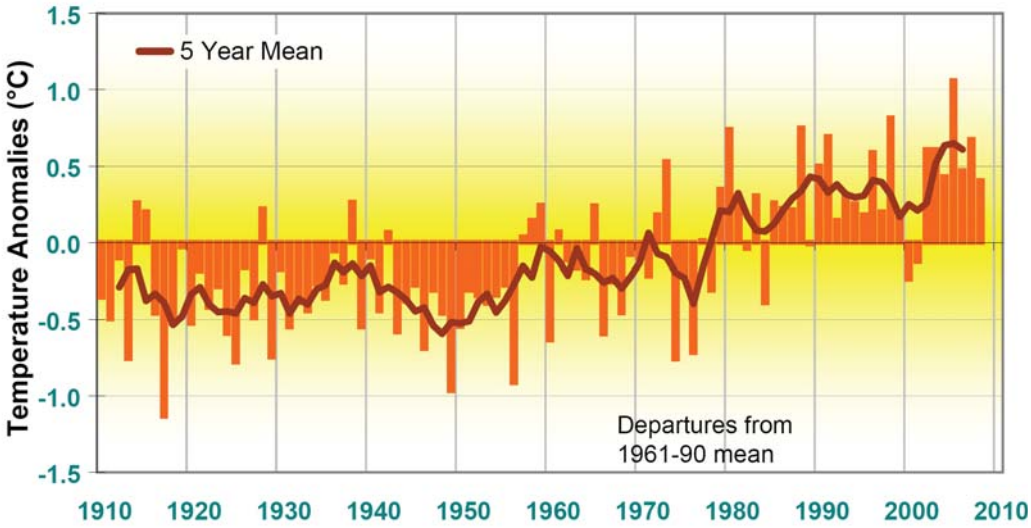
Due to natural climate variability, fluctuations will and have occurred in the temperature record, as can be seen in Figure 2. What is important, as Easterling and Wehner make clear, is the long-term trend, which is irrefutably one of a warming planet.[40] Figure 2 above clearly demonstrates this warming trend over the last century. The data emerging for the first decade of the 21st century indicates that this decade is more than likely set to become the hottest one on record, eclipsing all other previous decades. The period 2001-2008 already shows a rise of 0.19°C above the hottest complete decade on record, 1991-2000.[41]

This trend is supported by the most recent UK data published for the first nine months of 2009. While the data for the year 2009 is incomplete, the monthly temperatures recorded to the end of September indicate that this year could be one of the hottest single years on record. The global average temperatures for June, July and September were all the third hottest for those months on record, while August 2009 was the second warmest August ever recorded.[42] The UK data is supported by data from the NASA Goddard Institute for Space Studies.[43]

Australia and Victoria

According to the Australian Bureau of Meteorology, Australia has experienced a warming of approximately 0.9°C over the last century.[44] Australia's annual mean temperature for 2008 was 0.41°C above the standard average.[45] Figure 3 below shows the annual mean temperature anomalies for Australia for the period 1910 to 2008.

Figure 3: Annual mean temperature anomalies for Australia 1910-2008



Source: Bureau of Meteorology (2009) *Annual Climate Summary 2008*, copyright Commonwealth of Australia reproduced by permission

[40] D. Easterling and M. Wehner (2009) 'Is the Climate warming or cooling?', *Geophysical Research Letters*, Vol. 36, L08706, doi:10.1029/2009GL03810, 2009, pp. 1-3.
[41] Climatic Research Unit (2009) op. cit.; and see NASA GISS (2009) op. cit.
[42] Climatic Research Unit (2009a) 'Temperature', *Data*, CRU, University of East Anglia, viewed 18 November 2009, <http://www.cru.uea.ac.uk/cru/data/temperature/>. For the *HadCRUT3 global* data, see <http://www.cru.uea.ac.uk/cru/data/temperature/hadcrut3gl.txt>.
[43] With slightly higher temperature results, see NASA GISS (2009a) 'Global land-ocean temperature index', viewed 18 November 2009, <http://data.giss.nasa.gov/gistemp/tabledata/GLB.Ts+dSST.txt>.
[44] See Bureau of Meteorology (2009) *Annual Climate Summary 2008*, National Climate Centre, Bureau of Meteorology, Melbourne, viewed 19 November, <http://www.bom.gov.au/climate/annual_sum/2008/index.shtml>.
[45] This time series is also based on temperatures expressed as anomalies for the period 1961-1990.

It is interesting to note how the pattern of warming for Australia across the last 50 years, shown above, broadly replicates that depicted in the global temperature representation in Figure 2.

Partly due to the effect of La Nina, the mean temperature for 2008 was slightly lower than the temperatures recorded in the previous six years. However, all of the last seven years have been above the average. As Figure 3 shows, the past three decades have experienced considerable warming in Australia, in line with the trend globally. Each of the last three decades has been hotter than the last, and the trend is clearly towards a warmer Australia.

2009

While 2008 ranks as the 14th warmest year since records began, 2009 appears set to become one of the hottest years on record, particularly for the south-east of the country. In late January and the first week of February, heatwave conditions across south-east Australia produced record maximum temperatures in multiple locations. In late January Melbourne experienced three successive days of temperatures over 43°C for the first time ever, Adelaide recorded an historic four successive days over 43°C, while Tasmania recorded its highest temperature ever.[46]

On Black Saturday, the 7th of February, temperature records were broken across multiple locations in Victoria, with Melbourne experiencing its hottest day ever recorded at 46.4°C. Other all-time record maximum temperatures recorded on the 7th in Victoria include Hopetoun (48.8°C), Walpeup (48.1°C) and Avalon (47.9°C).[47]

The warming trend was also clearly evident this winter in Australia, with August 2009 experiencing the highest mean temperatures ever recorded. The mean temperatures for August were 2.47°C above the long-term average, breaking the previous record by almost one degree centigrade.[48] The winter in 2009 was the warmest on record for Victoria, New South Wales and South Australia, while for Australia as a whole it was just 0.01°C below the previous record set in 1996.

The late spring heatwave has brought record temperatures to South Australia, New South Wales and Victoria. Adelaide recorded its first ever spring heatwave, with eight consecutive days over 35°C in November.[49] In New South Wales record temperatures for November have been set in multiple locations, with Wilcannia recording 45.2°C on the 16th, while Broken Hill

[46] Bureau of Meteorology (2009a) 'Heatwave sets records across southeast Australia', media release, 4 February, Bureau of Meteorology, viewed 19 November, <http://reg.bom.gov.au/announcements/media_releases/ho/20090204.shtml>; Bureau of Meteorology (2009b) 'Melbourne sets heatwave record as Victoria bakes', media release, 30 January, Bureau of Meteorology, viewed 19 November, <http://reg.bom.gov.au/announcements/media_releases/vic/20090130.shtml>.

[47] Bureau of Meteorology (2009c) 'Victoria February 2009', *Monthly Weather Review*, Bureau of Meteorology, viewed 19 November, <http://www.bom.gov.au/climate/mwr/>.

[48] Bureau of Meteorology (2009d) 'Climate records broken', media release, 1 September, Bureau of Meteorology, viewed 19 November, <http://reg.bom.gov.au/announcements/media_releases/ho/20090901.shtml.>.

[49] Bureau of Meteorology (2009e) 'Record heat across South Australia in first half of the month', media release, 17 November, Bureau of Meteorology, viewed 19 November, <http://reg.bom.gov.au/announcements/media_releases/sa/20091117recordsaheatfirsthalfNov.shtml>.

has recorded nine consecutive days over 35°C.[50] In Victoria, many locations have recorded their highest temperatures ever for this time of year.

However, extreme heat conditions in 2009 have not been exclusive to the south-east of the continent. Darwin has experienced its hottest month ever recorded this year. The average maximum temperature in October was 34.8°C, surpassing the previous highest (34.4°C) set in October 2008.[51] The highest recorded daily temperature in Darwin in October was 38.0°C, the second highest temperature for the city ever recorded.

[50] Bureau of Meteorology (2009f) 'Excessive heat across NSW', media release, 18 November, Bureau of Meteorology, viewed 19 November, <http://reg.bom.gov.au/announcements/media_releases/nsw/20091118.shtml>.
[51] Bureau of Meteorology (2009g) 'Warmest month on record in Darwin', media release, 30 October, Bureau of Meteorology, viewed 19 November, <http://reg.bom.gov.au/announcements/media_releases/nt/20091030.shtml>.

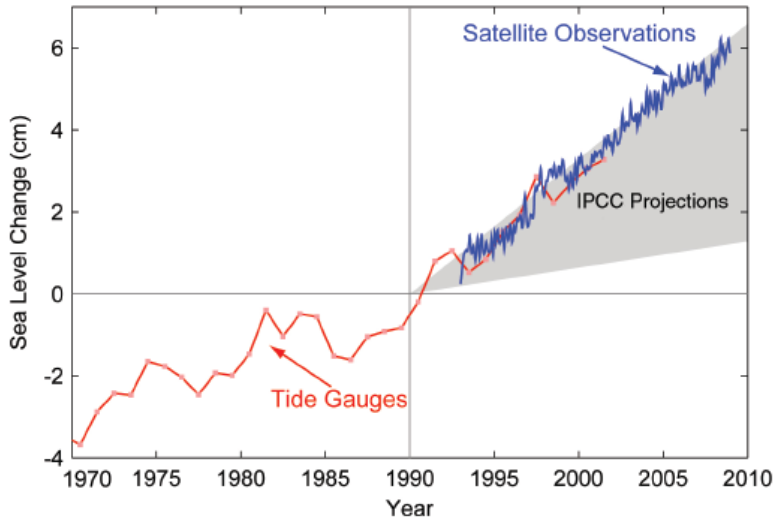
3. Sea Level Rise

Global sea level rise

Sea level rise projections in the IPCC's fourth assessment report were considered to be underestimates, mainly due to the high level of uncertainty surrounding the contribution from Greenland and Antarctica. However, there is now a considerable body of evidence pointing towards a sea level rise of between 0.5 and 1.0 metre by 2100, compared to 1990 values.[52] As Steffen notes, although there is still considerable uncertainty surrounding estimates of further sea level rise, nearly all of these uncertainties operate in one direction, towards higher rather than lower estimates.[53] Thus, sea level rise larger than the 0.5 and 1.0 metre range, perhaps as high as 1.5 metres by the century's end, cannot be ruled out.[54]

In the fourth assessment, sea level rise was estimated at a rate of 1.8 ± 0.5mm per year over the period 1961 to 2003. This rate accelerated to 3.1 ± 0.7mm per year for the period 1993 to 2003.[55] Observations from multiple satellites have shown a continuation of this trend, with sea levels rising at an average rate of around 3.32mm per year over the period 1993 to 2009.[56] As Figure 4 below demonstrates, sea level rise is continuing to track at the upper end of the IPCC projections, and well beyond the average rate for the 20th century of 1.7mm per year.

Figure 4: Observed sea level rise and IPCC projections (1970 to 2009)



Source: Allison et al. (2009) op. cit., p. 39.

Since the IPCC report new methods have emerged to measure the mass ice loss of Greenland and Antarctica, and the subsequent sea level rise contribution. One of the most recent studies

[52] Steffen (2009) op. cit., p. 11.
[53] ibid.
[54] ibid., see also Allison et al. (2009) 'The Copenhagen Diagnosis', op. cit., pp. 39-40.
[55] See Gardiner (2008) op. cit. p. 21.
[56] Archiving, Validation and Interpretation of Satellite Oceanographic data (AVISO) (2009) 'Mean Sea Level Rise', NASA-CNES, viewed 26 November 2009, <http://www.aviso.oceanobs.com/en/news/ocean-indicators/mean-sea-level/>. In recent studies for the period 2003 to 2008, using a different methodology, a sea level rise of around 2.5mm per year was estimated. See A. Cazenave et al. (2008) 'Sea level budget over 2003–2008: A reevaluation from GRACE space gravimetry, satellite altimetry and ARGO', *Global and Planetary Change*, doi: 10.1016/j.gloplacha.2008.10.004; and I. Allison et al. (2009) 'Review: Ice sheet mass balance and sea level', *Antarctic Science*, doi: 10.1017/S0954102009990137.

has shown that from 2003 to 2008, melting from the Greenland and Antarctica ice sheets contributed around 1 ± 0.15mm per year of sea level rise, more than double the rate of 0.4mm per year over 1993 to 2003 estimated in AR4.[57] Furthermore, other studies have shown that the rate of ice mass loss has doubled over the last seven years.[58] NASA scientists have warned that this trend is significant and a matter of concern, but are unsure about the potential implications of this development for the ice sheets and sea level rise.[59]

Greenland and Antarctica

Recent satellite observations have shown an increase in the mass loss of the Greenland ice sheet. Estimates of the mean rate of ice mass loss from 2003 to 2008 range from 136 ± 18 gigatonnes per year (equivalent to a global mean sea level rise of 0.38 ± 0.05mm per year)[60] to 179 ± 25Gt per year (equivalent to a sea level rise of 0.5 ± 0.1mm per year).[61] According to Allison et al. and Broeke et al. this rate is continuing to increase and may be contributing as much as 0.7mm per year to sea level rise in 2009.[62]

Since 1979 the total surface area of the Greenland ice sheet affected by summer melting has increased by 30 per cent; a trend consistent with warming air temperatures.[63] In 2007 a new record was set with around 50 per cent of the ice sheet affected by surface melting in the summer.[64] Recent research has also shown that dynamical processes can lead to a more rapid ice loss than by surface melt alone.[65] Pritchard et al. have observed dynamic thinning of glaciers at all latitudes in Greenland, with fast moving glaciers thinning at a rate of 0.84 metres per year.[66]

NASA scientists have reported significant ice mass loss in Antarctica over the period 2002 to 2009 at a rate of 190 ± 77Gt per year.[67] These findings support an earlier study which found an ice mass loss of 198 ± 22Gt per year for Antarctica over the period 2003 to 2008.[68] This represents a sea level rise contribution of around 0.56 ± 0.06mm per year.[69] Similar to Greenland, the rate of ice loss is accelerating in Antarctica and in a recent study covering the

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[57] Cazenave et al. (2008) op. cit; Allison et al. (2009) 'Review', op. cit., p. 4; Allison et al. (2009) 'The Copenhagen Diagnosis', op. cit., pp. 26-28.
[58] R. A. Kerr (2009) 'Both of the World's Ice Sheets May be Shrinking Faster and Faster', *Science*, vol. 326, p. 217; I. Velicogna (2009) 'Increasing rates of ice mass loss from the Greenland and Antarctic ice sheets revealed by GRACE', *Geophysical Research Letters*, doi: 10.1029/2009GL040222, pp. 1–4.
[59] Kerr (2009) op. cit., p. 217.
[60] A gigatonne is equivalent to a billion metric tons.
[61] See Allison et al. (2009) 'Review', op. cit., p. 6; Cazenave et al. (2008) op. cit. p. 3; B. Wouters (2008) 'GRACE observes small-scale mass loss in Greenland', *Geophysical Research Letters*, vol. 35, doi: 10.1029/2008GL034816, p. 1.
[62] Allison et al. (2009) 'The Copenhagen Diagnosis', op. cit., p. 26; M. van den Broeke et al. (2009) 'Partitioning Recent Greenland Mass Loss', *Science*, vol. 326, p. 984.
[63] Allison et al. (2009) 'The Copenhagen Diagnosis', op. cit., p. 26.
[64] ibid.
[65] See Steffen (2009) op. cit., p. 9; S. B. Das et al. (2008) 'Fracture Propagation to the Base of the Greenland Ice Sheet During Supraglacial Lake Drainage', *Science*, vol. 320, p. 778; I. M. Howatt et al. (2008) 'Rates of southeast Greenland ice volume loss from combined ICESat and ASTER observations', *Geophysical Research Letters*, vol. 35, doi:10.1029/2008GL034496; Allison et al. (2009) 'The Copenhagen Diagnosis', op. cit., p. 27.
[66] H. Pritchard et al. (2009) 'Extensive dynamic thinning on the margins of the Greenland and Antarctic ice sheets', *Nature*, vol. 461, doi: 10.1038/nature08471, p. 971.
[67] J. L. Chen et al. (2009) 'Accelerated Antarctic ice loss from satellite gravity measurements', *Nature Geoscience*, Advanced Online Publication, doi: 10.1038/NGEO694, p. 1.
[68] Cazenave et al. (2008) op. cit., p. 3.
[69] ibid.

period 2006-2009, it is now estimated to be losing 246Gt per year, which is equivalent to around 0.7mm per year of sea level rise.[70]

In the most recent study by the British Antarctic Survey, the data shows that melting from West Antarctica alone could contribute tens of centimetres to sea level rise, resulting in a total sea level rise of around 1.4 metres by the end of the century.[71] West Antarctica has been warming at over 0.1 degree celsius per decade over the last fifty years, with retreat and thinning of some glaciers.[72] In 2008, the Wilkins ice shelf lost more than 400 square kilometres to a sudden collapse, and over the last twenty years seven ice shelves have collapsed along the Antarctic Peninsula.[73]

Mountain ice caps and glaciers

Glaciers and mountain ice caps are a source of freshwater in many regions. Since early 1990, they have increased their contribution to global sea level rise to a current rate of 1.2mm per year.[74] If the climate continues to warm according to current trends, mountain ice caps and glaciers could contribute as much as 55 centimeters of sea level rise over the next 100 years.[75] Examples of melting mountain ice caps and glaciers can be found all over the world. Kilimanjaro has lost over 85 per cent of its summer ice cover since 1912, and at current rates the glaciers will disappear from the summit within decades.[76] Scientists in China have reported that glaciers in Tibet are melting at a rate of 7 per cent annually.[77] Similarly, glaciers in South America have been described as being in rapid retreat.[78]

Arctic sea ice extent

Arctic summer sea ice extent recorded a record low in 2007 of 39.2 per cent below the 1979 to 2000 average. 2008 was the second lowest extent recorded, at 33.6 per cent below the average, while 2009 recorded the third lowest level of summer sea ice extent at 23.9 per cent below the average.[79] The past five years have seen the five lowest levels of Arctic summer sea ice extent in the satellite record. Over the last thirty years Arctic sea ice has declined at an

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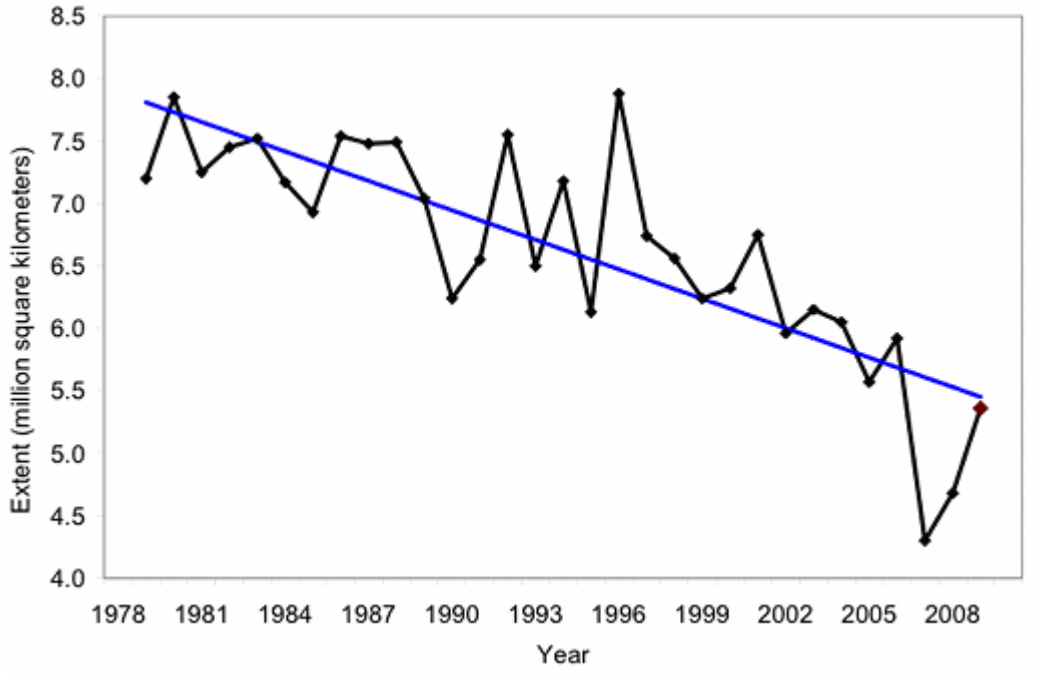
[70] Allison et al. (2009) 'The Copenhagen Diagnosis', op. cit., p. 28.
[71] British Antarctic Survey (2009) 'First Comprehensive review of the state of Antarctica's climate', media release, 1 December 2009, Natural Environment Research Council, viewed 2 December 2009, <http://www.antarctica.ac.uk/press/press_releases/press_release.php?id=1065>.
[72] E. J. Steig et al. (2009) 'Warming of the Antarctic ice-sheet surface since the 1957 International Geophysical Year', *Nature*, vol. 457, doi: 10.1038/nature07669, p. 459; Allison et al. (2009) 'The Copenhagen Diagnosis', op. cit., p. 28; Pritchard et al. (2009) op. cit., p. 971. As they are in the ocean ice shelves cannot contribute to sea level rise, but when their buttressing effect is lost outlet glaciers often show a sharp increase in flow rate, see Allison et al. (2009) 'The Copenhagen Diagnosis', op. cit., p. 29; National Snow and Ice Data Center (2009) 'Ice Shelves', University of Colorado, viewed 27 November 2009, <http://nsidc.org/sotc/iceshelves.html>.
[73] National Snow and Ice Data Centre (2009a) 'Wilkins Ice Shelf News', University of Colorado, viewed 27 November 2009, <http://nsidc.org/news/press/wilkins/>; Allison et al. (2009) 'The Copenhagen Diagnosis', op. cit., p. 30.
[74] Allison et al. (2009) 'The Copenhagen Diagnosis', op. cit., p. 25.
[75] ibid; and see, D. B. Bahr et al. (2009) 'Sea-level rise from glaciers and ice caps: A lower bound', *Geophysical Research Letters*, vol. 36, L03501, doi:10.1029/2008GL036309, p. 1.
[76] L.G. Thompson et al. (2009) 'Glacier loss on Kilimanjaro continues unabated', *PNAS*, doi:10.1073/pnas.0906029106, p. 1.
[77] China Daily (2009) 'Tibetan glacier melt leading to sandstorms', China Daily, 27 November 2009, viewed 27 November 2009, <http://www.chinadaily.com.cn/china/2006-05/02/content_582103.htm/>.
[78] Thompson et al. (2009) op. cit., p. 5.
[79] National Snow and Ice Data Centre (2009b) 'Sea Ice', University of Colorado, viewed 27 November 2009, <http://nsidc.org/sotc/sea_ice.html>.

average rate of 11.2 per cent per decade, during the summer months, relative to the average.[80] Figure 5 below shows the declining trend in the average monthly Arctic summer sea ice extent for September 1979 to 2009.

Arctic ice cover is also showing significant thinning leaving the ice vulnerable to melt in the summer. At the end of the summer in 2009, 49 per cent of the ice cover was only one year old, second year ice made up 32 per cent, but only 19 per cent of the ice cover was over two years old, the least in the satellite record and far below the 1981 to 2000 average of 52 per cent.[81] Based on this new data, some models have predicted that the Arctic summers may be ice free within a matter of decades.[82]

Figure 5: Average monthly Arctic sea ice extent (September 1979 to 2009)



Source: National Snow and Ice Data Centre (2009c) op. cit.

[80] National Snow and Ice Data Centre (2009c) 'Arctic sea ice extent remains low; 2009 sees third-lowest mark', University of Colorado, viewed 27 November 2009, <http://nsidc.org/news/press/20091005_minimumpr.html>.
[81] ibid.
[82] M. Wang and E. Overland (2009) 'A sea ice free summer Arctic within 30 years?', *Geophysical Research Letters*, vol. 36, L07502, doi: 10.1029/2009GL037820, p. 1.

4. United Nations Climate Change Conference in Copenhagen

International negotiations to address climate change are conducted within the United Nations Framework Convention on Climate Change (UNFCCC), the international treaty which was agreed to in 1992. One of the key agreements to be implemented through the UNFCCC is the Kyoto Protocol which committed signatories to reducing emissions by an average of five per cent by 2012 from 1990 levels.[83] As Kyoto is due to expire in 2012, negotiations for a new agreement will take place at the UNFCCC Copenhagen summit in December 2009. The Copenhagen summit aims to address four key issues, which are:

1. To provide clarity on mid-term emission targets that industrialised countries will commit to;
2. To provide clarity on the actions developing countries can undertake to mitigate greenhouse gas emissions;
3. To define stable and predictable financing to help the developing world reduce greenhouse gas emissions, and adapt to the effects of climate change; and,
4. To identify institutions that will allow technology and finance to be deployed transparently and verifiably, and in a way that treats developing countries as partners.[84]

The following selected list of countries have made the following commitments in the lead up to the summit (all commitments are to 2020).[85]

- The US President Barack Obama committed the US to a 17 per cent reduction in GHG emissions based on 2005 levels
- The Chinese Government announced it would cut its carbon intensity by 40-45 per cent
- The EU has committed to a 20 per cent reduction in emissions from 1990 levels
- The UK has committed to a 34 per cent reduction from 1990 levels
- Japan has committed to a 25 per cent reduction on 1990 levels
- Brazil has committed to a 36-39 per cent reduction compared to 1990 levels
- Indonesia has committed to a 26 per cent reduction
- South Korea has committed to a 30 per cent reduction on 'expected' levels
- Australia has proposed a reduction of between 5 and 25 per cent below 2000 levels[86]

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[83] United Nations Framework Convention on Climate Change (UNFCCC) (2009) 'Kyoto Protocol', viewed 14 October 2009, <http://unfccc.int/kyoto_protocol/items/2830.php>.

[84] UNFCCC (2009a) 'Fact Sheet: Copenhagen – why is a deal so important', viewed 27 November 2009, UNFCCC, <http://unfccc.int/press/fact_sheets/items/4976txt.php>; UNFCCC (2009b) 'Fact Sheet: 10 frequently asked questions about the Copenhagen deal', UNFCCC, viewed 27 November 2009, <http://unfccc.int/press/fact_sheets/items/4997txt.php>.

[85] For a comparison of emission pledges see SBS World News Australia (2009) 'How do emission reduction pledges compare?', viewed 27 November 2009, <http://www.sbs.com.au/news/article/1121637/How-do-emission-reduction-pledges-compare>.

[86] See, A. Morton et al. (2009) 'Obama and Rudd to meet on climate', *The Age*, 27 November 2009, p. 4; COP15 Copenhagen (2009) 'South Korea pledges 30 per cent emissions cut by 2020', UNFCCC, viewed 27 November 2009, <http://en.cop15.dk/news/view+news?newsid=2617>; If agreement can be reached, the UK expects to increase the target to 42 per cent, with a long term target of 80 per cent by 2050, see COP15 Copenhagen (2009a) 'UK first country in the world to set legally binding targets', UNFCCC, viewed 14 October 2009, <http://en.cop15.dk/news/view+news?newsid=1133>; Ecopolity (2009) 'Brazil sets a target to reduce future carbon emissions by 2020', viewed 27 November 2009, <http://www.ecopolity.com/2009/11/14/brazil-commits-to-a-target-to-reduce-future-carbon-emissions-by-2020/>; COP15 Copenhagen (2009b) 'Indonesia offers ambitious plan to fight global warming', UNFCCC, viewed 14 October 2009, <http://en.cop15.dk/news/view+news?newsid=2233>; Prime Minister of Japan and His Cabinet (2009) 'Press Conference by Prime Minister Yukio Hatoyama – 25 September 2009', viewed 27 November 2009, <http://www.kantei.go.jp/foreign/hatoyama/statement/200909/25naigai_e.html>.

COP15 Outcome

The Copenhagen Conference concluded on Saturday the 19th of December, following twelve days of talks marked by rancour and division. Facing the prospect of negotiations failing to reach any agreement, the conference concluded with a non-binding document titled the *Copenhagen Accord*. At the final meeting the conference formally took note of the *Copenhagen Accord*.

The Accord, which came into operation immediately, comprises twelve main points. These include: The recognition that the increase in global temperatures should be below two degrees celsius; that deep cuts in global emissions are required but recognising that the timeframe for peaking will be longer in developing countries; that developed countries shall provide adequate, predictable and sustainable financial and technological resources to developing countries; that some parties to the agreement commit to implement quantified emissions targets for 2020, while others will implement mitigation actions which will be subject to their domestic measurement; and that developed countries commit to a goal of mobilising a US$100 billion fund by 2020 to address the needs of developing countries.[87]

Australian Climate Change Minister Penny Wong said that Australia had hoped to achieve more at the conference but would abide by the accord.[88] US President Barack Obama stated that more confidence building between emerging economies, the least developed countries and developed countries would be needed before another legally binding treaty can be signed.[89] The Chinese Foreign Minister Yang Jiechi said that a broad consensus had been reached and that the summit had yielded significant and positive results. By contrast, environment groups widely condemned the accord, labelling it as an empty non-binding agreement, which provides no trajectory for limiting the global temperature rise to two degrees.[90]

The next round of the UNFCCC negotiations is due to be held in Mexico in December 2010. However, some reports suggest that this round may be held earlier in an endeavour to negotiate a legally binding treaty.[91]

[87] COP15 (2009c) 'A Copenhagen Accord it is', UNFCCC, viewed 21 December 2009, <http://en.cop15.dk/news/view+news?newsid=3070>.
[88] D. Flitton and T. Arup (2009) 'Summit result positive, Chinese declare', *The Age*, 21 December 2009, p. 1.
[89] COP15 (2009d) 'Obama: a binding deal is still our goal', UNFCCC, viewed 21 December 2009, <http://en.cop15.dk/news/view+news?newsid=3072>.
[90] See for example A. Hewett (2009) 'Poorest of the poor ask why Copenhagen failed to listen', *The Age*, 21 December 2009, p. 17.
[91] D. Flitton and T. Arup (2009) op. cit.

Glossary[92]

Business as usual	A scenario of future greenhouse gas emissions that assumes that there would be no major changes in policies on mitigation.
Carbon intensity	The amount of emissions of CO_2 per unit of gross domestic product (GDP) or per unit of energy generated.
Carbon sink	Parts of the carbon cycle, such as oceans or plants, that store carbon in various forms.
Global warming	Global warming refers to the gradual increase in global surface temperature as one of the consequences of radiative forcing caused by anthropogenic emissions.
Greenhouse gases	Greenhouse gases (GHGs) are those gaseous constituents of the atmosphere, natural and anthropogenic, that absorb and emit infrared radiation. This property causes the greenhouse effect. The primary GHGs in the atmosphere are water vapour, carbon dioxide, nitrous oxide, methane and ozone. Greenhouse effect: GHGs absorb and emit infrared radiation, including downwards to the earth's surface, and tend to trap heat in the atmosphere, like the panes of a greenhouse. This effect provides a suitable temperature for life as we know it - on average, 14°C. Enhanced greenhouse effect: Brought about by human activities, where GHGs are released into the atmosphere at a greater rate than would occur through natural processes and their concentrations are increasing. Global warming is one consequence.
Holocene period	The Holocene interglacial period is a geological epoch that began approx. 12-10,000 years ago, and within which period nearly all human civilisation has developed.
ppm (parts per million)	ppm (parts per million) or ppb (parts per billion) is the ratio of the number of greenhouse gas molecules to the total number of molecules of dry air: eg., 385ppm means 385 molecules of a greenhouse gas per million molecules of dry air.
Radiative forcing	A measure of the influence that a factor (such as CO_2 emissions) has on the energy balance of the climate system due to the absorption and emission of infrared and visible radiation.
A1FI scenario	A1FI is the most fossil-fuel intensive emissions scenario in the IPCC Special Report on Emissions Scenarios.
Thermal expansion	Refers to the increase in volume that results from warming water. A warming of the ocean leads to an expansion of the ocean volume and hence an increase in sea level.

[92] See IPCC (2007) op. cit.

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