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Climate Change: Science Update 2007

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Climate Change: Science Update 2007

Summary

In 2007, the fourth major assessment of technical information on climate change by the Intergovernmental Panel on Climate Change (IPCC) was published in November. The year also saw continued release of new scientific findings on various aspects of climate change.

The IPCC "Fourth Assessment Report" (AR4) critically reviewed the research on science, impacts, and mitigation strategies, and underscored large areas of agreement on climate issues (as well as some important uncertainties and disagreements). The IPCC concluded that the Earth's climate unequivocally has warmed over the past century, and that while natural factors, including changes in solar irradiance and volcanoes, have played roles in the observed changes, "most of the observed increase in globally averaged temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic greenhouse gas concentrations."[1] Additional research published in 2007 showed continuously rising concentrations of greenhouse gases and temperatures, record loss of Arctic sea ice in the summer, transit by sailboat through the legendary Northwest Passage through the Arctic, and other markers of climate change. Additional research indicated several ecological risks — including mortality of the eastern Pacific gray whale and lower survival rates among young polar bears — linked to climate change.

Concerns about climate change are based both on observed changes to date and projections of what is likely to occur in the future. The IPCC concluded that greenhouse gas emissions and concentrations in the atmosphere could be expected to grow through the 21st Century in the absence of concerted climate change mitigation policies. For a wide range of plausible GHG scenarios to 2100, the IPCC projected "best guess" increases in global average temperatures from 1.8°C to 4.0°C (3.2°F to 7.2°F). Its range of all scenarios to 2100, incorporating a fuller range of uncertainties, was 1.1°C to 6.4°C (2.0°F to 11.5°F). Associated with the projections are impacts that may be beneficial in some locations and for some sectors with small changes in globally averaged climate, but that would be adverse for others, particularly in regions that are already warm and dry, and may become more so. Adverse effects are expected to multiply with accumulating climate change. Sea levels could rise between 7 and 23 inches by 2100, not including the effects of possible accelerated melting of the Greenland or Antarctic ice sheets. The risks of abrupt and irreversible changes in the climate system — some potentially catastrophic — continue to grow as the atmosphere moves further from its state over the past several thousand years.

This report summarizes highlights of new scientific research and assessments released in 2007 related to global warming. For more extensive background on climate change, see CRS Report RL33849, *Climate Change: Science and Policy Implications*, by Jane A. Leggett.

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[1] Intergovernmental Panel on Climate Change Working Group I, *Climate Change 2007: The Physical Basis* (Cambridge, UK: Cambridge University Press, 2007), p. 8 of the *Summary for Policymakers*.

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Introduction

Attention to the risks of climate change continues to grow in the United States and worldwide. The attention is stimulated by continuing advances in scientific and economic understanding of the risks, and by debate over policy options to manage those risks. The year 2007 has yielded a number of important new research and assessment products, a selected set of which are summarized in this update report. A fuller explanation of the processes involved in climate change, along with uncertainties and controversies, is provided in CRS Report RL33849, *Climate Change: Science and Policy Implications*, by Jane A. Leggett.

Among the most important products of 2007 was release of the fourth assessment report of the Intergovernmental Panel on Climate Change (IPCC),[2] along with a Synthesis Report of the three volumes on science, impacts and vulnerabilities, and mitigation options. On November 16, 2007, government officials from most countries — including the United States — agreed on a *Summary for Policymakers of the Synthesis Report of the IPCC Fourth Assessment Report*. For the reader's convenience, key findings from this Summary for Policy Makers are provided in Appendix A of this report.[3] Many of the findings relating to science and impacts are discussed in this CRS report, along with a number of additional, important research findings that have been released in 2007.

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[2] The IPCC is organized under the auspices of the United Nations and engages participation of more than 2000 scientists from around the world. According to its website, "The IPCC was established to provide the decision-makers and others interested in climate change with an objective source of information about climate change. The IPCC does not conduct any research nor does it monitor climate related data or parameters. Its role is to assess on a comprehensive, objective, open and transparent basis the latest scientific, technical and socio-economic literature produced worldwide relevant to the understanding of the risk of human-induced climate change, its observed and projected impacts and options for adaptation and mitigation. IPCC reports should be neutral with respect to policy, although they need to deal objectively with policy relevant scientific, technical and socio-economic factors. They should be of high scientific and technical standards, and aim to reflect a range of views, expertise and wide geographical coverage" [http://www.ipcc.ch/about/index.htm] (extracted November 26, 2007). Previous assessment reports of the IPCC were published in 1990, 1995, and 2001.

[3] CRS has not independently evaluated and confirmed the IPCC conclusions.

Observed Warming and Additional Metrics of Climate Change

The Earth's climate has warmed by 0.6 to 0.9º Celsius (1.1 to 1.6º Fahrenheit)[4] since the Industrial Revolution. Precipitation has increased over the past century, although some regions have been wetter and some have become drier, consistent with scientists' understanding of how heightened greenhouse gas concentrations affect climate regionally. Observed increases in ocean temperatures, altered wind patterns, extreme weather events, melting glaciers and sea ice, and timing of seasons are also attributed in part to greenhouse gas forcing. The IPCC in 2007 declared that "[w]arming of the climate system is unequivocal. ...Observational evidence from all continents and most oceans shows that many natural systems are being affected by regional climate changes."[5]

Although there is substantial natural variability in the climate system, a warming trend continues into 2007. According to the U.S. National Climate Data Center, "anomalously warm temperatures have covered much of the globe" through October 2007. "The global surface temperature for the combined January-October year-to-date period tied with 2002 as the third warmest January-October on record, while the global land surface temperature ranked warmest on record for January-October 2007."[6]

Attribution of Observed Changes Mostly to Greenhouse Gases

The IPCC fourth assessment report concluded that "[m]ost of the observed increase in globally-averaged temperatures since the mid-20th century is *very likely* due to the observed increase in anthropogenic[7] GHG concentrations."[8] According to the report, natural phenomena, such as volcanoes, solar variability and land cover change, have undoubtedly influenced the observed climate change, but the dominant driver of change since the 1970s is estimated to be the increase of greenhouse gases (GHG) in the Earth's atmosphere due to emissions from human-related activities.

Although the most potent greenhouse gas in the Earth's atmosphere is water vapor, it is understood not to be directly influenced at a large scale by human activities, making carbon dioxide (CO_2) the most important human-influenced GHG globally. Other GHG are certain synthetic chlorinated and fluorinated chemicals, methane, nitrous oxide, tropospheric ozone, and regional scale pollutants, such as sulfur oxides, and tiny carbon-containing particles called aerosols. In some regions and over some periods, these latter greenhouse gases may dominate local climate

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[4] IPCC, "Summary for Policymakers of the Synthesis Report of the IPCC Fourth Assessment Report" (Intergovernmental Panel on Climate Change, 2007), at [http://www.ipcc.ch/index.htm] (accessed November 27, 2007), p. 1.

[5] Ibid, p. 1.

[6] See [http://www.ncdc.noaa.gov/oa/climate/research/2007/oct/global.html#introduction].

[7] Human-caused.

[8] IPCC, op.cit., p. 5.

changes. One research study published in 2007 found that tropospheric ozone and aerosol pollution (from other regions) may exert a stronger influence during non-summer seasons on the Arctic climate than carbon dioxide and other long-lived GHG.[9]

Carbon dioxide (CO_2) concentrations have grown from a pre-industrial concentration of about 280 parts per million volume (ppm) to 379 ppm in 2005.[10] The IPCC found that "Atmospheric concentrations of CO_2 (379ppm) and methane (1774 parts per billion - ppb) in 2005 exceed by far the natural range over the last 650,000 years."[11] Global average CO_2 concentrations reached 381 in 2006 and are very likely to exceed the maximum again in 2007. The IPCC found that the increases in CO_2 concentrations since the Industrial Revolution are due primarily to human use of fossil fuels, with land-use changes (primarily deforestation) making a significant but smaller contribution. While over the past few decades, countries have trended towards using cleaner, lower carbon fuels (such as natural gas instead of coal), the IPCC noted that "the long-term trend of declining CO_2 emissions per unit of energy supplied reversed after 2000."[12]

Methane concentrations also have grown from a pre-industrial value of about 715 ppb to 1774 ppb in 2005.[13] The rate of methane growth has slowed and has been negative in several years since about 1992 for a variety of reasons, including economic restructuring, methane recovery for energy value, etc. Methane concentrations have actually declined slightly since 2004.

The United States contributes almost one-fifth of net global greenhouse gas emissions. China and the United States are now neck-and-neck as the largest emitters of CO_2. With China's robust economic growth — dependent on industrialization fueled largely by coal — China will become and remain the largest global emitter of CO_2 for the foreseeable future.[14] Future greenhouse gas emissions will grow most rapidly from developing economies, as they strive to eliminate poverty and raise income levels towards those of the wealthier "Annex 1" countries.[15] Future GHG

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[9] Drew Shindell, "Local and remote contributions to Arctic warming," *Geophysical Research Letters* 34, no. L14704 (2007).

[10] IPCC Working Group I, Summary for Policymakers in *Climate Change 2007: The Physical Basis* (Cambridge, UK: Cambridge University Press, 2007), p. 5, at [http://ipcc-wg1.ucar.edu/].

[11] IPCC, op.cit., p. 4.

[12] Ibid.

[13] Ibid.

[14] While the U.S. emits less CO_2 per unit of economic production than China (with "GHG intensities" of about 562 versus 703 metric tonnes of CO_2-equivalent per million dollars of GDP), the United States emits about 24 tons of CO_2-equivalent per person while China emits only about 4 tons per person.

[15] "Annex 1" of the United Nations Framework Convention on Climate Change (UNFCCC) 38 wealthier, industrialized countries, including the United States, Canada, Japan, the (continued...)

trajectories are widely uncertain, depending largely on the rate and composition of economic growth, and technology and policy choices.

Observed Impacts of Climate Changes

The IPCC concluded in 2007 that

> ...discernible human influences extend beyond average temperature to other aspects of climate. Human influences have:
>
> - *very likely* contributed to sea level rise during the latter half of the 20th century
> - *likely* contributed to changes in wind patterns, affecting extra-tropical storm tracks and temperature patterns
> - *likely* increased temperatures of extreme hot nights, cold nights and cold days
> - *more likely than not* increased risk of heat waves, area affected by drought since the 1970s and frequency of heavy precipitation events.
>
> Anthropogenic warming over the last three decades has *likely* had a discernible influence at the global scale on observed changes in many physical and biological systems.[16]

Some highlights that emerged in 2007 of observed changes, understood to be the result, at least in part, of human-induced climate change, are summarized below.

Extent of Arctic Sea Ice at Lowest Recorded Levels. Arctic sea ice melted in 2007 to the smallest coverage since satellite measurements began in 1979 — perhaps 50% below sea ice extent of the 1950s.[17,18] Average sea ice extent for September 2007 was 4.28 million square kilometers (1.65 million square miles) — 23% below the previous record set in 2005 (**see Figure 1**). September 2007 was 39% below the average extent of sea ice between 1979 and 2000. The rate of sea ice decline since 1979, as measured in September 2007, is now approximately 10 percent per decade, or 72,000 square kilometers (28,000 square miles) per year.

While natural climate variability explains part of the observed rapid sea ice loss, it appears that scientists have been underestimating the sensitivity of the ice cover to the effects of GHG-induced warming. Updated estimates now project that the Arctic

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[15] (...continued)
European Union and its Members, Russia, Australia, New Zealand and others. Under the principal of "common but differentiated commitments," only the Annex 1 countries took on aims in the UNFCCC to develop national plans to limit GHG emissions. See CRS Report RL33826 *Climate Change: The Kyoto Protocol, Bali Negotiations, and International Actions*, by Susan R. Fletcher and Larry Parker.

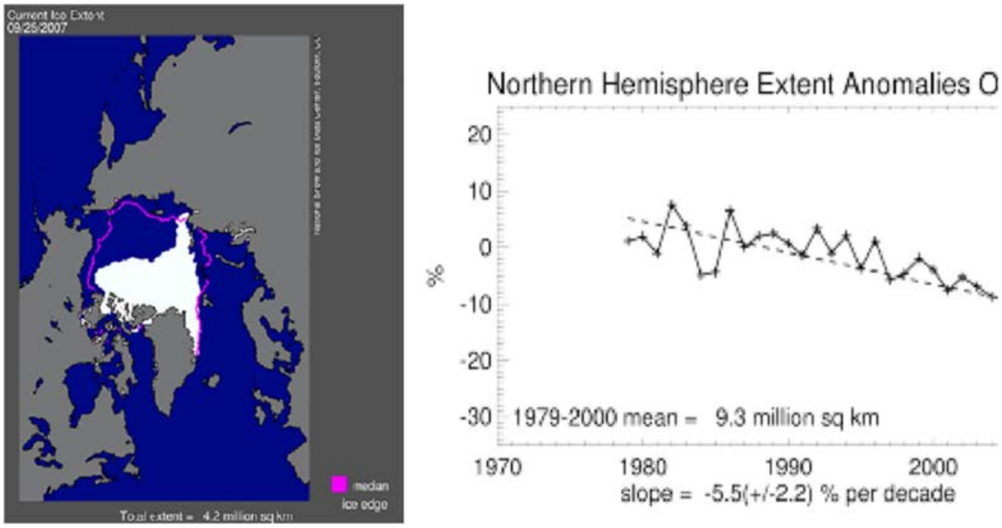
[16] IPCC, op. cit., p. 6.

[17] Using measurements from ship and aircraft before satellites became available.

[18] See [http://nsidc.org/news/press/2007_seaiceminimum/20070810_index.html], (accessed November 27, 2007).

Ocean could be ice-free in summer as early as 2040[19] or even 2030, if recent accelerations in sea ice loss continue.[20]

Figure 1. Record Low Sea Ice Extent in 2007



Source: National Snow and Ice Data Center [http://nsidc.org/].

Measurements by the National Aeronautics and Space Administration also found a 23% loss in 2007 of the thicker "perennial" ice that last lasts more than one year. A change in wind patterns starting around 2000 tripled the loss of perennial ice, compared to the average from the 1970s through the 1990s. The loss rate jumped higher again in 2007.

While extensive melting of Arctic sea ice is associated with GHG-induced warming, some sea ice has exited the Arctic toward the Atlantic Ocean as well. Simultaneously, Arctic currents seem to be reversing, returning to the pre-1990s direction, in what appears to be a decadal pattern. According to NASA, "The results suggest not all the large changes seen in Arctic climate in recent years are a result of long-term trends associated with global warming."[21]

Sea ice controls key aspects of Arctic ecology, atmospheric circulation, polar warming and other critical components of the Earth's climate system. Moreover, earlier seasonal melting of sea ice triggers a positive feedback that increases ocean

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[19] Marika Holland, Cecilia M. Bitz, and Bruno Tremblay, "Future abrupt reductions in the summer Arctic sea ice," *Geophysical Research Letters* 33, no. L23503 (2006) [http://www.cgd.ucar.edu/oce/mholland/abrupt_ice/holland_etal.pdf] (accessed December 22, 2006).

[20] According to Mark Serreze, US National Snow and Ice Data Center,University of Colorado, as quoted in David Adam, "Ice-free Arctic could be here in 23 years," The Guardian, September 5, 2007.

[21] See [http://earthobservatory.nasa.gov/Newsroom/NasaNews/2007/2007111325923.html].

warming, further increasing sea ice melting, and so on.[22] Some scientists have expressed concern that recently observed sea ice loss may have passed a "threshold" or a spiral of warming feedbacks.[23]

Further Melting of the Greenland Ice Sheet. U.S. satellite data revealed that 2007 has set a new record for melting across the Greenland ice sheet. The expanse of melting was twice the size of the United States.[24] However, recent observations — for example, the high melting rates in 2005 that startled many scientists — have exposed greater variability and complexity in ice dynamics than previously understood, as melting rates in 2006 returned closer to the average. Nonetheless, a 2007 reanalysis of surface melting of the Greenland ice sheet over the past 25 years found that the rate of acceleration of melting was about double previous estimates. The melting is closely correlated with summer temperatures. Between 1979 and 2005, the area of Greenland affected by melt on at least one day per year grew by 42%, while the mean temperature rose by 2.4°C.[25]

Melting and Thickening of Ice in Antarctica. Satellite observations analyzed in 2007 indicate that the Antarctic ice sheet is losing mass overall; the losses are mainly from the western Antarctic ice sheet. The NASA satellites have revealed that snow is melting farther inland, at higher altitudes than before and, increasingly, on the Ross Ice Shelf, which buffers land-based glaciers from the warmer ocean air.[26] Some high elevation regions of the Antarctic ice sheet do not show a significant rate of change or show less melting. Researchers identified a link between changes in temperatures and the duration and area of melting in Antarctica, suggesting a connection to global climate change. In another 2007 study, the British Antarctic survey found that 300 glaciers studied increased their average flow rate by 12% from 1993 to 2003. This was attributed to thinning of the lower glaciers at the edge of the sea, allowing the glaciers above them to flow faster, similar to phenomena observed in Greenland. The researchers tied local warming on the Antarctic Pennisula — some of the fastest recent warming on Earth (nearly 3°C — 4.4°F — over 50 years) — to retreat of 87% of its glaciers and the observed increase

[22] Donald K. Perovich et al., "Increasing solar heating of the Arctic Ocean and adjacent seas, 1979-2005: Attribution and role in the ice-albedo feedback," *Geophysical Research Letters* 34 (October 11, 2007).

[23] See, for example, [http://www.reuters.com/article/environmentNews/idUSL2815198120070928?sp=true].

[24] Marco Tedesco, "A New Record in 2007 for Melting in Greenland," *EOS Transactions* 88 (September 1, 2007).

[25] X. Fettweis, J.-P. van Ypersele, H. Gallée, F. Lefebre, and W. Lefebvre. "The 1979-2005 Greenland ice sheet melt extent from passive microwave data using an improved version of the melt retrieval XPGR algorithm." *Geophysical Research Letters*, 34, L05502, doi:10.1029/2006GL028787 (2007).

[26] NASA, "NASA Researchers Find Snowmelt in Antarctica Creeping Inland," September 20, 2007, at [http://www.nasa.gov/centers/goddard/news/topstory/2007/antarctic_snowmelt.html] (accessed November 30, 2007).

in their flow rates.[27]

No Melting of Some Permanent Ice Fields. Not all glaciers and ice fields are experiencing increased melting. For example, in Europe, while glaciers between 2,000 and 4,000 meters in altitude have lost an average of 1-1.5 kilometers of length through the 20th Century, others at high altitude — above 4200 meters — have changed very little in the same period. Some melting did occur, however, during the 2003 extreme heat wave.

Melting of Glaciers and Contribution to Sea Level Rise. Of the global melting of ice contributing to observed sea level rise, about 60% is currently coming from relatively small land-based glaciers, and only about 28% is coming from melting of the Greenland and Antarctic ice sheets. One report published in 2007 concluded that the net amount of melting ice from glaciers and ice caps flowing to the oceans each year is about 100 cubic kilometers — or about the volume of Lake Erie.[28] According to the report, the rate of melting has increased dramatically and demonstrates the poor understanding researchers have regarding the dynamic instability of snow and ice. Due in part to this poor understanding, the IPCC did not include any potential acceleration of melting from Greenland and Antarctica when it estimated potential sea level rise through the 21st Century of between 7 to 23 inches. With further warming, the acceleration of dynamic ice melt could raise the estimates of sea-level rise by an additional 4 to 10 inches by 2100.[29]

Weakened Uptake of Carbon in the Southern Ocean. Research published in 2007 concluded that net removal of CO_2 from the atmosphere by the Southern Ocean "sink" has weakened over the past 25 years. The researchers say this is due to higher winds caused by the elevated levels of GHG in the atmosphere and long-term depletion of stratospheric ozone. The greater storminess enhances mixing and upwelling of ocean waters and increases the rate of release of CO_2 to the atmosphere more than the increase in removals (photosynthetic) due to higher atmospheric CO2 concentrations.[30] This finding raises concern among some scientists about whether human-related GHG emissions will continue to be removed from the atmosphere by natural sinks at historic rates, which are assumed in many projections of future GHG concentrations and climate.

Observed Ecological Impacts of Climate Change. A growing number of studies are published each year investigating possible linkages between climate change and ecological changes. Results from a few released in 2007 are highlighted here.

Observations have suggested that a recent increase in deaths of the eastern

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[27] H. D. Pritchard and D. G. Vaughan, "Widespread acceleration of tidewater glaciers on the Antarctic Peninsula," *Journal of Geophysical Research* 112 (June 6, 2007).

[28] Mark F. Meier F. Meier et al., "Glaciers Dominate Eustatic Sea-Level Rise in the 21st Century," *Science* (July 19, 2007).

[29] Ibid.

[30] Corinne Le Quere et al., "Saturation of the Southern Ocean CO2 Sink Due to Recent Climate Change," *Science* 316, no. 5832 (June 22, 2007).

Pacific gray whale — taken off the endangered species list since the mid-1990s — to warmer than normal ocean temperatures, and "may represent first responses to altered ecological conditions and reduced carrying capacity in the Bering Sea and other habitats."[31] The increase in mortality is potentially due to a warming-linked shrinkage of food supplies in the Bering Sea feeding grounds of these whales.

In many ecological systems, climate is a primary — but not the sole — factor influencing the survival and behaviors of species. With the climate change experienced in recent decades, land-use, climate change and other factors have been associated with substantial range contractions, extinction of at least one species, and numerous changes in the timing of animal and plant behavior. One study published in 2007 found that, in western Europe, autumn 2006 and winter 2007 were extremely likely to have been the warmest for more than 500 years. Plant responses to the extreme warmth were visible, with some species having a second or extended flowering, and some species showed much earlier flowering following winter 2007.[32]

Polar bears are among the species that depend on sea ice for hunting and must fast during ice-free periods. The Western Hudson Bay of Canada has had ice-free summer periods for many years and, although the local polar bear population had previously appeared healthy, more recent observations have revealed lower survival rates among cubs and young bears.[33] Similar patterns have now emerged in Southern Hudson Bay and the Southern Beaufort Sea.[34]

Observations of several forest systems suggest that they are adapting to changes in climate more effectively than some scientists had expected. More specifically, NASA satellite imaging indicates that U.S. forests are adapting to the climate change experienced to date, and that the overall productivity response to weather and seasonal conditions has been closely linked to the number of different tree species in

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[31] S. Elizabeth Alter, Eric Rynes, and Stephen R. Palumbi, "DNA evidence for historic population size and past ecosystem impacts of gray whales," *Proceedings of the National Academy of Sciences* (September 11, 2007).

[32] Jürg Luterbacher et al., "Exceptional European warmth of autumn 2006 and winter 2007: Historical context, the underlying dynamics, and its phenological impacts," *Geophysical Research Letters* 34 (June 19, 2007).

[33] Regehr, Eric et al. "Survival and Population Size of Polar Bears in Western Hudson Bay in Relation to Earlier Sea Ece Breakup" *Journal of Wildlife Management*, v. 71, no. 8 (2007), pp. 2673-2683.

[34] USGS, USGS Science to Inform U.S. Fish & Wildlife Service Decision Making on Polar Bears: Executive Summary (Reston, VA, 2007), [http://www.usgs.gov/newsroom/special/polar%5Fbears/].

a forest area.[35] In Brazil, the productivity of Amazon forests has been resilient in spite of short but severe drought conditions in 2005, contrary to predictions of some ecosystem models, although whether the resistance will be sustained under longer drought — expected with climate change — is unknown.[36, 37]

Without Further GHG Mitigation Policies, GHG Emissions Will Grow

The U.S. Climate Change Science Program (US CCSP) released its second report in 2007, entitled "Scenarios of Greenhouse Gas Emissions and Atmospheric Concentrations and Review of Integrated Scenario Development and Application."[38] This research produced new scenarios of future GHG emissions and concluded that "In the reference scenarios,[39] economic and energy growth, combined with continued fossil fuel use, lead to changes in the Earth's radiation balance that are three to four times that already experienced since the beginning of the industrial age."[40] This research also explored scenarios aimed at stabilizing the growth of GHG concentrations in the atmosphere at four increasingly stringent levels: roughly 750 ppm, 650 ppm, 550 ppm and 450 ppm (including multiple GHGs as CO_2-equivalents[41]). The analysis concluded, "The timing of GHG emissions reductions varies substantially across the four radiative forcing stabilization levels. Under the most stringent stabilization levels [450-550 ppm] emissions begin to decline immediately or within a matter of decades. Under the less stringent stabilization levels [750 ppm], CO_2 emissions do not peak until late in the century or beyond, and they are 1½ to over 2½ times today's levels in 2100."[42]

The results of the CCSP reference scenarios are similar to those of the 2000 Special Report on Emission Scenarios (SRES) of the IPCC, though the latter

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[35] NASA, "NASA Satellites Can See How Climate Change Affects Forests," [http://www.nasa.gov/centers/goddard/news/topstory/2006/forest_changes.html] (accessed November 28, 2007).

[36] Scott R. Saleska et al., "Amazon Forests Green-Up During 2005 Drought," *Science* (September 20, 2007).

[37] Yadvinder Malhi et al., "Climate Change, Deforestation, and the Fate of the Amazon," Science (November 29, 2007).

[38] See [http://www.climatescience.gov/Library/sap/sap2-1/default.php].

[39] "Reference scenarios" typically represent the researchers' best estimates of future trajectories without significant policy changes. They are frequently used, as in this project, to compare with, estimate the impacts of, specific policy scenarios.

[40] On p. 3 of the US CCSP report.

[41] In order to compare and aggregate different greenhouse gases, various techniques have been developed to index the effect each greenhouse gas to that of carbon dioxide, where the effect of CO_2 equals one. When the various gases are indexed and aggregated, their combined quantity is described as the CO_2-equivalent. In other words, the CO_2-equivalent quantity would have the same effect on, say, radiative forcing of the climate, as the same quantity of CO_2.

[42] Ibid., p. 3.

explored a wider range of uncertainty in its reference projections. The SRES projected global GHG emissions, without further climate change mitigation policies, to increase by 25-90% (CO_2-equivalent) from 2000 to 2030, with CO_2-equivalent concentrations growing in the atmosphere to 600-1550 ppm.

Projections of Future Climate

Scientists have found it very likely that rising greenhouse gas concentrations, if they continue unabated, will increase global average temperature above natural variability by at least 1.5^o Celsius (2.7^o Fahrenheit) during the 21st Century (above 1990 temperatures), with a small likelihood that the temperature rise may exceed 5^{o}C (9^{o}F).[43] The projections thought most likely by many climate modelers are for greenhouse gas-induced temperature rise of approximately 2.5 to 3.5^{o}C (4.5 to 6.3^{o}F) by 2100. Future climate change may advance smoothly or sporadically, with some regions experiencing more fluctuations in temperature, precipitation, and frequency or intensity of extreme events than others. Wet regions are expected to get more precipitation and dry regions are expected to become drier. Floods, droughts, storms and other extreme weather events are projected to increase, with impacts for ecological and human systems.

Sea levels could rise by between 18 and 59 centimeters (between 7 and 23 inches) by 2100 due to expansion of oceans waters as they warm and additions of meltwater (at current rates of melting) from land-based glaciers and ice caps. The IPCC scientists were unable to include a quantitative estimate of the risks of accelerated melting or possible collapse of the Greenland or Antarctic ice sheets due to inadequacies of existing understanding of their dynamics.

Projections of Future Impacts

Some impacts of climate change are expected to be beneficial in some locations with a few degrees of warming (e.g., increased agricultural productivity in some regions, less need for space heating, opening of the Northwest Passage for shipping and resource exploitation). Most impacts are expected to be adverse (e.g., lower agricultural productivity in many regions, drought, rising sea levels, spread of disease vectors, greater needs for cooling). Risks of abrupt, surprising climate changes, with accompanying dislocations, are expected to increase as global average temperature increases, and could push natural and socio-economic systems past key thresholds.

As the degree and distribution of climate changes continue, ranges of species are likely to change. Climate change is highly likely to create substantial changes in ecological systems and services in some locations, and may lead to ecological surprises. The disappearance of some types of climate also raises risks of extinctions of species, especially those with narrow geographic or climatic distributions, and

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[43] To put the magnitude of these potential increases in context, the current global, annual mean temperature (GMT) of the Earth is approximately 14^{o}C (57^{o}F). The difference between the current GMT and the low point of the last Ice Age, about 21,000 years ago, was roughly 7-8^{o}C (44-46^{o}F).

where existing communities disintegrate. Research published in 2007[44] projects that, under the highest IPCC emissions scenario, 12 to 39% of the Earth's land areas may experience novel climates while 10 to 48% of land areas' climates may disappear by 2100 AD. In the lowest IPCC climate change scenarios, 4 to 20% of land areas gain novel climates and 4 to 20% see existing climates disappear.

Because climate change will occur with different magnitudes and characteristics in different regions, resulting dislocations and disparities across locations are expected to increase pressure on international aid and migration, with possible implications for political stability and security. Impacts may be alleviated with investments in adaptation, although adaptation as a strategy is thought to be more challenging and potentially less effective the more widespread, uncertain and severe the climate changes.

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[44] John W Williams, Stephen T Jackson, and John E Kutzbach, "Projected distributions of novel and disappearing climates by 2100 AD," Proceedings of the National Academy of Sciences of the United States of America 104, no. 14 (April 3, 2007).

Appendix A. Summary for Policymakers of the Synthesis Report of the Fourth Assessment Report of the Intergovernmental Panel on Climate Change

On November 16, 2007, government officials from most countries — including the United States — agreed on a *Summary for Policymakers of the Synthesis Report of the IPCC Fourth Assessment Report*. The Synthesis Report is derived from three technical reports: "*The Physical Science Basis*" (February 2007); "*Impacts, Adaptation and Vulnerability*" (April 2007); and "*Mitigation of Climate Change*" (May 2007). It represents a consensus among government officials and researchers, and will "constitute the core source of factual information about climate change [upon which policymakers will] base their political action... in the coming years" (IPCC *Media Advisory*, November 17, 2007). Key conclusions are excerpted (and slightly reordered) below:

> "Warming of the climate system is unequivocal...." (p. 1) "Observational evidence from all continents and most oceans shows that many natural systems are being affected by regional climate changes." (p. 2)
>
> "Global GHG emissions due to human activities have grown since pre-industrial times....Carbon dioxide (CO2) is the most important anthropogenic [greenhouse gas] GHG. Its annual emissions grew by about 80% between 1970 and 2004. The long-term trend of declining CO2 emissions per unit of energy supplied reversed after 2000." (p. 4)
>
> "Atmospheric concentrations of CO2 (379ppm) and CH4 (1774 ppb) in 2005 exceed by far the natural range over the last 650,000 years. Global increases in CO2 concentrations are due primarily to fossil fuel use, with land-use change providing another significant but smaller contribution." (p. 4)
>
> "Most of the observed increase in globally-averaged temperatures since the mid-20th century is *very likely* due to the observed increase in anthropogenic GHG concentrations." (p. 5)
>
> "Even if the concentrations of all greenhouse gases and aerosols had been kept constant at year 2000 levels, a further warming of about 0.1ºC per decade would be expected. Afterwards, temperature projections increasingly depend on specific emission scenarios." (p. 6)
>
> "Anthropogenic warming could lead to some impacts that are abrupt or irreversible, depending upon the rate and magnitude of the climate change." (p. 13)
>
> "The uptake of anthropogenic carbon since 1750 has led to the ocean becoming more acidic.... Increasing atmospheric CO2 concentrations lead to further acidification.... [P]rogressive acidification of oceans is expected to have negative impacts on marine shell-forming organisms (e.g. corals) and their dependent species." (p. 11)

"Sea level rise under warming is inevitable....The eventual contributions from Greenland ice sheet loss could be several metres ... should warming in excess of 1.9-4.6°C above pre-industrial be sustained over many centuries." (p. 21)

"Some systems, sectors and regions are *likely* to be especially affected by climate change. Systems and sectors:

- particular ecosystems:
- terrestrial: tundra, boreal forest and mountain regions because of sensitivity to warming; mediterranean-type ecosystems because of reduction in rainfall; and tropical rainforests where precipitation declines
- coastal: mangroves and salt marshes, due to multiple stresses
- marine: coral reefs due to multiple stresses; the sea ice biome because of sensitivity to warming
- water resources in some dry regions at mid-latitudes and in the dry tropics, due to changes in rainfall and evapotranspiration, and in areas dependent on snow and ice melt
- agriculture in low-latitudes , due to reduced water availability
- low-lying coastal systems, due to threat of sea level rise and increased risk from extreme weather events
- human health in populations with low adaptive capacity." (p. 11)

"[M]ore extensive adaptation than is currently occurring is required to reduce vulnerability to climate change. There are barriers, limits and costs, which are not fully understood." (p. 14)

"[International cooperation] will help to reduce global costs for achieving a given level of mitigation, or will improve environmental effectiveness. Efforts can include ... emissions targets; sectoral, local, sub-national and regional actions; RD&D programmes; adopting common policies; implementing development oriented actions; or expanding financing instruments." (p. 19)

"Decisions about macroeconomic and other non-climate policies can significantly affect emissions, adaptive capacity and vulnerability." (p. 19)

"Determining what constitutes 'dangerous anthropogenic interference with the climate system' in relation to Article 2 of the UNFCCC involves value judgements." (p. 19)

"Limited and early analytical results from integrated analyses of the costs and benefits of mitigation indicate that they are broadly comparable in magnitude, but do not as yet permit an unambiguous determination of an emissions pathway or stabilisation level where benefits exceed costs." (p. 23)

"Many impacts can be reduced, delayed or avoided by mitigation." (p. 20)

"There is *high agreement* and *much evidence* that all stabilisation levels assessed can be achieved by deployment of a portfolio of technologies that are either currently available or expected to be commercialised in coming decades, assuming appropriate and effective incentives are in place...." (p. 22)

"An effective carbon-price signal could realise significant mitigation potential in all sectors. Modelling studies show global carbon prices rising to 20-80 US$/tCO2-eq by 2030 are consistent with stabilisation at around 550 ppm CO2-

eq by 2100. For the same stabilisation level, induced technological change may lower these price ranges to 5-65 US$/tCO2-eq in 2030." (p. 18)

"All assessed stabilisation scenarios indicate that 60-80% of the reductions would come from energy supply and use, and industrial processes, with energy efficiency playing a key role in many scenarios. Including non-CO2 and CO2 land-use and forestry mitigation options provides greater flexibility and cost-effectiveness. Low stabilisation levels require early investments and substantially more rapid diffusion and commercialisation of advanced low emissions technologies. Without substantial investment flows and effective technology transfer, it may be difficult to achieve emission reduction at a significant scale. Mobilizing financing of incremental costs of low-carbon technologies is important." (p. 22)

"The macro-economic costs of mitigation generally rise with the stringency of the stabilisation target." (p. 22)

"Impacts of climate change are *very likely* to impose net annual costs which will increase over time as global temperatures increase. Peer-reviewed estimates of the social cost of carbon in 2005 average US$12 per tonne of CO2, but the range from 100 estimates is large (-$3 to $95/tCO2). This is due in large part to differences in assumptions regarding climate sensitivity, response lags, the treatment of risk and equity, economic and non-economic impacts, the inclusion of potentially catastrophic losses, and discount rates. Aggregate estimates of costs mask significant differences in impacts across sectors, regions and populations and *very likely* underestimate damage costs because they cannot include many non-quantifiable impacts." (p. 23)

"Choices about the scale and timing of GHG mitigation involve balancing the economic costs of more rapid emission reductions now against the corresponding medium-term and long-term climate risks of delay." (p. 23)