Congressional Research Service

Climate Change: Science Highlights

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Specialist in Energy and Environmental Policy

February 23, 2009

Congressional Research Service
7-....
www.crs.gov
RL34266

CRS Report for Congress
Prepared for Members and Committees of Congress

Summary

Scientific conclusions have become more compelling regarding the influence of human activities on the Earth's climate. In 2007, the Intergovernmental Panel on Climate Change (IPCC) declared that evidence of global warming was "unequivocal." It 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 [human-related] greenhouse gas [GHG] concentrations."

The IPCC concluded that human activities have markedly increased atmospheric concentrations of "greenhouse gases" (GHG), including carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and gases (such as chlorofluorocarbons, CFC) that are controlled under the Montreal Protocol to protect the stratospheric ozone layer. From the beginning of the Industrial Revolution, CO_2 has risen from about 280 parts per million (ppm) to about 386 ppm today (up 38%). The concentration of CO_2 is higher now than in at least 800,000 years before present.

Additional human influences on the climate that are not easily compared to GHG emissions could, nonetheless, be managed to moderate regional and global climate change. These include tropospheric ozone pollution (i.e., smog), particulate and aerosol emissions, and land cover change. New chemicals, such as nitrogen trifluoride (NF_3), also may play a small role.

Without radical changes globally from current policies and economic trajectories, experts uniformly expect that GHG emissions will continue to grow and lead to continued warming of the Earth's climate. Experts disagree, however, on the timing, magnitude and patterns of future climate changes. 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^{o}C to 4.0^{o}C (3.2^{o}F to 7.2^{o}F). Although these temperature changes may seem small, they compare to the current global, annual average temperature of around 14^{o}C (57^{o}F). While precipitation overall is expected to increase, its distribution may become more uneven: regions that now are dry are likely to get drier, while regions that now are wet, are likely to get wetter. Extreme precipitation and droughts are expected to become more frequent. Experts project that warming ocean waters will expand, and melting glaciers and ice sheets will further add to sea level rise. The Arctic Ocean could become ice free in summers within a few decades. Ocean salinity is expected to fall, and the Meridional Overturning Circulation in the Atlantic Ocean could slow, reducing ocean productivity and altering regional climates in both North America and Europe. The climate would continue changing for hundreds of years after GHG concentrations were stabilized, according to most models. There are also possibilities of abrupt changes in the state of the climate system, with unpredictable and potentially catastrophic consequences. Much concern is focused now, among scientists and economists, about the likelihoods and implications of exceeding such thresholds of abrupt change, sometimes called "tipping points."

This report summarizes highlights of scientific research and assessments related to human-induced climate change. For more extensive explanation of climate change science and analytical methods, see CRS Report RL33849, *Climate Change: Science and Policy Implications*.

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Introduction

The focus of policy-makers on climate change science has shifted from debate over whether the Earth's climate has changed and whether human-related greenhouse gases are responsible for a major portion of it. Focus has turned to debate over the magnitude and patterns of future climate change, how adverse such changes may be, and how projections may inform mitigation and adaptation policy choices. There is also growing recognition of a wider variety of human-related "forcings" of climate change than the six "Kyoto gases" to include other kinds of pollution, newly developed chemicals, and land use patterns.

Understanding of potential impacts of climate change has deepened as well, but remains hindered by poor time and spatial resolution of predictions and, especially, by the wide divergence of projections across different climate models. This divergence reflects continuing uncertainties concerning clouds, oceans, and vegetation feedbacks to climate change, among other questions. It also reflects re-emerging recognition of the importance of socio-economic factors in technological change, climate change projections, potential damages (or opportunities) of those changes, and appropriate policy responses. Confidence has grown in some aspects of climate change science, allowing policy-makers to deliberate over appropriate risk management strategies, but needs for further research continue.

This report highlights major scientific observations, conclusions, and issues. The principal scientific findings from the 2007 Fourth Assessment Report (AR4) of the Intergovernmental Panel on Climate Change (IPCC)[1] continue to stand, and will be summarized in this report.[2] A fuller explanation of climate change processes, analytical methods, uncertainties, and controversies is provided in CRS Report RL33849, *Climate Change: Science and Policy Implications*, by (name redacted).

Observed Warming and Additional Metrics of Climate Change

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." The Earth's climate has warmed by 0.6^o to 0.9^o Celsius (1.1 to 1.6^o Fahrenheit) since the Industrial Revolution and approximately 0.5^oC

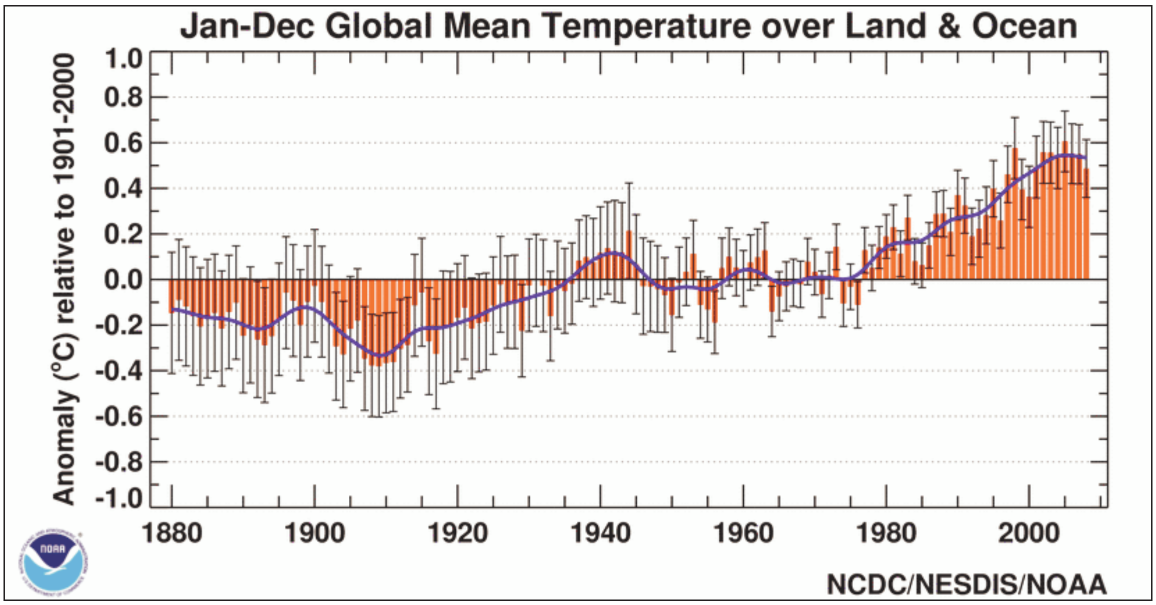
[1] The IPCC is organized under the auspices of the United Nations and engages participation of more than 2000 scientists from around the world. According to its website, "The IPCC was established to provide the decision-makers and others interested in climate change with an objective source of information 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.

[2] For the reader's convenience, key findings from *this Summary for Policy Makers* are provided in the **Appendix** of this report. CRS has not independently verified all the findings in the IPCC report.

compared to the 20th century average (see **Figure 1**). Precipitation has increased over the past century, although some regions have become 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. Although there is substantial natural variability in the climate system, a warming trend continued through 2008, with the year tied with 2001 as the eighth warmest globally since reliable measurements began in 1880.[3]

Figure 1. Global Annual Temperature Anomalies Compared to the 20th Century Average

1880 - 2008



Source: National Climate Data Center, *Climate of 2008*, National Oceanic and Atmospheric Administration, December 16, 2008.

Notes: An anomaly is the difference between the value in a given year (or other time period) and the long-term average for a specified period, which in this case is one century. It describes how the annual value differs from a defined "normal."

The blue smoothed line in that graph is obtained by applying a "21-point binomial filter" to the time series plotted as red bars. The "whisker" (thin black vertical) lines represent confidence or possible error levels. Levels of confidence have improved sizably over the past century.

Figure 1 also shows that the global climate varies from year-to-year and over longer cycles, as well as showing a century-long trend to warming. Some influences are natural and some are very likely human-related. At regional and local scales, climate is generally even more variable. This illustrates the caution that should be exercised in trying to detect changes in trends in the context of variability. One or a series of hot or cool years, or a few extreme weather events, do not necessarily represent more than normal climate variability. For example, better scientific

3 National Climate Data Center, *Climate of 2008*, National Oceanic and Atmospheric Administration, December 16, 2008, http://www.ncdc.noaa.gov/oa/climate/research/2008/ann/ann08.html#majorhighlights. The NCDC is the federal government's official source for climate data.

understanding of natural phenomena like La Nina, and solar variability have helped scientists to understand their cooling influence on global average temperatures since the year 2000, or the impact of El Nino on the extreme high temperature of 1998.[4] Detecting changes in the climate system requires measurements and assessment over decades or longer.

The U.S. Climate Change Science Program (CCSP) produced a new synthesis report in 2008, "reanalyzing" the U.S. climate from 1950 to the present,[5] evaluating observed and modeled changes, and attributing changes to different factors. The researchers estimated average warming over North America to have been 0.9°C (1.6°F) from 1951 to 2006, with almost all of the warming later than 1970. The reanalysis concluded, among other findings, that:

- The largest yearly average regional temperature increases have occurred over northern and western North America, with up to 2.0°C (3.6°F) warming in 56 years over Alaska, the Yukon Territories, Alberta, and Saskatchewan. On the other hand, there have been no significant yearly average temperature changes in the southern United Sates and eastern Canada.

- There has not been a significant trend in North American precipitation since 1951, although there have been substantial changes from year to year and even decade to decade.

The report did not find a significant trend in continental precipitation. Nor did it find systematic changes in how often or where severe droughts have occurred in the contiguous United States over the past decades. However, the demands and competition for water resources have increased in some regions, so that the vulnerability to drought is more severe.

Attribution of Observed Changes Mostly to Greenhouse Gases

In 2007, 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 GHG concentrations."[6] 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.

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4 National Climate Data Center, *2008 Annual Climate Review: U.S. Summary*, National Oceanic and Atmospheric Administration, Asheville, NC, December 16, 2008, http://www.ncdc.noaa.gov/oa/climate/research/2008/ann/us-summary.html.

5 Randall Dole, Martin Hoerling, and Siegfried Schubert, *Reanalysis of Historical Climate Data for Key Atmospheric Features: Implications for Attribution of Causes of Observed Change*, Final Report, CCSP Synthesis and Assessment Product 1-3 (Asheville: NOAA/NCDC, 2008), http://www.climatescience.gov/Library/sap/sap1-3/final-report/default.htm.

6 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.

The CCSP reanalysis of North American climate data[7] concluded that there is more than a 66% likelihood that more than half the average continental warming since 1951 has been due to human activities, but also that the regional differences in summer surface temperatures are unlikely to have been driven by human influences alone. The reanalysis found that sea surface temperatures likely have affected temperature trends, regional differences in temperature and regional and seasonal differences in precipitation. It also concluded that sea surface temperatures have likely contributed to multi-year droughts.[8]

Human-Related Influences on Climate Change

Although the most potent greenhouse gas in the Earth's atmosphere is water vapor, it is thought not to be directly influenced at a large scale by human activities.[9] Most policy attention has been given to the "basket" of six gases covered by the Kyoto Protocol: Carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), sulfur hexafluoride (SF_6), hydrofluorocarbons (HFC), and perfluorocarbons (PFC). CO_2 is the most important human-influenced GHG globally.

Less policy attention has been give to other GHG and other human-related "forcings" of climate change, which might also offer climate change abatement opportunities:

- certain synthetic chlorinated and fluorinated chemicals (e.g., chlorofluorocarbons (CFC), hydrochlorofluorocarbons (HCFC), the production of which is controlled to reverse destruction of the ozone layer in the stratosphere (but which continue to be emitted from certain sources);
- tropospheric ozone (or "smog"), which is controlled in many countries as an air pollutant with adverse health and environmental effects, and is not emitted but is formed in the atmosphere due to emissions of nitrogen oxides (NOx), volatile organic compounds (VOC), and carbon monoxide (CO);
- regional scale air pollutants, such as sulfates, and tiny carbon-containing particles called *black carbon aerosols*.[10]

In some regions and over some periods, these air pollutants may dominate local climate changes, including how much precipitation falls and where. Aerosols also darken reflective surfaces, such as snow, and absorb more of the Sun's radiation. On snow, scientists have shown particles to increase melt, and hence create feedbacks that may accelerate climate changes. Some researchers

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[7] Dole, op.cit.

[8] Dole, op.cit.

[9] Water vapor in the atmosphere is indirectly affected by human activities, as greenhouse-gas induced global warming would lead to an increase in atmosphere moisture. Depending on how this occurs, this indirect effect is considered a "positive feedback" that reinforces initial warming.

[10] CCSP *Atmospheric Aerosol Properties and Impacts on Climate*, A Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research. [Mian Chin, Ralph A. Kahn, and Stephen E. Schwartz (eds.)]. National Aeronautics and Space Administration, Washington, DC, USA. (2009); CCSP, *Climate Projections Based on Emissions Scenarios for Long-Lived and Short-Lived Radiatively Active Gases and Aerosols*. A Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research. H. Levy II, D.T. Shindell, A. Gilliland, M.D. Schwarzkopf, L.W. Horowitz, (eds.). Department of Commerce, NOAA's National Climatic Data Center, Washington, DC, USA, 100 pp. (2008).

argue that abatement of black carbon aerosols could help to slow atmospheric warming and melting in the Arctic and mountainous regions.[11]

New types of emissions are emerging that also have small, but potentially growing, effects on climate change. For example, nitrogen trifluoride (NF_3) is a gas used in certain manufacturing processes, introduced as a more benign alternative to CFC, but with a strong Global Warming Potential.[12] While the current influence of this new, substitute gas is very small (well less than half a percent of CO_2 forcing), its appearance points to the need for attention to Global Warming Potentials as new chemicals are developed, and for flexibility in incorporating new climate change influences into policy approaches over time.

Land use and land use changes have long been recognized for their influence on local climates, and increasingly on global climate. For example, the built environment is often constructed with dark materials, such as asphalt roads or roof shingling, that absorbs the Sun's radiation and heats the environment. These *urban heat islands* have a very small global effect. However, other changes, such as the warming influences of loss of snow cover, and the influences of changing vegetation (e.g. forest losses in the tropics) , and possibly of agricultural irrigation, have been raised as meriting attention for their regional effects and potential global influence. While these influences do not reduce the importance of CO_2 emissions and other GHG forcing, they raise opportunities for enhancing mitigation and management of climate changes locally and globally.

Trends in Atmospheric Concentrations of Greenhouse Gases

Carbon dioxide (CO_2) concentrations have grown from a pre-industrial concentration of about 280 parts per million volume (ppm) to 386 ppm in 2008 (see **Figure 2**).[13] The IPCC had concluded in 2007 that "[a]tmospheric concentrations of CO_2 (379ppm) and methane (1774 parts per billion - ppb) in 2005 exceed[ed] by far the natural range over the last 650,000 years." The IPCC found that the increases in CO_2 concentrations since the Industrial Revolution were 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.[14]

Methane concentrations also grew from a pre-industrial value of about 715 ppb to about1786 ppb in 2008[15] (see **Figure 2**). The rate of methane growth slowed and had been negative in several years since about 1992 for a variety of reasons, including economic restructuring, methane recovery for energy value (e.g., from landfills, animal wastes), etc. Methane concentrations grew

[11] See, for example, Kathy S Law and Andreas Stohl, "Arctic air pollution: origins and impacts," Science (New York, N.Y.) 315, no. 5818 (March 16, 2007): 1537-40.

[12] Global Warming Potential (GWP) is an index of different molecules' potential to influence climate, molecule for molecule, compared to carbon dioxide. CO_2 has a GWP of 1, but its far greater abundance in the atmosphere compared with other greenhouse gases makes it the most important human-related GHG.

[13] The 2008 value is the preliminary annual mean measured at Mauna Loa. ftp://ftp.cmdl.noaa.gov/ccg/co2/trends/co2_annmean_mlo.txt.

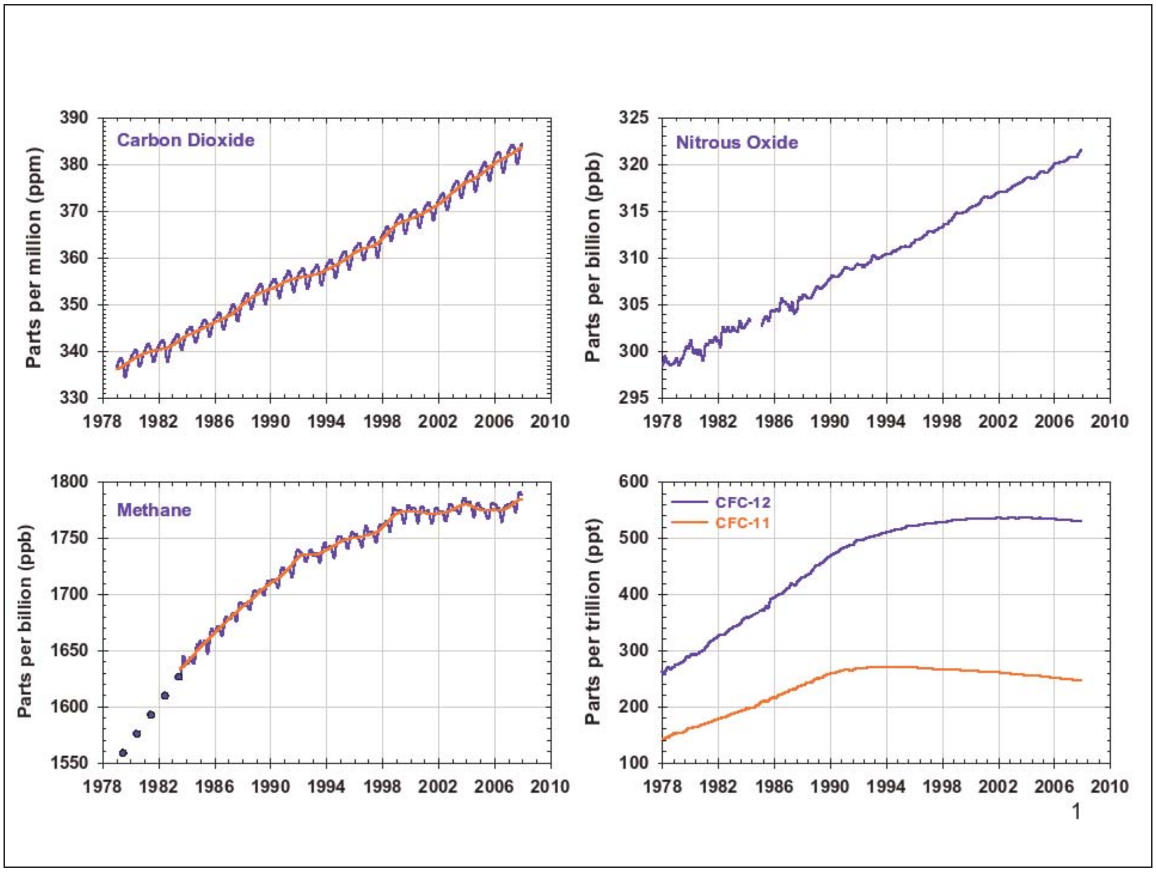
[14] CRS Report RS22970, *Are Carbon Dioxide Emissions Rising More Rapidly Than Expected?*, by (name redacted) and (name redacted).

[15] http://www.noaanews.noaa.gov/stories2008/20080423_methane.html.

only slightly since around 1999 but turned upwards again in 2007. Nitrous oxide emissions continue to grow at a roughly constant rate. In contrast, CFC and HCFC have level or declining concentrations since the early- to mid-1990s.

Figure 2. Global Average Atmospheric Concentrations of Five Major Greenhouse Gases

1978 to 2008



Source: National Oceanic and Atmospheric Administration, http://www.esrl.noaa.gov/gmd/aggi/.

Notes: Global averages of the concentrations of the major, well-mixed, long-lived greenhouse gases - carbon dioxide, methane, nitrous oxide, CFC-12 and CFC-11 from the NOAA global flask sampling network since 1978. These gases account for about 97% of the direct radiative forcing by long-lived greenhouse gases since 1750. The remaining 3% is contributed by an assortment of 10 minor halogen gases (see text). Methane data prior to 1983 are annual averages from *Etheridge et al. (1998)*, adjusted to the NOAA calibration scale *[Dlugokencky et al., 2005]*.

Greenhouse Gas Emissions and Growth Globally

The United States contributes almost one-fifth of net global greenhouse gas emissions and China contributes slightly more. China's CO_2 emissions exceeded those of the United States sometime around 2005, though changes in 2008 in economic growth rates, energy use and uncertainty preclude precise estimates for China. With its robust economic growth—dependent on industrialization fueled largely by coal—China is likely to remain the largest global emitter of CO_2 for the foreseeable future, although the government has established ambitious policies to improve energy efficiency, promote renewable energy and reduce polluting emissions.[16] Future greenhouse gas emissions will likely grow most rapidly in developing economies, as they strive to eliminate poverty and raise income levels towards those of the wealthier "Annex 1" countries. Future GHG trajectories are widely uncertain, depending largely on the rate and composition of economic growth, as well as technology and policy choices.

Observed Impacts of Climate Changes

The IPCC concluded in 2007[17] 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.

Extent of Arctic Sea Ice Near Lowest Recorded Levels

Sea ice at the poles is a vital component of the Earth's current climate system. Sea ice controls key aspects of Arctic atmospheric circulation, polar warming and other critical components of the Earth's climate system. Polar sea ice is of cultural and iconic value to some people. It also affects a number of human activities, such as shipping, fishing, resource accessibility, and tourism. Sea ice is important to current Arctic ecology, such as habitat for polar bear, seals, whales and others.

Arctic sea ice shrunk to its smallest extent in 2007, and nearly to the same extent in 2008, since satellite measurements began in 1979. Sea ice cover has reached perhaps 50% below the sea ice extent of the 1950s. Average sea ice extent in September 2008 was about 4.67 million square kilometers, compared to the record low of September 2007 of 4.28 million square kilometers (1.65 million square miles). Compared to the average extent of sea ice between 1979 and 2000, 2008 was 34% below and 2007 was 39% below. The rate of sea ice decline since 1979 has reached approximately 11% per decade, or 78,000 square kilometers (28,000 square miles) per year.[18] While rapid Arctic ice loss appears in climate model runs, the loss of Arctic sea ice extent has been more rapid than produced by climate models.[19]

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[16] CRS Report RL34659, *China's Greenhouse Gas Emissions and Mitigation Policies*, by (name redacted), (name re dacted), and Anna Mackey.

[17] IPCC, op.cit.

[18] Data from the National Snow and Ice Data Center (NSIDC), http://nsidc.org/sotc/sea_ice.html, based on calculations by Walt Meier, NSIDC.

[19] J. Stroeve, M.M. Holland, W. Meier, T. Scambos, and M. Serreze. 2007. Arctic sea ice decline: Faster than forecast. Geophysical Research Letters doi:10.1029/2007GL029703.

While the record melting of Arctic sea ice is associated with GHG-induced warming, the winds in 2007 pushed sea ice from the Arctic toward the Atlantic Ocean. Simultaneously, Arctic currents seemed to be reversing, returning to the pre-1990s direction. In addition, low cloudiness led to more solar warming than usual. 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." In 2008, there were near-record lows despite return of more "normal" wind and atmospheric conditions.

Earlier seasonal melting of sea ice triggers a positive feedback that increases ocean warming, further increasing sea ice melting, and so on.[20] Updated estimates now project that the Arctic Ocean could be ice-free in summer as early as 2040,[21] 2030[22] (or sooner) if recent accelerations in sea ice loss continue. Some scientists have expressed concern that recently observed sea ice loss may have passed a "threshold" or a spiral of warming feedbacks.[23] Melting ice in the Arctic would contribute very little to global sea level rise because it already floats, with its volume already displacing sea water; however, it contributes to concern because of the impact loss of Arctic sea ice would have in warming Arctic waters and atmosphere, and consequent effects on warming and melting of the Greenland Ice Sheet.

Melting of the Greenland Ice Sheet

Between 1979 and 2005, the area of Greenland that melted on at least one day per year grew by 42%, while the mean temperature rose by 2.4^{o}C.[24] However, recent changes in rates of melting of the Greenland Ice Sheet point to variability in the climate system and the difficulties in discerning trends among the changes. Beginning in the late 1990s, ice flows from two of Greenland's biggest glaciers that flow into the ocean accelerated rapidly, surprising scientists at the speed of change. The lack of prediction of the phenomenon contributed to the IPCC's decision not to include the contribution of ice sheet melting in its projections of sea level rise due to global warming in the 21st Century. The high melting rates in 2005 startled many scientists and raised major concerns about the potential impacts on sea level rise. Some scientists have argued that policy goals to address climate change should avoid passing certain "tipping points" of the climate system that could have potentially catastrophic impacts, naming melting of the Greenland Ice Sheet on one of these thresholds. (See section "Projections of Future Climate" for further discussion of possible tipping points.) However, as melting rates in 2006 returned closer to the average, they have exposed greater variability and complexity in ice dynamics than previously understood.[25] Now some scientists believe that warming waters near the glacier outlets accelerate ice flows and results in retreat of their floating leading margins. However, after a point, the glacier regains

[20] 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).

[21] 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).

[22] 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.

[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] Richard B. Alley, Mark Fahnestock, and Ian Joughin, "Understanding Glacier Flow in Changing Times," *Science* 322, no. 5904 (November 14, 2008): 1061-1062, doi:10.1126/science.1166366.

stability on its grounding rock and the retreat slows, though it will continue to melt with warm air temperatures.

Melting and Thickening of Ice in Antarctica

Over the past few decades, the atmosphere over Antarctica has warmed. 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. NASA satellites 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. Unlike Greenland, the Western Antarctic Ice Sheet is not well grounded like the outlet glaciers of Greenland, so that disintegration of the lead glacial margins could lead to persistently accelerated flows of ice to the sea. The researchers tied local warming on the Antarctic Peninsula—some of the fastest recent warming on Earth (nearly 3^{o}C, or 4.4^{o}F, over 50 years)—to retreat of 87% of its glaciers and the observed increase in their flow rates.[27]

In 2008, parts of the Antarctic Pennisula's Wilkins Ice Sheet disintegrated in three stages, which is especially significant because two of the stages occurred during the cold season. The pattern of breakup was smaller but similar to that of the Larsen A and B ice shelves, in1995 and 2002 respectively. According to the NSIDC, preliminary studies of the sea floor below the Larsen B ice shelf suggest that the 2002 disintegration was the first such in 12,000 years.[28] While the general warming of ocean waters in both the Arctic and Antarctica contributes to loss of ice sheets, two studies in 2008 indicate that other factors (winds and current changes) may circulate warm water in the vicinity of ice shelves.[29]

No Melting of Some Permanent Ice Fields

Not all glaciers and ice fields are experiencing increased melting. One study published in 2008 indicated that snow accumulation has doubled in the south-western Antarctica Peninsula since 1850, with rates accelerating in the past few decades. [30]In Europe, while glaciers between 2,000

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[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).

[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] http://nsidc.org/news/press/larsen_B/2002_seafloor.html.

[29] Rignot, E., J.L. Bamber, M.R. van den Broeke, C. Davis, Y. Li, W.J. van de Berg, and E. van Meijgaard. 2008. Recent Antarctic ice mass loss from radar interferometry and regional climate modelling. Nature Geoscience 1: 106-110. And Stammerjohn, S.E., D.G. Martinson, R.C. Smith, and R.A. Iannuzzi. 2008. Sea ice in the western Antarctic Peninsula region: Spatio-temporal variability from ecological and climate change perspectives. Deep Sea Research Part II: Topical Studies in Oceanography doi:10.1016/j.dsr2.2008.04.026.; as described by NSIDC in the State of the Cryosphere, http://nsidc.org/sotc/iceshelves.html.

[30] Elizabeth R. Thomas, Gareth J. Marshall, and Joseph R. McConnell, "A doubling in snow accumulation in the (continued...)

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 4,200 meters—have changed very little in the same period. Some melting did occur, however, during the 2003 extreme heat wave.

Contributions of Melting Ice and Warming Oceans to Sea Level Rise

A 2008 assessment of satellite-based data suggests that most of the sea level rise observed in recent years can be explained by an increased mass of the oceans (i.e., more water). Of the global melting of ice contributing to observed sea level rise, about half has come from relatively small land-based glaciers, with the other half contributed by melting of the Greenland and Antarctic ice sheets.[31] 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.

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. Recent articles have proposed a range of new estimates for sea level rise in the 21st Century that would include contributions of sea ice melt, particularly from Greenland. Pfeffer et al. conclude that physical constraints would preclude more than 2 meters (6.6 feet) of sea level rise over the coming century (with a range of 2.6 to 6.6 feet), and put forward a best guess, with low confidence, of about 0.8 meters rise by 2100.[32] Grinsted et al. suggest a range of 0.9 to 1.3 meters (3 to 4.3 feet) of sea level rise in 2090 to 2100, using a moderate climate change scenario.[33]

Hydrological Changes in the Western United States

A modeling study published in 2008 concluded that human factors may have induced as much as 60% of the changes observed between 1950 and 1999 in the hydrological cycle in the western United States. Climate changes were found to have influenced river flows, winter air temperatures and snow pack. The authors concluded that these changes, and their human influences, suggest an impending water supply crisis in the West.[34]

(...continued)

western Antarctic Peninsula since 1850" (January 12, 2008). http://www.agu.org/pubs/crossref/2008/2007GL032529.shtml.

[31] A Cazenave et al., "Sea level budget over 2003–2008: A reevaluation from GRACE space gravimetry, satellite altimetry and Argo," Global and Planetary Change 65, no. 1-2 (January 2009): 83-88, doi:10.1016/j.gloplacha.2008.10.004.

[32] W. T. Pfeffer, J. T. Harper, and S. O'Neel, "Kinematic Constraints on Glacier Contributions to 21st-Century Sea-Level Rise," Science 321, no. 5894 (September 5, 2008): 1340-1343, doi:10.1126/science.1159099.

[33] Aslak Grinsted, J. Moore, and S. Jevrejeva, "Reconstructing sea level from paleo and projected temperatures 200 to 2100 A.D.," Climate Dynamics, doi:10.1007/s00382-008-0507-2, http://dx.doi.org/10.1007/s00382-008-0507-2., using the IPCC "A1B" scenario of GHG emissions.

[34] Tim P. Barnett et al., "Human-Induced Changes in the Hydrology of the Western United States," Science 319, no. 5866 (February 22, 2008): 1080-1083, doi:10.1126/science.1152538.

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 2008 are highlighted here.

One study concluded that warming of the Southern Ocean around Antarctica is threatening King penguin populations on the continent.[35]

A number of new studies continue to underscore threats to coral reefs globally by a variety of stressors that include heat stress from warm ocean events, and "ocean acidification" caused by absorption of CO_2 from the atmosphere by the oceans. One of these studies concluded that almost one-third of 704 reef-building coral species that could be assessed with data show enhanced risk of species extinction. It further concluded that the share of coral species at risk has risen in recent decades. The Caribbean was the region with the highest share of corals at high risk of extinction, while the Coral Triangle in the western Pacific had the greatest share of coral species in all categories at risk.[36] Another 2008 study concluded that throughout Australia's Great Barrier Reef, coral calcification (a measure of growth) has decreased by 14% since 1990. The authors further concluded that the severity and abruptness of the observed decline was unprecedented in at least the past 400 years.[37]

While risks to coral reefs from global warming and ocean acidification are increasingly studied, the associated risks to reef fish communities have been acknowledged but not documented. A 2008 study assessed the impacts of the major 2008 coral bleaching events across seven countries, 66 sites and 26 degrees of latitude in the Indian Ocean. The study concluded that, while impacts across sites were variable, ocean scale integrity of fish communities was lost, reflected in size structure, diversity, and food-chain composition of the reef fish. The authors also found that management regimes did not appear to affect the ecosystem responses to the bleaching event, suggesting a need to develop strategies for system-wide resilience to climate variability and change.[38] At least one study found evidence that some corals may be able to adjust to bleaching events by shifting the types of algae (zooxanthellae) with which they co-depend.[39]

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.

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[35] Céline Le Bohec et al., "King Penguin Population Threatened by Southern Ocean Warming," Proceedings of the National Academy of Sciences of the United States of America 105, no. 7 (February 19, 2008): 2493–2497, doi:10.1073/pnas.0712031105.

[36] Kent E. Carpenter et al., "One-Third of Reef-Building Corals Face Elevated Extinction Risk from Climate Change and Local Impacts," Science (July 10, 2008): 1159196, doi:10.1126/science.1159196.

[37] Glenn De'ath, Janice M. Lough, and Katharina E. Fabricius, "Declining Coral Calcification on the Great Barrier Reef," Science 323, no. 5910 (January 2, 2009): 116-119, doi:10.1126/science.1165283.

[38] Nicholas A. J. Graham et al., "Climate Warming, Marine Protected Areas and the Ocean-Scale Integrity of Coral Reef Ecosystems," PLoS ONE 3, no. 8 (2008): e3039, doi:10.1371/journal.pone.0003039.

[39] 1. Nicholas A. J. Graham et al., "Climate Warming, Marine Protected Areas and the Ocean-Scale Integrity of Coral Reef Ecosystems," PLoS ONE 3, no. 8 (2008): e3039, doi:10.1371/journal.pone.0003039.

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.[40] Similar patterns have now emerged in Southern Hudson Bay and the Southern Beaufort Sea.[41]

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 a forest area.[42] 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.[43] Studies have shown increases in primary productivity in the Amazon as well as in above-ground biomass. They also show, however, changes in the composition of plant species, with fast-growing species faring better than slow-growing ones. The authors attributed these changes to global environmental changes, including elevated levels of CO_2 in the atmosphere.[44] Another study examined the influences of high temperatures on tropical forest uptake of CO_2 from the atmosphere. It found that elevated temperatures initially raised CO_2 uptake, then CO_2 uptake declined. The authors concluded that, in the particular tract of forest studied, temperatures were approaching a threshold above which CO_2 uptake would drop sharply.[45]

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."[46] This research produced new scenarios of

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[40] 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. See also CRS Report RL33941, *Polar Bears: Listing Under the Endangered Species Act*, by (name redacted), (name redacted), and (name redacted).

[41] 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/.

[42] 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).

[43] Scott R. Saleska et al., "Amazon Forests Green-Up During 2005 Drought," Science (September 20, 2007); Yadvinder Malhi et al., "Climate Change, Deforestation, and the Fate of the Amazon," Science (November 29, 2007).

[44] Jérôme Chave et al., "Assessing Evidence for a Pervasive Alteration in Tropical Tree Communities," PLoS Biology 6, no. 3 (March 2008): e45, doi:10.1371/journal.pbio.0060045.

[45] Catia M. Domingues et al., "Improved estimates of upper-ocean warming and multi-decadal sea-level rise," Nature 453, no. 7198 (June 19, 2008): 1090-1093, doi:10.1038/nature07080.

[46] See CCSP, *Scenarios of Greenhouse Gas Emissions and Atmospheric Concentrations*. Sub-report 2.1A of Synthesis and Assessment Product 2.1 by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research.[Clarke, L., J. Edmonds, H. Jacoby, H. Pitcher, J. Reilly, R. Richels] Department of Energy, Office of Biological & Environmental Research, Washington, DC., USA. (2007) p. 3. http://www.climatescience.gov/Library/sap/sap2-1/default.php.

future GHG emissions and concluded that "In the reference scenarios,[47] 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."[48] This research also explored scenarios aimed at stabilizing the growth of GHG concentrations in the atmosphere at four increasingly stringent levels: roughly 750 parts per million (ppm), 650 ppm, 550 ppm, and 450 ppm (including multiple GHGs as CO_2-equivalents[49]). 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."[50]

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 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). The projections thought most likely by many climate modelers are for greenhouse gas-induced temperature rise of approximately 2.5^o to 3.5^o C (4.5 to 6.3^o F) by 2100.[51] Future climate change may advance smoothly or sporadically,

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[47] "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.

[48] CCSP, *Scenarios of Greenhouse Gas Emissions and Atmospheric Concentrations*. Sub-report 2.1A of Synthesis and Assessment Product 2.1 by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research.[Clarke, L., J. Edmonds, H. Jacoby, H. Pitcher, J. Reilly, R. Richels] Department of Energy, Office of Biological & Environmental Research, Washington, DC., USA. (2007) p. 3. http://www.climatescience.gov/Library/sap/sap2-1/default.php.

[49] 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.

[50] CCSP, *Scenarios of Greenhouse Gas Emissions and Atmospheric Concentrations*. Sub-report 2.1A of Synthesis and Assessment Product 2.1 by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research.[Clarke, L., J. Edmonds, H. Jacoby, H. Pitcher, J. Reilly, R. Richels] Department of Energy, Office of Biological & Environmental Research, Washington, DC., USA. (2007) p. 3. http://www.climatescience.gov/Library/sap/sap2-1/default.php. Scenarios *of Greenhouse Gas Emissions and Atmospheric Concentrations*. Sub-report 2.1A of Synthesis and Assessment Product 2.1 by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research.[Clarke, L., J. Edmonds, H. Jacoby, H. Pitcher, J. Reilly, R. Richels] Department of Energy, Office of Biological & Environmental Research, Washington, DC., USA. (2007) p. 3. http://www.climatescience.gov/Library/sap/sap2-1/default.php.

[51] 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).

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.

A report by the CCSP found that short-lived air pollutants, such as tropospheric ozone and black carbon aerosols could contribute as much as 20% of global warming by 2050. It found that one "climate model using projected changes in emissions and pollutant levels that occur primarily over Asia predicts significant increases in surface temperature and decreases in rainfall over the continental United States during the summertime throughout the second half of this century."[52] While most policy attention has been on the long-lived GHG, such as carbon dioxide and methane, including other climate forcings, such as short-lived air pollution, offers additional opportunities to abate near-term climate change, with the co-benefits of reducing health and environmental impacts.

With projected global warming, 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.

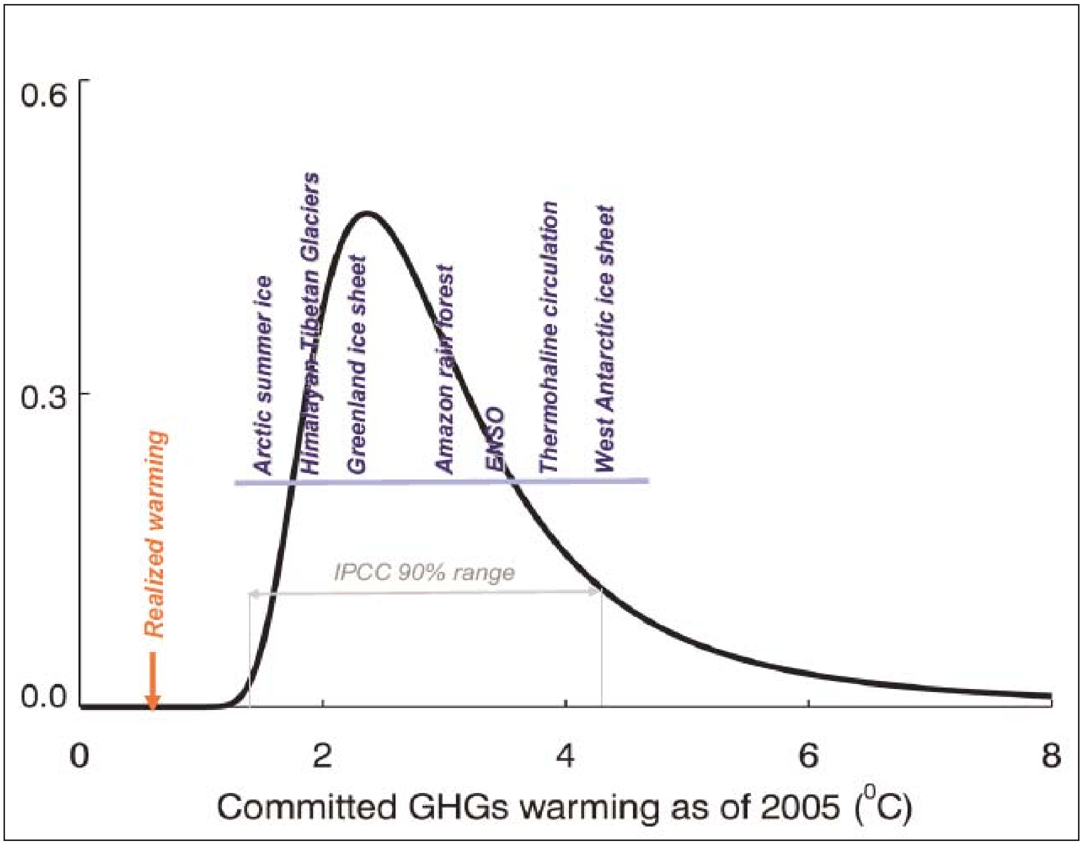
Concern About Abrupt "Tipping Points" in the Climate System

Some people are concerned less about chronic damages due to slow and continuing climate change than they are about the potential for abrupt "tipping points" in the current climate system. Once the climate system reaches certain thresholds of change or tipping points, major aspects of the Earth's climate could change abruptly and in uncertain ways.[53] **Figure 3** shows one recent set of estimates of where dangerous "tipping points" may exist in the climate system relative to potential future global temperature increases. It also shows an estimate of the likelihoods, or probability density function (the black curve), that human-related GHG emissions since 1750 have already committed the planet to degrees of warming. In other words, according to the estimates represented in this figure, it is most likely that greenhouse gas emissions from 1750 to 2005 will lead to global average warming of 1^{o}-$3^{o}C$, and potentially result in ice-free Arctic summers, major reduction of area and volume of the Hindu-Kush-Himalaya-Tibetan (HKHT) glaciers, major melting of the Greenland Ice Sheet, and so non. According to the estimates in the cited study, it is less likely that the committed warming is already greater than the "tipping points" for collapse of the Amazon rain forest and other identified components.

[52] CCSP, *Climate Projections Based on Emissions Scenarios for Long-Lived and Short-Lived Radiatively Active Gases and Aerosols*. A Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research. H. Levy II, D.T. Shindell, A. Gilliland, M.D. Schwarzkopf, L.W. Horowitz, (eds.). Department of Commerce, NOAA's National Climatic Data Center, Washington, DC, USA, 100 pp. (2008)

[53] See, for example, CCSP, 2008: Abrupt Climate Change. A report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research [Clark, P.U., A.J. Weaver (coordinating lead authors), E. Brook, E.R. Cook, T.L. Delworth, and K. Steffen (chapter lead authors)]. U.S. Geological Survey, Reston, VA, 459 pp. (2008)

Figure 3. Possible "Climate-Tipping" Elements and their Possible Likelihoods for Committed Global Temperature Change that May Precipitate the Tipping



Source: I. V. Ramanathan and Y. Feng, "On Avoiding Dangerous Anthropogenic Interference with the Climate System: Formidable Challenges Ahead," *Proceedings of the National Academy of Sciences* 105, no. 38 (September 23, 2008

Notes: Seven climate system components are identified that could undergo major, potentially abrupt and catastrophic, changes, as global temperatures increase. (ENSO includes El Nino/La Nina oscillations, and thermohaline circulation is the large-scale ocean overturning and circulation driven by temperature differences between the tropics and the poles and ocean salinity/freshwater). Each "climate-tipping" component is graphed above an estimated Increase in global average temperature (compared to pre-industrial levels) that could initiate the tipping, according to T.M. Lenton et al., Tipping Elements in the Earth's Climate System, Proceedings *of the National Academy of Sciences,* Vol.105:1786-1793 (2007). The estimated likelihoods (probability density function) that GHG emissions had already committed the climate system to different degrees of warming are represented by the black curve. See Ramanathan and Feng for further detail.

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,[54] spread of disease vectors, greater needs for cooling). Risks of abrupt, perhaps

[54] See CCSP, *Coastal Sensitivity to Sea-Level Rise: A Focus on the Mid-Atlantic Region.* A report by the U.S. Climate (continued...)

unidentified climate changes in aspects of the environment, with accompanying dislocations, are expected to increase as global average temperature increases, and could push natural and socio-economic systems past key thresholds.[55] An example that recently occurred is the rapid and widespread infestation of beetles in western North America.[56] Such changes could precipitate major reorganization of ecosystems, and under some circumstances, stresses on nearby or dependent human systems.

Impacts on water resources are expected to be among the most serious due to climate change, combined with rising demand and management issues in many regions. Earlier melting of snowpack and ice in some regions (e.g., the Andes, the U.S. West) and loss of ice and snow would reduce water supply to settlements that now depend on the snowmelt, and change the seasonality of water supply. Snowfall in some regions is expected to increase, however, with greater atmospheric moisture.

One CCSP assessment examined the implications of projected sea level rise, with emphasis on the U.S. mid-Atlantic region. It concluded:

> Today, rising sea levels are submerging low-lying lands, eroding beaches, converting wetlands to open water, exacerbating coastal flooding, and increasing the salinity of estuaries and freshwater aquifers. Other impacts of climate change, coastal development, and natural coastal processes also contribute to these impacts. In undeveloped or less developed coastal areas where human influence is minimal, ecosystems and geological systems can sometimes shift upward and landward with the rising water levels. Coastal development, including buildings, roads, and other infrastructure, are less mobile and more vulnerable. Vulnerability to an accelerating rate of sea-level rise is compounded by the high population density along the coast, the possibility of other effects of climate change, and the susceptibility of coastal regions to storms and environmental stressors, such as drought or invasive species.[57]

Agriculture in many regions, especially in the tropics, may experience losses of productivity, especially where higher temperatures coincide with increased dryness and limits on irrigation. The general shift upward in growing season temperatures could raise typical temperatures to or above those considered extreme today.[58] Agriculture may also confront challenges from invasive species, including pests. One 2008 study examined four key pests of maize in the United States

(...continued)

Change Science Program and the Subcommittee on Global Change Research. [James G. Titus (Coordinating Lead Author), K. Eric Anderson, Donald R. Cahoon, Dean B. Gesch, Stephen K. Gill, Benjamin T. Gutierrez, E. Robert Thieler, and S. Jeffress Williams (Lead Authors)], U.S. Environmental Protection Agency, Washington DC, USA. (2009).

[55] See, for example, CCSP, Thresholds of Climate Change in Ecosystems. A report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research. [Fagre D.B., Charles C.W., Allen C.D., Birkeland C., Chapin F.S. III, Groffman P.M., Guntenspergen G.R., Knapp A.K., McGuire A.D., Mulholland P.J., Peters D.P.C., Roby D.D., and Sugihara G.] (2009) U.S. Geological Survey, Department of the Interior, Washington DC, USA.

[56] CRS Report R40203, *Mountain Pine Beetles and Forest Destruction: Effects, Responses, and Relationship to Climate Change*, by (name redacted).

[57] CCSP, Coastal Sensitivity to Sea-Level Rise: A Focus on the Mid-Atlantic Region. A report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research. [James G. Titus (Coordinating Lead Author), K. Eric Anderson, Donald R. Cahoon, Dean B. Gesch, Stephen K. Gill, Benjamin T. Gutierrez, E. Robert Thieler, and S. Jeffress Williams (Lead Authors)], U.S. Environmental Protection Agency, Washington DC, USA. (2009).

[58] David. S. Battisti and Rosamond L. Naylor, "Historical Warnings of Future Food Insecurity with Unprecedented Seasonal Heat," Science 323, no. 5911 (January 9, 2009): 240-244, doi:10.1126/science.1164363.

with climate change. It projected increased winter survival and expanded ranges of all four pests, especially of the corn earworm, which may be resistant to insecticides. The authors concluded that even with pest management adaptations, the effects of climate change could increase seed and insecticide costs, decrease yields and alter crop yield variability.[59]

In 2008, a number of studies highlighted risks to human health with climate change, and at least one study found potential benefits of reduced cold weather mortality.[60] Raised risks and adaptation costs could be associated with increased diarrhoeal disease, renal disease, heat stress, malaria, cholera, malnutrition, and respiratory and other health effects associated with elevated ozone and particulate air pollution due to higher temperatures, among other concerns.[61]

Effects on, and concerns about, mental health have been raised by several studies, especially associated with projected increases in extreme weather events.[62]

One 2008 study found potential for higher temperatures to result in lower ratios of male to female births and reduced male longevity in humans, at least in Nordic countries.[63]

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 where existing communities disintegrate. One study projected that, under the highest IPCC emissions scenario, 12% to 39% of the Earth's land areas may experience novel climates (i.e., climate conditions not existing now) 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.[64]

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[59] Noah S. Diffenbaugh et al., "Global warming presents new challenges for maize pest management," http://www.iop.org/EJ/article/1748-9326/3/4/044007/erl8_4_044007.html.

[60] A. Analitis et al., "Effects of Cold Weather on Mortality: Results From 15 European Cities Within the PHEWE Project," Am. J. Epidemiol. (October 24, 2008): kwn266, doi:10.1093/aje/kwn266.

[61] CCSP, *Analyses of the Effects of Global Change on Human Health and Welfare and Human Systems*. A Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research. [Gamble, J.L. (ed.), K.L. Ebi, F.G. Sussman, T.J. Wilbanks, (Authors)]. U.S. Environmental Protection Agency, Washington, DC, USA (2008); Bernard Doyon, Diane Bélanger, and Pierre Gosselin, "The potential impact of climate change on annual and seasonal mortality for three cities in Québec, Canada," International Journal of Health Geographics 7 (2008): 23, doi:10.1186/1476-072X-7-23; Kristie L Ebi, "Adaptation costs for climate change-related cases of diarrhoeal disease, malnutrition, and malaria in 2030," Globalization and Health 4 (2008): 9, doi:10.1186/1744-8603-4-9; Michael Emch et al., "Seasonality of cholera from 1974 to 2005: a review of global patterns," International Journal of Health Geographics 7 (2008): 31, doi:10.1186/1476-072X-7-31; Paola Michelozzi et al., "High Temperature and Hospitalizations for Cardiovascular and Respiratory Causes in 12 European Cities," Am. J. Respir. Crit. Care Med. (December 5, 2008): 200802-217OC, doi:10.1164/rccm.200802-217OC; Paul Reiter, "Global warming and malaria: knowing the horse before hitching the cart," Malaria Journal 7, no. Suppl 1 (2008): S3, doi:10.1186/1475-2875-7-S1-S3;.

[62] Jessica G Fritze et al., "Hope, despair and transformation: Climate change and the promotion of mental health and wellbeing," International Journal of Mental Health Systems 2 (2008): 13, doi:10.1186/1752-4458-2-13; Alana Hansen et al., "The Effect of Heat Waves on Mental Health in a Temperate Australian City," Environmental Health Perspectives 116, no. 10 (October 2008): 1369–1375, doi:10.1289/ehp.11339.

[63] Ralph Catalano, Tim Bruckner, and Kirk R. Smith, "Ambient temperature predicts sex ratios and male longevity," Proceedings of the National Academy of Sciences (February 4, 2008): 0710711104, doi:10.1073/pnas.0710711104.

[64] 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 (continued...)

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. Adaptation as a strategy, however, is thought to be more challenging and potentially less effective the more widespread, uncertain and severe the climate changes.

(...continued)

(April 3, 2007).

Appendix. 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 (CO_2) 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 CO_2 emissions per unit of energy supplied reversed after 2000." (p. 4)
>
> "Atmospheric concentrations of CO_2 (379ppm) and CH_4 (1774 ppb) in 2005 exceed by far the natural range over the last 650,000 years. Global increases in CO_2 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 0.1^{o}C 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 CO_2 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^{o}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.

terrestrial ecosystems: 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 ecosystems: mangroves and salt marshes, due to multiple stresses

marine ecosystems: 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$/tCO2-eq by 2030 are consistent with stabilisation at around 550 ppm CO_2-eq by 2100. For the same stabilisation level, induced technological change may lower these price ranges to 5-65 US$/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- CO_2 and CO_2 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 CO_2, but the range from 100 estimates is large (-$3 to $95/t CO_2). 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)

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